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Land Use Change in Fast-Growth Counties

Analysis of Study Methods

Marlow Vesterby

LAND USE CHANGE IN FAST-GROWTH COUNTIES: ANALYSIS OF STUDY METHODS. By Marlow Vesterby, Resources and Technology Division, Economic Research Service, U.S. Department of Agriculture. Staff Report No. AGES880510.

ABSTRACT

This report focuses on techniques, procedures, and data sources for studying whether land in fast-growth counties is shifting from rural to urban uses. This focus outlines the best elements for conducting the national land use analysis which began in 1986 and will continue beyond 1988. The national study, being conducted by the U.S. Department of Agriculture's Economic Research Service, is using aerial photography, a stratified systematic random sample design, and the U.S. Geological Survey land classification system. These methods and procedures were chosen from the alternatives discussed in this report.

Keywords: Land, land use, land classification, population, sampling, aerial photography, remote sensing, paired-point sampling, satellite telemetry.

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SUMMARY

This report focuses on techniques, procedures, and data sources for studying whether fast-growth counties are shifting from rural to urban uses. This focus outlines the best elements for conducting the national land use analyses which began in 1986 and will continue beyond 1988. The national study, being conducted by the U.S. Department of Agriculture's Economic Research Service, is using aerial photography, a stratified systematic random sample design, and the U.S. Geological Survey land classification system. These methods and procedures were chosen from the alternatives discussed in this report.

This report documents procedures, lists alternatives, and explains methods of detecting land use change. These factors will help ERS analysts examine relationships among land use change, population, and socioeconomic variables. The national study will cover 192 counties, including 135 of 139 currently fast-growth counties, in 32 States.

The national study, the first since the 1960's, will identify where land use shifts occur and how much and how fast changes have taken place. Data gathered from the national study will be combined with population, employment, and income statistics to determine the causes and effects of land use change.

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INTRODUCTION

This report documents such measurements of land use change in fast population growth counties as sample design and size, land use classification systems, and sources of information. We explain procedures, list alternatives, and examine choices of methods.

This report will help support the national study being conducted by the Economic Research Service (ERS) which will determine how rapidly major land classes, such as cropland, are changing; examine relationships among land use change, population, and other socioeconomic variables; and explore other aspects of the causes and effects of land use change. The national study, a follow-up to studies in the 1950's and 1960's, will focus on 192 counties in 32 States.

Paired-point sampling, assessed from aerial photography, is still the best way to measure changes in fast-growth counties. Paired-point sampling places the same sample point on two different dates of photos to assess changes in land use. This report examines ways of studying land use change. We examined sampling techniques, land classification systems, and sources of information.

BACKGROUND

A 1976 comprehensive study by Zeimetz and others examined land use change in the United States for the decade of the 1960's (47).1/ Using a technique of paired-point sampling, they were able to make definitive statements about the source and destination of land use changes. They addressed concerns, prevalent at the time, that the country was rapidly losing cropland to urbanization and concluded that the problem was not as serious as previously believed (5, 7, 20, 37, 47):

> "Cropland declined from about 33 percent of the total study area in 1961 to 30.4 percent in 1970. Only 49 percent of this net decline resulted directly from urbanization. More new cropland was developed, in fact, than was lost to urban development. Other factors accounted for more cropland decline than urban

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1/ Underlined numbers in parentheses cite sources listed in the References section at the end of the report.

encroachment. These include abandonment of marginal cropland to pasture and diversion of cropland to open idle as changing technology makes farming of some land uneconomic."

The national ERS study for the 1970's examines changes that have occurred since 1970, addressing the rates of land use change, the origin and destination of change, and how changes are related to socioeconomic variables.

Technology has advanced since ERS studies in the 1950's and 1960's of land use change. These advances included remote sensing from satellites, high resolution photography, and computer-aided interpretation of land use. Two pilot studies, in Clackamas and Washington Counties near Portland, Oregon, began the national ERS program. The Environmental Remote Sensing Applications Laboratory and the Geography Department at Oregon State University conducted the studies (33, 3). Results from the pilot studies and from comprehensive literature reviews determined which methods and procedures were applicable as techniques in studying 1970's land use change at the national level.

Land use change estimates come from various sources, including ground surveys, maps, and remote sensing. Land use change comparisons made from most published sources, such as census data, do not show origins and destinations of change. Interpretation of land use on two dates of photography using paired point sampling shows the transition between land uses, from the category of origin to the category of destination.

Marschner pioneered the use of aerial photos as a source of land use information in the 1940's when he researched land use patterns while with the United States Department of Agriculture (USDA) (27). Dill and Otte advanced the technique of aerial photointerpretation in the 1950's by comparing different photo dates and computing ratios of land use change shifts (11, 12). Zeimetz and others made another step forward by using paired-point sampling to determine the origin and destination of change (47, 48). The present study advances the techniques more by plotting sample points on maps before transferring to photos, allowing the use of different size photos, which meant we could cover 96 percent of the fast-growth counties, compared with 41 percent for the Zeimetz study.

Land Classification Systems

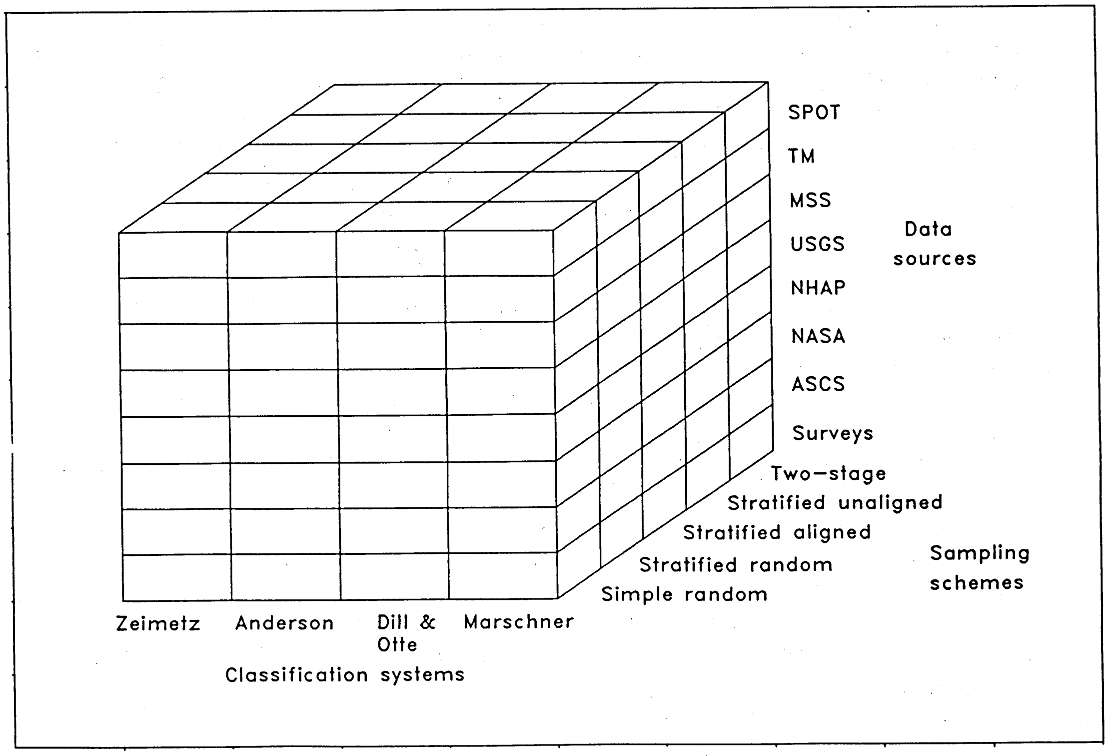
While the quality and quantity of information vary greatly from source to source, so does the choice of classification systems. A land use classification system may directly affect other choices of study methods. Anderson and others have recognized one of the major problems of classification (1):

> "For many years, agencies at the various governmental levels have been collecting data about land, but for the most part they have worked independently and without coordination. Too often this has meant duplication of effort, or it has been found that data collected for a specific purpose were of little or no value for a similar purpose only a short time later. ...it is nearly impossible to aggregate the available data because of the differing classification systems used."

Sampling Schemes

Choices of land use collection techniques vary from total inventories to assorted sampling schemes, each using several classification systems. Add variations in sampling designs and sample sizes, and the number of study methods become even larger (fig. 1).

Figure 1--Variations of Methods for a Study of Land Use Change



The Study Area

We chose study counties based on their population growth and on whether they gained or lost significant amounts of cropland. The United States counted 139 fast-growth counties (population growth of at least 25,000 persons and a 25-percent increase) between 1970 and 1980. An additional 39 counties had significant cropland losses over the 1970's but not necessarily due to urbanization. Another 20 counties showed significant cropland gains over the decade while experiencing significant increases in population (app. 1). Six counties of the total 198 counties, however, lacked adequate photo coverage and were omitted, including 4 fast-growth counties.

Excluded Areas

Seventy-five of the fast-growth counties are located in the West, where much of the land is federally owned. We excluded Federal lands since little land use change likely occurred on them. We also excluded Indian reservations for the same reason and large bodies of water (over 40 acres).

SOURCES OF INFORMATION

Choices of sampling techniques and classification systems are dependent on sources of data. Spatial sampling can be done with various sources of photography, maps, and satellite telemetry. Different sources affect both study efficiency and accuracy. Given two sources at the same cost, the one providing the greatest accuracy, of course, would be the clear choice. But time and expense in plotting and interpreting sample points must also be considered. For example, two sources of photography may have sufficient resolution, but one may require more interpreter time or the use of expensive equipment. Information for use in a study of land use change may be limited to only one choice, or available for only one date. Sometimes, no record of land use change exists.

Satellites

Satellite telemetry is becoming more reliable and precise. Satellite telemetry is a possible primary data source for the national study of land use change. Although satellites provide useful information for inventories of land use, they are less reliable to determine land use change at the rural-urban fringe.

Satellite terms

- **Remote sensing**--Acquisition of information by a detection device that is not in physical contact with the object under study. Sensors can include cameras and satellites (24).

- **Landsat**--Formerly Earth Resources Technology Satellite (ERTS)--Earth-orbiting satellites that transmit a flow of information about the surface of the earth to ground-based receiving stations (31).

    - **MSS**--Multi-spectral scanner--A sensor aboard Landsat which is set to receive reflectance radiation from earth surface features which is converted to digital form for transmission to ground receiving stations. Resolution is 80 meters (31).

    - **TM**--Thematic Mapper--Sensor aboard Landsat that records earth surface radiation at a spatial resolution of 30 meters.

- **SPOT**--French satellite launched in 1986 that provides 10-meter resolution.

Public satellite telemetry began with Landsat in 1972. The two principal sensor devices on Landsat are the multi-spectral scanner (MSS), and on more modern satellites, the thematic mapper (TM). The most recent nonmilitary satellite, the French SPOT, launched in 1986, can provide a resolution of 10 meters, compared to 30 meters for the TM satellite and 80 meters for MSS.

Resolution of Satellite Telemetry

Resolution is essential to differentiate changes in land use (1, 24, 45). Resolution is the minimum separation between two objects at which the objects appear distinct and separate on an image. The resolution of MSS is 80 meters (6,400 square meters or 1.1 acres), which leads to difficulty in detecting many land uses typically occurring at the rural-urban fringe. Welch concluded "... resolutions of better than ... 5 [meters] ... are required to construct land use maps depicting Level II (or finer) class information" (45).2/ Many changes in land use occurring in rural-urban fringe areas are at the Level II category.

Satellites observe differences in the intensity of light reflected from the surface of the earth and convert these observations into code that can be read by computers and recorded on magnetic tapes. The code, known as digital data, can then be automatically classified by computers. Jensen stated, "Digital change detection is a difficult task to perform accurately. The results will not be as accurate as those produced by a photointerpreter analyzing large-scale aerial photography" (22). Stow, Tinney, and Estes concluded the following from their study of the feasibility of using satellite telemetry to derive change statistics (39):

> "... single-date Landsat MSS data for areas encompassing the agricultural-urban fringe cannot be automatically classified to a level of reasonable accuracy that will allow accurate land use/land cover change statistics to be derived."

Other limitations exist with satellite telemetry (18, 21, 23, 39). Lee examined the feasibility of using Landsat to inventory new cropland development and concluded that MSS sensors were not sufficiently technologically advanced to interpret cropland use consistently and accurately. For example, in one case "... where logging was underway, clear cutting as a part of a timber operation was indistinguishable from land cleared for crops" (23). Of the two primary Landsat scanning devices, MSS and TM, only MSS has been operational long enough to provide a record for a 10-year timespan. Thematic mapper telemetry is unavailable for most of the fast-growth counties for the latter part of the decade and not available at all for the beginning of the decade.

While satellite telemetry lacks resolution compared with photography, it has some advantages not found in all photos. For example, aerial photography varies greatly in size and quality, but a given satellite sensor is constant. Photographic coverage is often available only for certain areas, for varying purposes, and at irregular intervals. Satellite telemetry can often be obtained on a set schedule, such as every 18 days for Landsat. Satellite resolution is consistent, 80 meters for MSS, 30 meters for TM, and 10 meters for SPOT. Until the resolution of satellite telemetry improves and it

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2/ Land use classifications consist of four levels with Level I the most generalized and Level IV the most detailed. Classifications are explained later in detail in the section, Classification Systems.

becomes available over the range of years for which land use change is desired, photographic sources will continue to be the alternative for detection of land use change at the rural-urban fringe.

Photography

Photography has been used in ERS since the 1940's to determine land use and land use change. One of the first uses of photos was to determine major land uses in the United States (27, 28). Airphoto interpretation has since been used by ERS as a tool for flood-damage appraisal (4, 10, 32, 38), for the study of land use change on the lower Mississippi River alluvial plain (19), and to determine land use change in rapidly growing areas (11, 12, 44, 47, 48). ERS studies used a variety of aerial photography from several agencies, including the Agricultural Stabilization and Conservation Service (ASCS), the Soil Conservation Service (SCS), the Forest Service (FS), the U.S. Air Force, the U.S. Geological Service (USGS), and the National Aeronautics and Space Administration (NASA). Sources of photography and advantages and disadvantages of each are discussed below.

ASCS Black and White Photography

ASCS has used black and white photography in the regulation of USDA programs since the 1930's. Until the 1970's most ASCS photography was at a scale of 1:20,000.3/ Since the early 1970's, ASCS photography has been at a scale of 1:40,000. Figure 2 shows an example of areas covered by different scale maps and photos.

NASA Small-Scale Photography

The National Aeronautics and Space Administration (NASA) uses small-scale photography in color, color infrared, or black and white. Film taken before the mid-1970's sometimes appears fuzzy or grainy. Often NASA photography has greater than 10-percent cloud cover on one or more frames in a flight strip. Much of NASA photography is at a small scale, 1:120,000, which if combined with poor quality, or cloud cover, can prove troublesome for interpreters. Coverage may be extremely detailed over a specified area for a given year, and for other areas or time periods may be nonexistent.

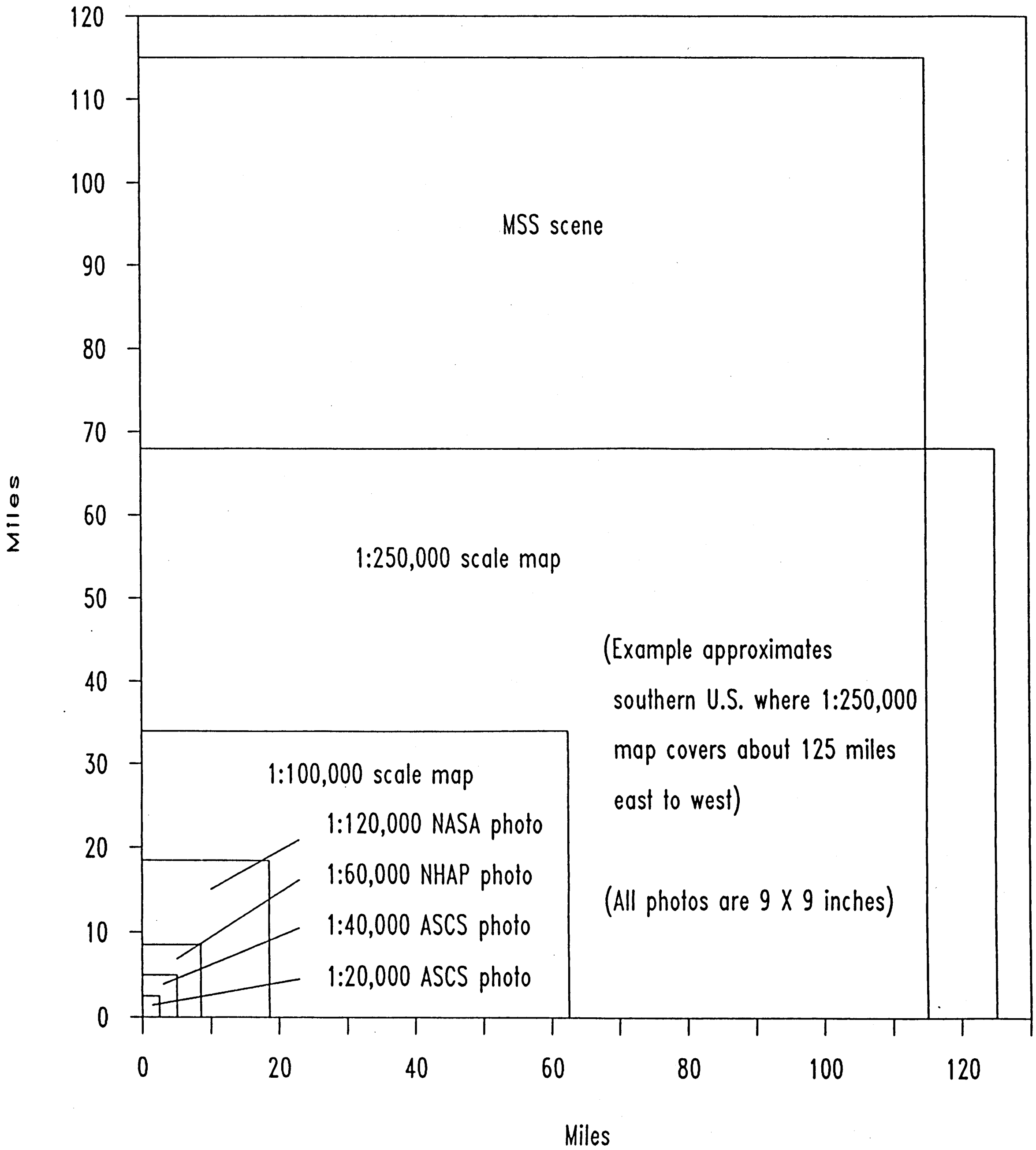
The indexing system for NASA photography can be difficult to use. Index maps often show flight strips flown in different directions. The flight strips often overlap or leave gaps in coverage. Adjacent strips usually appear on separate maps. Index maps for NASA photos may be at a very small scale (often 1:1,000,000) and seldom show county boundaries. Thus, county coverage may be difficult to discern. Gaps in coverage may go unnoticed.

3/ Scale is "... the mathematical relationship between a distance on an image and the corresponding distance on the earth" (24). Scale is expressed as a ratio and can be stated in any linear unit of measurement, such as inches. Scale in inches of 1:20,000 means one inch on an image equals 20,000 inches on the ground. Photographic sources may range in size from large-scale ASCS photography at 1:20,000, to small-scale NASA photos at 1:120,000. For ease of interpretation, large scale is preferable, but large scale means increased costs since more photos are needed to cover a given area (fig. 2). Smaller scale photos must have good resolution to be accurately interpreted. A scale of 1:120,000 is about the smallest that can be accurately interpreted for land classifications at the rural-urban fringe (3).

NHAP Color Infrared and Black and White Photography

The Federal Government started a program in 1980 to photograph the Nation. The National High Altitude Photography (NHAP) program, using systematic, uniform procedures, coordinated by the United States Geological Survey (USGS), provided high-quality aerial photography in color, color infrared, and black and white. By 1985, NHAP coverage was available for most of the Nation.

Figure 2--Comparison of various scales



Photography sources

- . **ASCS**--Agricultural Stabilization and Conservation Service, U.S. Department of Agriculture--Has photography dating back to the 1930's for most agricultural land in the United States for use in administering commodity programs.

- . **NCIC**, USGS--National Cartographic Information Center, U.S. Geological Survey--Provides ordering services and searches for a large amount of maps, photos, and cartographic materials available from several different Federal, State, and private agencies.

- . **SCS**--Soil Conservation Service, U.S. Department of Agriculture--Has available soil information. They provide soil surveys and maps which determine soil mapping units for cropland sample points.

- . **NASA**--National Aeronautics and Space Administration--Flew much of the photography available for the early part the 1970's. Much of it is at a very small scale, 1:120,000, poor quality, and often has a large amount of cloud cover. Even though NASA photos are often difficult to identify because of the lack of county boundaries on flight indexes, the photography is the only available early coverage of many counties.

- . **NHAP**--National High Altitude Photography. Begun in 1980 to obtain high-quality photography to cover the Nation. Most of the problems with NASA photography were corrected with the NHAP program. Funding for NHAP was contributed by several Federal agencies. About 95 percent of the country is now covered.

- . **EROS**--Earth Resources Observation Systems, U.S. Geological Survey--This agency is the depository and source of all NASA and USGS photography obtained for the national study of land use change and for most of the NHAP.

The NHAP program corrected nearly all problems with NASA photography. Film is high quality. Cloud cover is essentially nonexistent. Flight strips are recorded north and south, and adjacent strips appear on the same index map.

Index maps display a workable 1:250,000 scale and show county boundaries. Photo identification is easier and quicker for NHAP than for NASA photography.

USGS Photography

USGS has available photography specifically flown to provide information for mapping and other special purposes. Coverage is sporadic by both area and date, but the quality of this black and white photography is usually good.

Table 1 compares resolution, dates of coverage, status, and costs of selected photography and satellite telemetry.

Maps

Accurate placement of sample points is an important aspect of land use change studies in point sampling. Errors frequently occur when plotting sample points directly on photos because of differences in scale varying from 1:20,000 for ASCS photos to 1:120,000 for NASA. Even in a single photographic series such as NASA's, variances in scale range from 1:100,000 to 1:130,000, so constructing sample point templates to represent each point at the same place on each photo would be impractical. The solution to the problem is to use maps true to scale.

Experience from the pilot studies showed that sample points plotted first on maps, then on photos, remained true to scale. In the Washington County study, a 1:24,000 scale USGS topographic map was a base upon which sample points were plotted. The large-scale topographic map worked fine for the local Washington County study area. However, for a national study, a smaller, more efficient scale was needed. The 1:100,000 scale maps available from USGS and Bureau of Land Management (BLM) had sufficient detail and usefulness to allow identification of features needed to plot sample points and to keep the number of maps down to a manageable level.

This is the first land use change study where constant scale maps were available for all study counties. Using these maps meant that photography ranging in scale from 1:20,000 to 1:130,000 could be used to identify land use change. We were thus able to obtain data on 96 percent of the study counties. The Zeimetz study, using 1:20,000 ASCS photos, obtained data on only 41 percent of the 1960's study counties.

BLM Surface Management Status Maps

Federal lands, excluded from the study, had to be identified during the photointerpretation process. Where Federal ownership exceeded 15 percent of the total area in a county, BLM has prepared 1:100,000 scale Surface Management Status maps. The Federal Government owns large tracts in many western counties. Some counties are over 90-percent Federal, with most of the Federal land managed by BLM or FS.

USGS 1:100,000 Scale Metric Maps and County Maps

USGS produces maps at the same scale as BLM Surface Management Status maps. When USGS maps were acquired for the study, some were only available as preliminary copies. The series is now complete for most of the country.

Table 1--Remote sensing comparisons

Source	Resolution: meters	Status	Years	Land class levels	1986 cost	Dollars per square kilometer 1/
ASCS 1:20,000	1m	Cropland covered about every 8 years	1930's - 1970's	I-IV	10X10 - $3 12X12 - $6 17X17 - $8 24X24 - $12	.21
1:40,000	1m		1971 - present	I-III		
NHAP 1:58,000	1m	About 95 percent of country covered	Early to mid 1980's	I-III	$15 for color	.12
1:80,000	1m				$5 for black and white	.02
NASA variable to 1:130,000	1m to 3m	Obtained for various purposes	1960's to present	I-II	$15 for color $5 for black and white	.03
USGS variable	1m	Major source of mapping data		I-III	$5 for black and white	
Landsat MSS 1:250,000	80m	Landsat 5 in operation	1972 to present	I	$350 for color print, $200 extra for color generation	.01
TM 1:250,000	30m	Data available from Landsat 1 - 4.	1984 to present	I-II	$500 for color print, $300 extra for color generation	.02
SPOT 1:250,000	10m	Began operating in 1986	1986 to present	I-II	$410 for color print.	.16

1/ Adjustments were made for side and end overlap. Photography based on alternate frames. Prices for satellite scenes do not include computer tape processing.

USGS Land Use/Land Cover Map Problems

An evaluation was made by Parker of the possibility of using USGS land use/land cover maps as a substitute for one date of photography (33). The idea was not feasible because land use/land cover maps were available for only a few counties in the study, and standards used in constructing this series of maps allowed 15-percent error. Studies show land use change at the rural-urban fringe seldom exceeds 5 percent (11, 12, 47), so a 15-percent allowable error could easily mask or confuse any real change in land use. We cannot always determine the dates of sample points because maps are often constructed from photos of several different dates. Also, map interpretations are not necessarily consistent with photo interpretations for the national study.

Soil Survey Maps

SCS soil surveys are another source of information. Soil survey maps are the source of soil mapping units recorded for cropland that changed in use. SCS local and State offices furnished soil surveys for 163 study counties. Soil mapping units indicate the quality of cropland lost to other uses.

Bureau of the Census Maps

The Bureau of the Census prepares maps of County Census Divisions (CCD) and Minor Civil Divisions (MCD) for use in enumerations. To obtain more accurate information relating land use change to population change, we recorded CCD/MCD codes for each sample point.

CLASSIFICATION SYSTEMS

Researchers can classify land use by different systems depending on their needs. Classification directly affects the choice of methods. More land use classes means adding more sample data to make significant statements about each class. Obtaining information for broad, generalized classes, such as rangelands and cropland, is easier than acquiring smaller, specific classes like urban industrial or transitional lands.

Classification systems have not often been compatible. Anderson and others developed a land use and land cover system which has served as a model since 1976 for many classification system studies (1). The Anderson system starts with nine one-digit, or Level I categories, ranging from urban to perennial snow or ice (table 2). Each Level I category contains up to seven Level II categories. For example, within the urban category, there are seven Level II categories, starting with residential and ending with other urban. We can use Level I categories to interpret MSS satellite telemetry. Level II classifications employ photo scales from 1:80,000 to 1:250,000. The Anderson system can be subdivided into Level III and Level IV categories. Level III is for scales from 1:20,000 to 1:80,000. Level IV is for scales greater than 1:80,000. The Anderson system had not yet been published at the time of the Zeimetz study (47).

We can formulate many classifications using different combinations. The primary interest in the pilot studies was land near urban areas since these lands have the fastest population growth and are assumed to have the greatest rate of change in land use. Twelve categories, based on the Anderson system, applied to the Washington County study (table 2).

Table 2--Classifications for land use 1/

USGS classification system Level I/level II	Washington County classes	Clackamas County classes	National Study classes
1 Urban or Built-up Land			
11 Residential	11	11	11*
12 Commercial and Services	12, 13, 15, 16	12, 13, 15	12, 13, 15
13 Industrial			
14 Transportation, Communications, and Utilities	14	14 Other Urban	14
15 Industrial and Commercial Complexes		Urban Idle Rural	
16 Mixed Urban or Built-up		Residential	
17 Other Urban or Built-up	17	Nonurban	16, 17
2 Agricultural Land		Transitional	
21 Cropland and Pasture	21	Cropland 21	21
22 Orchards, Groves, Vineyards Nurseries, and Ornamental Horticultural Areas	22	Pasture 21 22	22
23 Confined Feeding Operations	23, 24	23, 24	23, 24**
24 Other Agricultural Land			
3 Rangelands	3	3	3
31 Herbaceous Rangelands			
32 Shrub and Brush Rangelands			
33 Mixed Rangelands			
4 Forest Land	4	4	4
41 Deciduous Forest Land			
42 Evergreen Forest Land			
43 Mixed Forest Land			
5 Water	5	5	5
51 Streams and Canals			
52 Lakes			
53 Reservoirs			
54 Bays and Estuaries			
6 Wetland	6	6	6
61 Forested Wetland			
62 Nonforested Wetland			
7 Barren Land	7	Other land	71-75, 77
71 Dry Salt Flats			
72 Beaches			
73 Sandy Areas except Beaches			
74 Bare Exposed Rock			
75 Strip Mines, Quarries, and Gravel Pits			
76 Transitional Areas			76
77 Mixed Barren Land			
8 Tundra			
9 Perennial Snow or Ice			

1/ Numbers refer to standard USGS Classification System codes.
* Includes farm residence and rural dwellings.
** Includes all other farm buildings.

In the Clackamas County study, we gained additional information on the dynamics of land use change at the rural-urban fringe. The Anderson Level II classes, mixed urban and other urban or built-up, were arranged into urban idle, and other urban. Two new classes were added, nonurban transitional, and rural residential. All classes were mutually exclusive (table 2).

The national system is similar to the Washington County classification with minor exceptions. We combined mixed urban with other urban or built-up and we separated transitional land from barren land (table 2). Transitional land is of major interest in this study because of its relationship between rural and urban lands. We also included farm residences and rural dwellings in the residential class to be comparable with Zeimetz (47, 48).

SAMPLE DESIGN AND PROCEDURES

Two common processes provide information on land use: the total inventory approach, termed wall-to-wall inventories, and sampling scheme choices. Researchers use total inventories to prepare maps and to study small areas such as cities and counties, which require a high degree of accuracy. A total inventory approach for a national study of land use change is impractical because of excessive cost and time requirements. Researchers can obtain information on land use within acceptable error standards through sampling techniques. Information relating either to wall-to-wall inventories or to sampling may be obtained from on-the-ground surveys, remote sensing, or various combinations.

Previous Study Designs

Berry used spatial sampling in 1962 to obtain information on land use. "Sampling is a well-established method whereby part of a whole is selected to reduce the cost, increase the speed and scope, and improve the accuracy of estimates relating to the whole ..."(4). Berry used spatial sampling to examine methods to obtain flood plain data for research while with the Department of Geography at the University of Chicago.

Sloggett and Cook used sampling in 1967 to evaluate flood prevention benefits in small watershed projects in Oklahoma (38). They employed point samples with aerial photos in place of maps to locate sample points and gathered information through ground surveys.

Frey and Dill combined point sampling and aerial photo interpretation to study land use change in the Mississippi River alluvial plain (19). The study used a systematic aligned sample of points, one per square mile. Dill and Otte used the 1958 National Inventory of Soil and Water Conservation Needs (CNI)(2) to sample urbanization in 96 counties in 12 Northeastern States. Their sample consisted of randomly selected 100- and 160-acre plots. The sample was targeted to achieve a 2-percent sampling rate. Federal land was excluded (11).

The choices of sampling design vary according to whether the sample is random or systematic, stratified or independent, aligned or unaligned (fig. 3). The samples for two or more time periods in land use change studies may come from proportional or paired-point sampling, which can be expanded by selection of stages and by the selection of points versus polygons (13) or "quadrats" (4) as sample units.

Spatial Sampling Terms

- **Paired point**--Places sample points at the same spatial location on two different dates of photography. Allows determination of the specific origin and destination of a change in land use (47).

- **Proportional**--Done at two dates independently with allocation of the land uses determined separately for each date. The researcher can then say change occurred but cannot say for a given increase in one category from which use the change originated (3).

- **Stratification**--Refers to a selection of equal-sized grids overlaying the area to be sampled, from which sample points are drawn. The term may also refer to delineation of subareas for the purpose of establishing different sampling densities, such as distinguishing the urban areas from rural areas to sample at different densities (17, 48).

- **Systematic and random**--Systematic sampling, denotes a method of selecting sample points such that the points are evenly dispersed over a geographic area, usually on the basis of a fixed number of points per some equally sized, fixed strata. Random sampling allows each coordinate value an equal chance of selection over the study area (4).

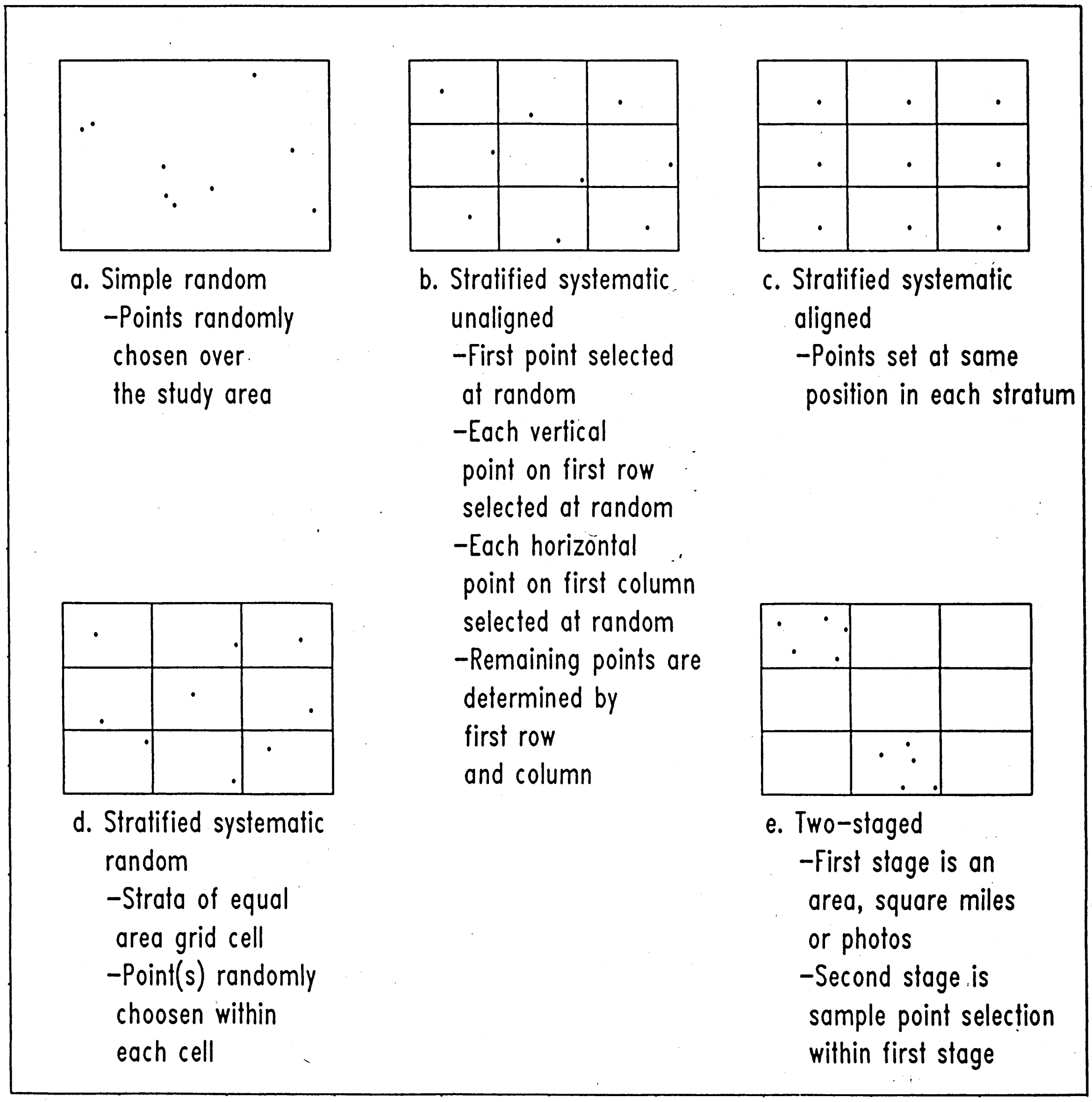
- **Two-staged**--First stage, may be geographical areas selected from a population, such as the areas represented on photos in the Zeimetz study (48), or square mile grids used in the Washington County pilot study (3). Second stage, is sample point(s) selected within the first stage.

- **Unaligned**--Refers to a method of selecting sample points to ensure they do not regularly fall on commonly occurring features, such as roads or fence rows which would bias the sample (3).

The 1976 Zeimetz study used a two-stage process (47, 48). In the first stage, analysts selected areas from every tenth photo frame on alternate rows of ASCS county photography. They chose points within each selected photo in the second stage, based on a systematic, geographically stratified criterion. Randomly chosen points averaged 20 per square mile for each photo. In the first step "the original aim was to obtain an area sample of at least 10 percent or more of the surface area of each county." The goal "... was exceeded and approximately 15 percent of the area was used for the second step, the point sample" (48).

The Zeimetz study is significant because it used paired-point, two-stage sampling. The study plotted points at the same location on two different dates of photography. The area, size, and number of sample points in two-stage samples have varied, depending on the needs of the particular study.

Figure 3--Sampling schemes



Frazier and Shovic used sampling procedures similar to Zeimetz in a land use change study in Whatcom County, Washington. They used 2.6-square-kilometer (km^2) areas for the first stage and 8 points per km^2 in the second stage (17). A form of two-stage sampling, used in the 1977 National Resource Inventory, consisted of the primary sample unit (PSU), usually 160 or 640 acres (first stage), and three sample points per PSU (second stage) (41).

Two sampling schemes were tested for the Oregon studies (table 3). Behm and Pease (3) used two-stage sampling similar to that used by Zeimetz (47) and Frazier and Shovic (17). The Behm and Pease study of a portion of Washington County used a random selection of square mile grids plotted on a USGS base map. Behm and Pease randomly placed the grid and rotated it to assure nonalignment with the public land survey. The second stage consisted of a point-sampling density of 20 points per square mile. They based their selection of 20 points per square mile on the work of Frazier and Shovic who tested a number of different designs of sample area and dot densities, concluding 20 dots per square mile was an efficient combination with an acceptable error factor (17).

Parker, using the systematic, aligned sampling procedure, sampled non-Federal land in Clackamas County (table 3). The sample consisted of one point per square mile for a 750-square-mile area. Parker aligned sample points on the dot overlay, which was rotated to avoid periodicity (33).

Earlier studies were limited to black and white photography because color was not available. Also, smaller scale photos had not advanced sufficiently in quality until the more recent studies to permit detailed interpretation.

More on Sampling Design

If the first stage of two-stage sampling involves restricting photography as in the Zeimetz study where every tenth photo was selected, then photo acquisition costs are lowered. Cost was an important consideration in earlier studies because often the only photography available was ASCS at the 1:20,000 scale and many more photos were needed to cover the same area than at a 1:120,000 scale. (Refer to figure 2 for an example of the differences in scale.) Higher quality NHAP photos are now available and more area can be covered per 9- or 10-inch photo at less cost and there is less incentive to use two-stage sampling. (Refer to table 1 for cost comparisons). Systematic sampling, where the entire study area is evenly covered by sample points (4, 35), is relatively more attractive. While the Washington County study used a two-stage random sample which was preferred "...to allow the calculation of sample error...", the authors recognized "An alternative ... is the stratified, systematic, unaligned design ..."(3).

Berry observed, "... no dependable method for estimating the variance of the means from systematic samples is known, because systematization implies lack of equality of opportunity of places being included in the sample" (4). Berry went on to cite Yates (46), Cochran (8), and Quenouille (34) who proposed methods of estimating variance by using additional samples, blocking samples, or using wider spacing. Berry concluded, "...checkerboard systematic samples may be only as good as simple random samples, and inferior to stratified random samples, because of the effects of gradients and periodicities" (4). Rosenfield employed variance and confidence limit formulas based on simple random sampling in the normal distribution, citing Cochran. Simple random variance formulas provide approximations of the variance of stratified systematic samples (35). Such estimates will be unbiased as sample size approaches infinity (9).

Table 3--Comparison of land use change studies

Item	Study: Washington County, Oregon (3)	Clackamas County, Oregon (34)	53-county study (47)	ERS National study
Agency	Geography Department, Oregon State Univerity	ERSAL, Oregon State University	Economic Research Service, USDA	Economic Research Service, USDA
Area	163-sq.-mi. portion	750-sq.-mi. portion	53 U.S. counties	192 counties
Sample procedure	Two-stage random sampling - 33 one-sq.-mi. sample units for first stage - 20 points per sq. mi., second stage	Systematic unaligned - One point per sq. mi.	Two-stage - Every 10 frames on alternate ASCS flight strips - 20 random points per sq. mi.	Stratified systematic random
	Two-date, paired-point sampling	Two-date, paired-point sampling	Two-date, paired-point sampling	Two-date, paired-point sampling
Design accuracy	90-percent confidence, 10-percent interval at county level	90-percent confidence, 10-percent interval at region level	10-percent coverage	95-percent confidence, 2-percent interval nationally
Classification system	USGS--Anderson classification, 12 land classes	USGS--Anderson classification, 17 land classes	12 land classes	USGS--Anderson classification, 12 land classes
Dates	1973 1981-1982	1970 1980	early 1960 early 1970	early 1970 early 1980
Data source	Photography: - NASA 1:130,000 - NHAP 1:58,000	Photography: - ASCS 1:20,000 - ASCS 1:40:000	Photography: - ASCS 1:20,000	Photography: - ASCS, NASA, USGS, NHAP, and SCS 1:20,000-1:130,000

Berry suggested that the stratified systematic unaligned design may be more efficient than the stratified systematic random design (4). Rosenfield employed the latter, however, in a stratified acid rain survey using census data and land use variables (36). While the stratified systematic unaligned design may be slightly more efficient, error estimation with the stratified systematic random design may be simpler. The national study uses a stratified systematic random sample design (fig. 3). Both systematic designs are more efficient than simple random sampling (4).

The systematic random sample design tends to avoid problems of periodicity associated with systematically aligned designs where a row of sample points may pick up certain features, such as roads or power lines which form straight-line segments. Stratification by equal-sized stratum avoids biased clustering problems associated with simple random designs where nonrandom features on the landscape could be sampled more frequently. Bryan and Russwurm write, "... if properly applied, a stratified sampling scheme gives a more precise estimate of the population parameter than a simple random sample of the same size; thus, for a given level of precision, a stratified sampling scheme requires a smaller sample size (and thus cost) than a simple random sample..." (6).

Proportional and Paired-Point Sampling

Paired-point sampling is clearly desirable over proportional sampling for studies of land use change (3, 29, 47, 48). Paired-point sampling has less variance than proportional sampling, which means fewer sample points to achieve the same level of precision (3). Paired-point sampling makes it possible to determine the originating land use when change is detected and to construct from and to land use change transition matrixes, similar to those for the Washington County and Clackamas County pilot studies (appendix b)(3, 33, 44).

Stratification

There are two types of stratification. Stratification in the national study used grid cells on sample dot overlays. Study counties were stratified by equal area cells, each containing a randomly placed sample point. Thus, the sample is disbursed evenly over the study area (See table 3).

Stratification on a geographic basis is also possible. For example, increasing the sampling density in rural-urban fringe areas and decreasing sampling density in rural areas is a form of geographic stratification. Stratification can increase precision by creating more homogeneous units and may decrease costs because of fewer overall sample points to plot and interpret. But, two drawbacks to stratification exist. Determining a basis for establishing stratification boundaries is difficult. Where does one draw the line between rural and urban, especially for a large number of diverse counties for a national study? And, stratification adds to the computational complexity of statistical tests of accuracy and confidence limits. The national study was stratified by grid cell, not geographically.

Sample Point Transfer

An essential component of the analysis of land use change between two dates using paired sample points is to locate the points at exactly the same spot on different dates of photography. Misplacement of points could result in erroneous interpretation of land use change.

Point Plotting

Plotting random sample points, first from square mile grid cells to maps, then to photography, and again from one date of photography to another, requires exacting diligence by the photointerpreter. Different procedures exist for placement of sample points. Whatever the procedure used, it must account for different scales between sources of photography and even for scales which vary on a single photo due to distortion.

Visual inspection is the simplest method of plotting sample points between time periods. Points are placed on one date of photography and then visually relocated on the photo of a different date. Another method of point location involves a triangulation process, relocating points from one photo to the next, by measuring from objects identified on both photos, and adjusting for differences in scale. A third method employs special equipment such as the zoom transfer scope which optically equalizes different scales to allow the plotter to place sample points at the same location.

Dot Grids

Initial sample point location may be accomplished by using a dot grid overlay. The transparent overlay is constructed with points distributed according to the sampling scheme being employed, such as random, systematic aligned, or unaligned. Sample density is determined by study area and sample size. The grid may be used in conjunction with maps or with photos if adjusted for differences in scale.

For the Washington County study, Behm first plotted sample points on a USGS 1:24,000 scale base map using a rectangular grid of square-mile cells covering the study area (3). The grid was randomly placed and rotated to assure nonalignment with the public land survey. The national study used USGS and BLM 1:100,000 topographic and surface land management maps with random placement of sample points within stratified grid cells.

USGS generated the dot grids for the national study. The grids are transparent overlays, based on the stratified systematic random sampling design with sample points randomly chosen within each strata. Similar grids have been used in studies involving spatial sampling for accuracy and consistency comparisons of land use and land cover maps (13, 14, 15, 16).

SAMPLE SIZE

Sample size and choice of methods are directly related. Sample size depends on the desired precision, the number of land use classes, the anticipated size of classes, the population distribution, and the number of areas or regions in the study. More areas require more sample points. The number of sample points depends on the type of sampling method, such as two-stage or systematic. Whether the sample is paired point or proportional may have a bearing on sample size. A sample must be sufficiently large to provide statistically reliable results. However, a sample size larger than necessary to achieve the desired precision translates into additional labor to plot and interpret land use. Sample size also directly affects choices of information storage and retrieval.

Sample Distribution

Studies involving qualitative classification of observations, such as classes of land use where the observations must fall within one of two or more mutually exclusive categories, have a multinomial distribution, according to Rosenfield (35). The multinomial distribution is an extension of the binomial distribution. Classification studies with a multinomial distribution have the following characteristics:

1. The study consists of n identical sample points,
2. Sample points fall into one of k classes, and
3. The probability of a single sample point falling into a particular class is:

$$q_i \qquad i = 1, 2, \ldots, k.$$

Tortora provides a method of determining sample size for classification variables of a multinomial population (40). Rosenfield expanded on the Tortora method in a 1958 study of land use and land cover change in Pennsylvania by discussing standard deviation in relation to sample size (35). Tortora's method of determining sample size is used to set minimum sample sizes for studies of land use change. The equation is:

If have 5 classes
5.02 × 78.84 = 395
10 classes P = .8
~ 5.02 × 78.84 = 395

5.02

$$n = \chi^2_{1,\,1-\frac{\alpha}{k}} \frac{q_i(1-q_i)}{\delta^2},$$

$1 - \frac{.2}{10}$ $\quad 6.63 \cdot \left(\frac{.27(.73)}{.05^2}\right)$

$1 - \frac{.1}{5}$

where n = sample size,

χ^2 = Chi square distribution with 1 degree of freedom

α = probability of exceeding the confidence interval

k = number of classifications

q_i = proportion of observations in the ith class

δ = percentage 1/2 width of the confidence interval

For example, when P = 0.90 and the number of classes, k, is equal to 10, Chi Square with 1 degree of freedom is 6.63. If the 1/2 width of the confidence interval is 0.05 and if *a priori* knowledge shows q is 0.27, then n is 523 sample points. Figures 4 and 5 show sample sizes for selected probabilities, classifications, and confidence intervals. The difference between figure 4 and figure 5 is q, the proportion of observations. The figures show sample sizes needed at the indicated probability and confidence intervals when the cropland and pasture class changes from a proportion of 27 percent (fig. 4), based on some *a priori* knowledge, to 50 percent (fig. 5). The proportion, q = 0.5 for any single category, is the conservative scenario requiring the maximum sample size (35).

Figure 4--Sample sizes, q=0.27, k=10

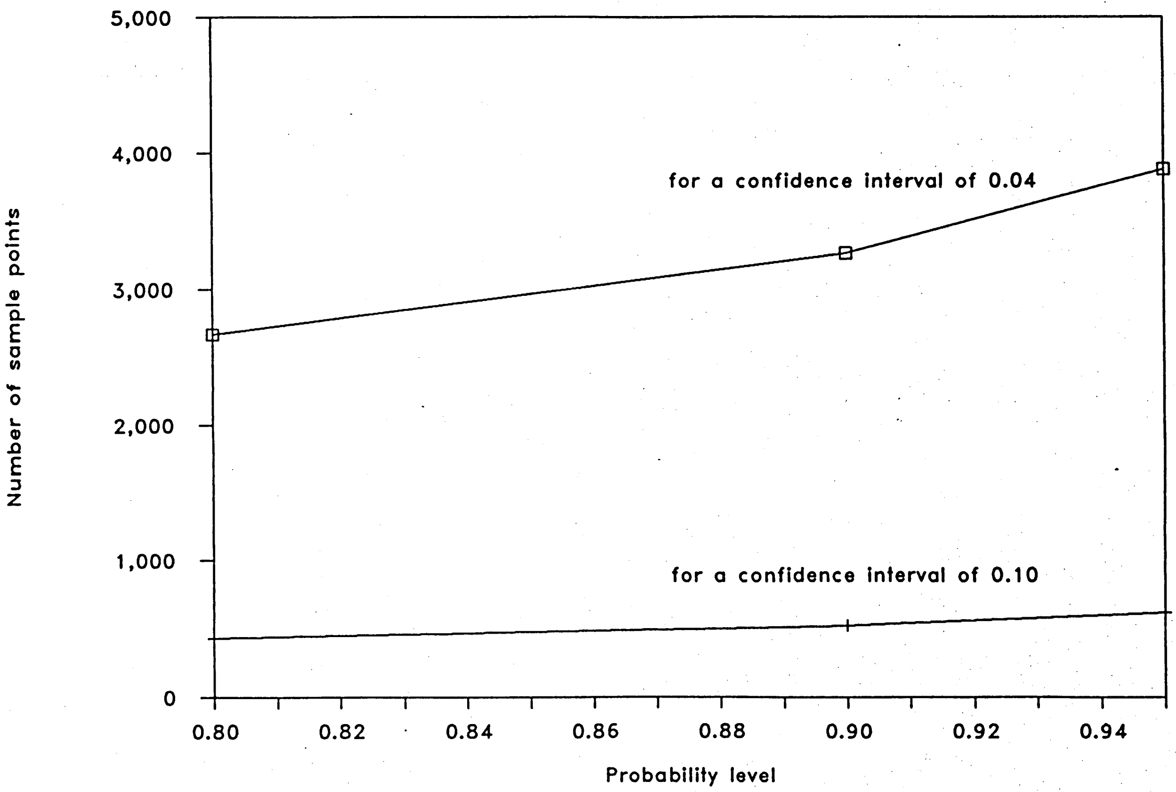
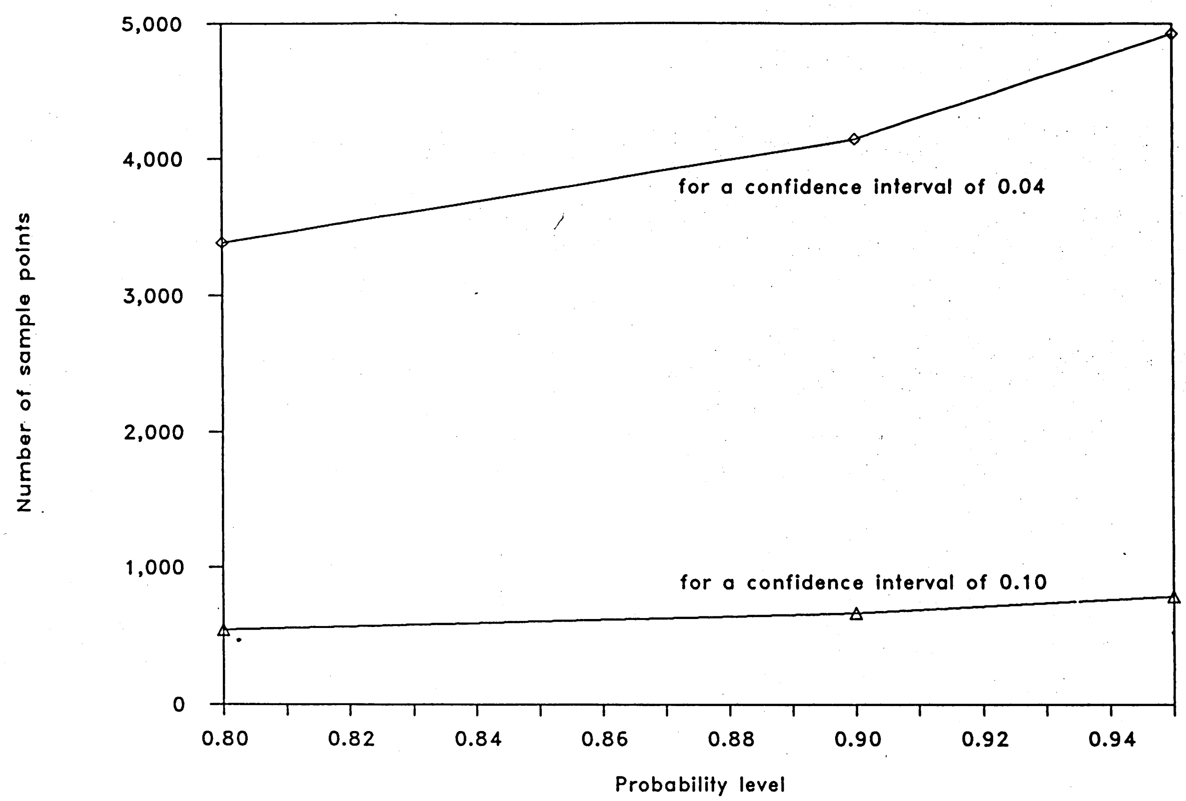


Figure 5--Sample sizes, q=0.50, k=10



Sample Sizes at Different Levels of Precision

Mergerson conducted an independent determination of sample sizes necessary for a national study (30). He provided the minimum sample sizes necessary for levels of precision, ranging from 95-percent probability with a confidence interval of plus or minus 2 percent to 80-percent probability with a confidence interval of plus or minus 5 percent. Sample sizes, shown below and in fig. 4, represent the national level and each of four equal regions.

Statistical Accuracy		Number of	Sample
Probability	Interval	Categories	Size
95%	+ or - 5%	10	2,540 (635 per region)
		5	2,088 (522 per region)
90%	+ or - 5%	10	2,088 (522 per region)
		5	1,628 (407 per region)
80%	+ or - 5%	10	1,628 (407 per region)
		5	1,176 (294 per region)
95%	+ or - 2%	10	15,864 (3,966 per region)
		5	13,032 (3,258 per region)
90%	+ or - 2%	10	13,032 (3,258 per region)
		5	10,176 (2,544 per region)
80%	+ or - 2%	10	10,176 (2,544 per region)
		5	7,344 (1,836 per region)

Sample Size for National Study

The sample size for the national study was set at 27,500 paired points, 10,000 beyond the 15,864 needed for the 95-percent probability, plus or minus 2-percent interval, level of precision. The sample size was set larger than needed to allow for uncertainties regarding the number of sample points to be discarded due to missing photography and cloud cover, the exact amount of Federal and Indian lands to be excluded from the study, and other factors affecting the final number of useful points.

County-level accuracy is neither desired nor intended and could only have been obtained by increasing the number of sample points and, consequently, study costs. The Washington County study estimated county-level accuracy could have been obtained for all study counties at a cost of $5.4 million, well beyond the study budget (3). Regional accuracy permits analysis of differences in land use consumption and an examination of economic trends among areas of the county which differ in population, employment, and income.

CONSIDERATIONS FOR A NATIONAL STUDY

The preceding studies, literature reviews, and analyses tested and developed methods for a national study of land use change. The information was used by the Land Economics Branch, ERS, to obtain bids from contractors interested in plotting and interpreting sample points. The data collection phase of the national study started in the fall of 1986 when Earthsat Corporation was awarded the contract and ended April, 1988, with the final data delivery.

Compilation and analysis of secondary socioeconomic information, collected by ERS, will be combined with the interpreted land use change results from the 192 study counties. Secondary information will also be correlated with the 1960's Zeimetz land use change study (47).

The national study will provide basic information to help answer such questions as: What shifts are occurring among major land use categories? Are shifts to and from certain uses more prevalent than shifts between other uses, such as from cropland to urban? What land uses are changing to urban and at what rates? Are the rates changing? What are the impacts of population growth within urbanizing areas and between regions?

Results from the fast-growth study will help USDA researchers, urban planners, demographers, geographers, and sociologists. The study is an integral part of a planned series of data collection and analyses which will provide useful information on resource use and the dynamics of land use change.

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Appendix 1--Study counties

State	County	Type	Area: Federal	Area: Non-Fed	Area: Total	Federal portion
			- - - Square miles	- - -		Percent
Alabama	Baldwin	CL 1/	0	1,578	1,578	0
	Houston	CL	1	574	575	0
	Shelby	FG 2/	0	800	800	0
Arizona	Coconino	FG	7,297	11,311	18,608	39
	Maricopa	FG	3,791	5,336	9,127	42
	Mohave	FG	9,894	3,391	13,285	74
	Pima	FG	2,526	6,661	9,187	27
	Pinal	CL	887	4,477	5,364	17
	Yavapai	FG	3,777	4,345	8,122	46
	Yuma	FG	1,562	8,432	9,994	16
Arkansas	Benton	FG	63	781	844	7
	Craighead	CL	1	715	716	0
	Greene	CL	1	578	579	0
California	Butte	FG	235	1,411	1,646	14
	El Dorado	FG	824	891	1,715	48
	Kern	CG 3/	1,712	6,440	8,152	21
	Lassen	CL	2,563	1,998	4,561	56
	Merced	FG	65	1,879	1,944	3
	Nevada	FG	290	670	960	30
	Placer	FG	567	849	1,416	40
	Riverside	FG	3,689	3,525	7,214	51
	San Bernardino	FG	11,992	8,072	20,064	60
	San Diego	FG	730	3,531	4,261	17
	San Joaquin	CG	2	1,410	1,412	0
	San Luis Obispo	FG	375	2,933	3,308	11
	Santa Clara	CL	12	1,288	1,300	1
	Santa Cruz	FG	0	446	446	0
	Shasta	FG	1,524	2,262	3,786	40
	Solano	FG	7	827	834	1
	Sonoma	FG	38	1,566	1,604	2
	Stanislaus	FG	8	1,498	1,506	1
	Tulare	FG	2,384	2,424	4,808	50
	Ventura	FG	898	964	1,862	48
Colorado	Adams	FG	0	1,235	1,235	0
	Arapahoe	FG	7	793	800	1
	Boulder	FG	261	481	742	35
	Jefferson	FG	161	607	768	21
	Larimer	FG	1,229	1,375	2,604	47
	Mesa	FG	2,362	947	3,309	71
	Weld	FG	310	3,680	3,990	8
Florida	Alachua	FG	0	902	902	0
	Broward	FG	0	1,211	1,211	0
	Charlotte	FG	0	690	690	0
	Citrus	FG	1	628	629	0
	Clay	FG	0	592	592	0
	Collier	FG	612	1,382	1,994	31

See footnotes at end of table.

Continued--

Appendix 1--Study counties (continued)

State	County	Type	Area			Federal portion
			Federal	Non-Fed	Total	
			- - - Square miles - - -			Percent
Florida	Dade	FG	309	1,646	1,955	16
	Hernando	FG	0	477	477	0
	Hillsborough	FG	1	1,052	1,053	0
	Indian River	CG	0	506	506	0
	Lake	FG	131	823	954	14
	Lee	FG	2	801	803	0
	Leon	FG	163	513	676	24
	Manatee	FG	0	747	747	0
	Marion	FG	435	1,175	1,610	27
	Martin	FG	1	554	555	0
	Okeechobee	CG	0	777	777	0
	Orange	FG	0	910	910	0
	Palm Beach	FG	0	1,993	1,993	0
	Pasco	FG	0	738	738	0
	Pinellas	FG	0	280	280	0
	Polk	FG	0	1,823	1,823	0
	St. Lucie	FG	0	581	581	0
	Sarasota	FG	0	573	573	0
	Seminole	FG	0	298	298	0
	Suwannee	CL	0	686	686	0
	Volusia	FG	25	1,088	1,113	2
Georgia	Bulloch	CG	0	685	685	0
	Clayton	FG	0	148	148	0
	Cobb	FG	14	329	343	4
	Decatur	CG	31	544	575	5
	Douglas	FG	0	203	203	0
	Gwinnett	FG	3	432	435	1
Idaho	Ada	FG	313	739	1,052	30
Illinois	Du Page	FG	0	337	337	0
	Franklin	CG	20	414	434	5
	McHenry	FG	0	607	607	0
	Will	FG	0	844	844	0
Indiana	Hamilton	FG	0	398	398	0
	Porter	FG	11	408	419	3
Kentucky	Calloway	CG	0	384	384	0
	Warren	CL	0	546	546	0
Louisiana	Concordia	CG	21	697	718	3
	East Baton Rouge	FG	7	340	347	2
	Jefferson	FG	7	340	347	2
	Lafayette	FG	0	270	270	0
	Pointe Coupe	CG	2	561	563	0
	St. Tammany	FG	1	872	873	0
Maine	York	FG	0	1,008	1,008	0
Maryland	Carroll	FG	0	452	452	0
	Charles	FG	2	450	452	0
	Frederick	FG	12	651	663	2

See footnotes at end of table.

Continued--

Appendix 1--Study counties (continued)

State	County	Type	Area			Federal portion
			Federal	Non-Fed	Total	
			- - - Square miles - - -			Percent
Maryland	Harford	FG	0	447	447	0
	Howard	FG	0	251	251	0
Massachusetts	Barnstable	FG	0	400	400	0
Michigan	Livingston	FG	0	575	575	0
Minnesota	Anoka	FG	0	430	430	0
	Dakota	FG	1	574	575	0
	Douglas	CL	0	647	647	0
	Kandiyohi	CL	0	783	783	0
	Washington	FG	2	388	390	1
Mississippi	De Soto	CG	28	448	476	6
	Hinds	CG	1	875	876	0
	Jackson	FG	40	691	731	5
	Lowndes	CG	12	496	508	2
Missouri	Cass	CL	0	698	698	0
	Jefferson	FG	0	661	661	0
	Lincoln	CL	5	620	625	1
	St. Charles	FG	9	549	558	2
Nevada	Clark	FG	7,735	146	7,881	98
	Washoe	FG	4,487	1,830	6,317	71
New Hampshire	Rockingham	FG	0	699	699	0
New Jersey	Ocean	FG	0	641	641	0
	Sussex	FG	33	492	525	6
New Mexico	Bernalillo	FG	147	1,022	1,169	13
	Dona Ana	FG	1,865	1,954	3,819	49
	San Juan	FG	1,364	4,158	5,522	25
New York	Saratoga	FG	2	808	810	0
North Carolina	Tyrrell	CG	0	390	390	0
	Wake	FG	26	828	854	3
	Washington	CG	0	343	343	0
North Dakota	Burleigh	CL	19	1,606	1,625	1
Ohio	Adams	CL	0	587	587	0
	Clermont	FG	17	439	456	4
	Medina	FG	0	422	422	0
Oklahoma	Beckham	CL	0	907	907	0
	Cleveland	FG	16	513	529	3
	Grady	CL	0	1,096	1,096	0
	Lincoln	CL	0	973	973	0
	Logan	CL	0	751	751	0
	Woodward	CL	13	1,238	1,251	1
Oregon	Clackamas	FG	799	1,071	1,870	43
	Crook	CL	1,469	1,506	2,975	49
	Deschutes	FG	2,231	794	3,025	74
	Jackson	FG	729	2,058	2,787	26
	Lane	FG	2,141	2,421	4,562	47
	Marion	FG	322	862	1,184	27
	Umatilla	CG	669	2,558	3,227	21

See footnotes at end of table.

Continued--

Appendix 1--Study counties (continued)

State	County	Type	Area: Federal	Area: Non-Fed	Area: Total	Federal portion
			- - - Square miles	- - -		Percent
Oregon	Washington	FG	4	721	725	1
South Carolina	Anderson	FG	50	668	718	7
	Berkeley	FG	302	806	1,108	27
	Dorchester	FG	0	575	575	0
	Horry	FG	0	1,143	1,143	0
	Lexington	FG	0	707	707	0
Tennessee	Dyer	CG	2	527	529	0
	Hawkins	CL	0	480	480	0
	Rutherford	CL	26	586	612	4
	Sevier	CL	194	403	597	33
	Sumner	FG	17	512	529	3
Texas	Atascosa	CL	0	1,206	1,206	0
	Bastrop	CL	0	890	890	0
	Bell	FG	59	996	1,055	6
	Brazoria	FG	0	1,407	1,407	0
	Brazos	FG	0	588	588	0
	Cameron	FG	0	905	905	0
	Collin	FG	58	793	851	7
	Coryell	CL	2	1,041	1,043	0
	Dallas	CS 1/	15	844	859	2
	Denton	FG	88	823	911	10
	Ellis	CL	14	926	940	1
	El Paso	FG	0	1,014	1,014	0
	Fort Bend	FG	4	872	876	0
	Gaines	CG	0	1,489	1,489	0
	Guadalupe	CL	0	714	714	0
	Harris	FG	37	1,697	1,734	2
	Hays	CL	0	650	650	0
	Hidalgo	FG	0	1,569	1,569	0
	Johnson	CL	1	739	740	0
	Kaufman	CL	0	815	815	0
	Live Oak	CL	25	1,030	1,055	2
	Montgomery	FG	74	973	1,047	7
	Randall	CL	0	914	914	0
	Smith	FG	0	932	932	0
	Starr	CG	0	1,211	1,211	0
	Tarrant	CL	27	834	861	3
	Travis	FG	0	989	989	0
	Webb	FG	0	3,363	3,363	0
	Williamson	FG	30	1,107	1,137	3
Utah	Davis	FG	55	244	299	18
	Salt Lake	FG	148	608	756	20
	Utah	FG	1,096	922	2,018	54
Virginia	Chesterfield	FG	0	434	434	0
	Fairfax	FG	5	388	393	1
	Prince William	FG	28	311	339	8

See footnotes at end of table.

Continued--

Appendix 1--Study counties (continued)

State	County	Type	Area: Federal	Area: Non-Fed	Area: Total	Federal portion
			- - - Square miles		- - -	Percent
Virginia	Virginia Beach	FG	0	256	256	0
Washington	Benton	FG	82	1,633	1,715	5
	Clark	FG	11	616	627	2
	Grant	CG	188	2,487	2,675	7
	Kitsap	FG	0	393	393	0
	Snohomish	FG	982	1,116	2,098	47
	Thurston	FG	1	726	727	0
Wyoming	Sublette	CL	3,801	1,050	4,851	78

Number of counties		Federal	Non-Fed	Total	Federal portion
135	1/ FG--Fast growth	84,014	171,158	255,172	33
36	2/ CL--Cropland loss	9,061	36,130	45,191	20
20	3/ CG--Cropland gain	2,688	23,242	25,930	10
1	4/ CS--Case study county	15	844	859	2
192	All counties	95,778	231,374	327,152	29

Sources: (35 and 43).

APPENDIX 2--Land use transition matrixes (1,000 acres)

1970	Clackamas County, Oregon, 1980 Land use classes																
	UR	CII	TCU	OU	UI	RR	NUT	CR	PA	HT	OA	RG	FR	WE	WA	OL	Total
UR	11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	11
CII	-	2	-	-	-	0	-	-	-	-	-	-	-	-	-	-	2
TCU	-	-	18	-	-	-	-	-	-	-	-	-	-	-	-	-	18
OU	-	-	-	4	-	-	-	-	-	-	-	-	-	-	-	-	4
UI	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
RR	1	-	-	-	-	12	-	-	-	-	-	-	-	-	-	-	13
NUT	0	1	-	-	-	-	1	-	-	-	-	-	-	-	-	-	3
CR	5	2	-	0	-	3	1	115	0	4	4	1	-	-	0	-	136
PA	-	-	-	-	-	0	-	-	2	-	-	-	-	-	-	-	2
HT	-	-	-	-	-	0	-	-	-	6	-	0	-	-	-	-	7
OA	-	-	-	-	-	-	-	-	-	-	4	-	-	-	-	-	4
RG	1	0	0	-	-	4	-	2	-	-	-	23	1	-	-	0	33
FR	1	-	1	-	-	1	-	0	0	-	-	1	230	-	-	0	236
WE	-	-	-	-	-	-	-	-	-	-	-	-	-	0	-	-	0
WA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10	-	10
OL	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	1	2
Total	19	5	21	4	-	21	2	118	3	10	8	26	231	0	11	2	480

1973	Washington County, Oregon, 1981-82 Land use classes												
	UR	CII	TCU	OBU	CR & PA	HT	OA	RG	FR	WA	WE	OL	Total
UR	15	0		-	0	-	-	-	-	-	-	-	16
CII	-	3	-	-	-	-	-	-	-	-	-	-	3
TCU	-	-	0	-	-	-	-	-	-	-	-	-	0
OBU	0	0	-	1	-	-	-	-	-	-	-	-	2
CR	6	2	-	0	54	1	0	-	-	-	-	-	63
HT	-	-	-	-	2	4	-	-	-	-	-	-	6
OA	0	-	-	0	-	-	-	-	-	-	-	-	0
RG	-	-	-	-	-	-	-	-	-	-	-	-	-
FR	1	0	-	0	1	-	-	-	12	-	-	-	14
WA	-	-	-	-	-	-	-	-	-	0	-	-	0
WE	0	-	-	-	-	-	-	-	-	-	-	-	0
OL	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	23	6	0	2	56	5	0	-	12	0	-	-	104

UR-Residential; CII-Commercial, Industrial, Institutional; TCU-Transportation, Communication, Utilities; OU-Other Urban; UI-Urban Idle; RR-Rural Residential; NUT-Nonurban Transitional; CR-Cropland; PA-Pasture; HT-Horticulture; OA-Other Agriculture; RG-Range; FR-Forest; WE-Wetlands; WA-Water; OL-Other Lands; OL-Other Lands; OBU-Other Urban Built-up; CP & PA-Cropland and Pasture.

Definitions of classes in Clackamas County and Washington County were nearly the same with the following exceptions: 1. Other Urban Built-up for Washington County is comparable to Other Urban and Urban Idle for Clackamas County. No observations occurred in the Urban Idle class in Clackamas County. 2. Clackamas classes, RR, NUT, CR, PA, HT, and OA are primarily the equivalent of CP, HT and OA for Washington County.

- = No observations. Zeros denote less than 500 acres.

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