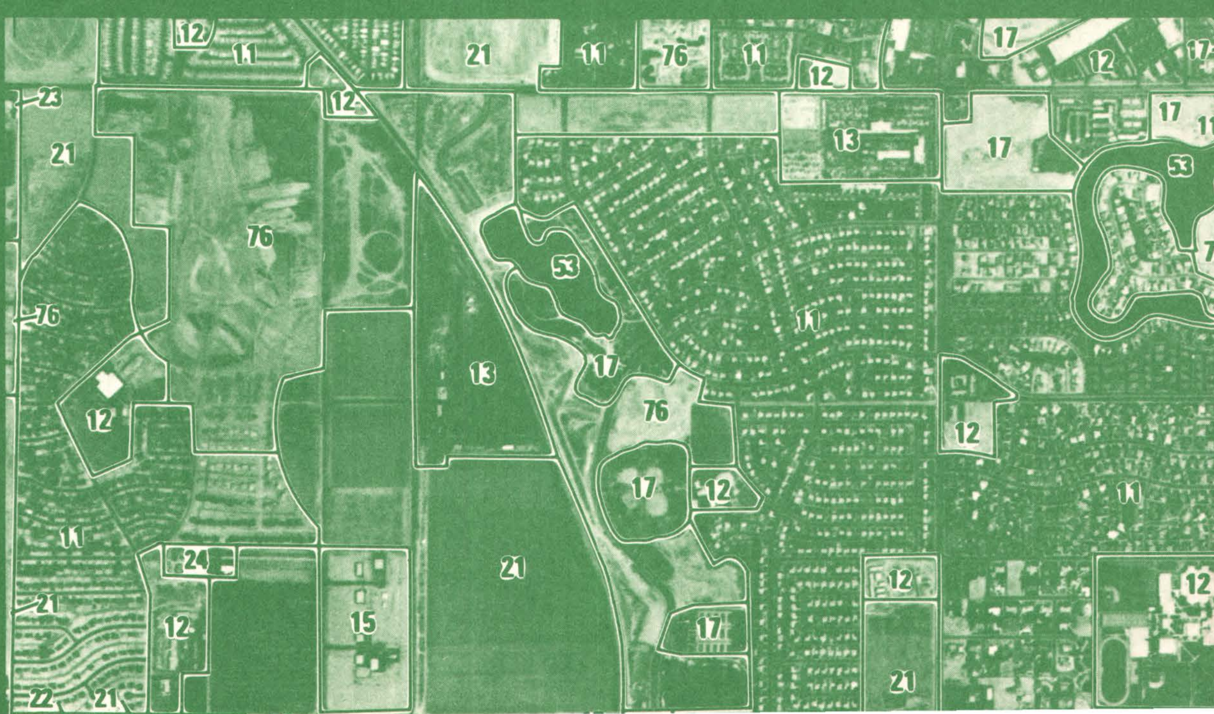
GEOLOGICAL SURVEY CIRCULAR 826

A REVIEW AND EVALUATION OF ALTERNATIVES FOR UPDATING U.S. GEOLOGICAL SURVEY LAND USE AND LAND COVER MAPS



A Review and Evaluation of Alternatives for Updating U.S. Geological Survey Land Use and Land Cover Maps

By Valerie A. Milazzo

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PREFACE

Land use and land cover maps and data must be kept current for effective planning and management of the Nation's land resources. In order to meet the increasing demands for up-to-date land use and land cover information, a primary goal of the U.S. Geological Survey's national land use and land cover mapping program is to update existing maps and data in a timely and uniform manner. Plans are now underway to begin the selective updating of this land use and land cover information as part of an ongoing program of nationwide land use and land cover mapping. Requisite to establishing an update-mapping program, however, is a careful evaluation of the various alternatives for updating land use and land cover maps.

This circular has been written to satisfy three purposes. The first is to present a review of the considerations that are important in planning a program to update nationwide land use and land cover maps. The second is to evaluate the options within each of the considerations for their applicability to the requirements of the U.S. Geological Survey's land use and land cover mapping program and to offer recommendations concerning those options thought to best satisfy these requirements. The third purpose is to stimulate thinking about additional approaches to updating land use and land cover maps. We hope that users of land use and land cover maps and data will consider their requirements and desires for updated land use and land cover data, and we invite their input. An addressed, postpaid response card which can be detached for use in replying is included in the back of this circular.

COVER: Two aerial photographs of a southern part of Tempe, Ariz., in 1970 (top) and 1979 (bottom). The photographs shown are portions of two 9-by 9-inch black-and-white aerial photographs taken for the Agricultural Stabilization and Conservation Service of the U.S. Department of Agriculture. They are shown here at a scale of about 1:20,000. Each photograph is overlaid with a polygon map delineating Level II land use and land cover categories as interpreted from the photograph.

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By Valerie A. Milazzo

ABSTRACT

Since 1974, the U.S. Geological Survey has been engaged in a nationwide program of baseline mapping of land use and land cover and associated data at a scale of 1:250,000. As 1:100,000-scale bases have become available, they have been used for mapping certain areas and for special applications. These two scales are appropriate for mapping land use and land cover data on a nationwide basis within a practical time frame, and with an acceptable degree of standardization, accuracy, and level of detail. An essential requisite to better use of the land is current information on land use and land cover conditions and on the rates and trends of changes with time. Thus, plans are underway to update these maps and data. The major considerations in planning a nationwide program for updating U.S. Geological Survey land use and land cover maps are as follows: (1) How often should maps be updated? (2) What remotely sensed source materials should be used for detecting and compiling changes in land use and land cover? (3) What base maps should be used for presenting data on land use and land cover changes? (4) What maps or portions of a map should be updated? (5) What methods should be used for identifying and mapping changes? (6) What procedures should be followed for updating maps and what formats should be used? These factors must be considered in developing a map update program that portrays an appropriate level of information, relates to and builds upon the existing U.S. Geological Survey land use and land cover digital and statistical data base, is timely, cost-effective and standardized, and meets the varying needs of land use and land cover data users.

INTRODUCTION

Since 1974, the U.S. Geological Survey (USGS) has been engaged in nationwide baseline mapping of land use and land cover and associated data at a scale of 1:250,000. As 1:100,000-scale base maps have become available, they have been used for special applications and for mapping certain areas. These scales are appropriate for mapping land use and land cover data on a nationwide basis within a practical time frame, and with an acceptable degree of standardization, accuracy, and level of detail. Land use and land cover has been mapped using remotely sensed data at Level II of the classification system presented by Anderson and others (1976) (see table 1 of this report) and using the compilation specifications documented by Loelkes (1977). As part of this program, the land use

TABLE 1.—*USGS land use and land cover classification system for use with remotely sensed data*

[From Anderson and others, 1976]

Level I	*Level II*
1 Urban or Built-up Land	11 Residential
	12 Commercial and Services
	13 Industrial
	14 Transportation, Communications and Utilities
	15 Industrial and Commercal Complexes
	16 Mixed Urban or Built-up Land
	17 Other Urban or Built-up Land
2 Agricultural Land	21 Cropland and Pasture
	22 Orchards, Groves, Vineyards, Nurseries, and Ornamental Horticultural Areas
	23 Confined Feeding Operations
	24 Other Agricultural Land
3 Rangeland	31 Herbaceous Rangeland
	32 Shrub and Brush Rangeland
	33 Mixed Rangeland
4 Forest Land	41 Deciduous Forest Land
	42 Evergreen Forest Land
	43 Mixed Forest Land
5 Water	51 Streams and Canals
	52 Lakes
	53 Reservoirs
	54 Bays and Estuaries
6 Wetland	61 Forested Wetland
	62 Nonforested Wetland
7 Barren Land	71 Dry Salt Flats
	72 Beaches
	73 Sandy Areas Other than Beaches
	74 Bare Exposed Rock
	75 Strip Mines, Quarries, and Gravel Pits
	76 Transitional Areas
	77 Mixed Barren Land
8 Tundra	81 Shrub and Brush Tundra
	82 Herbaceous Tundra
	83 Bare Ground Tundra
	84 Wet Tundra
	85 Mixed Tundra
9 Perennial Snow or Ice	91 Perennial Snowfields
	92 Glaciers

and land cover maps and associated data are digitized and the information is stored in digital format in a computerized geographic information system, as described by Mitchell and others (1977). The system has the capability to input, store, manipulate, and retrieve the data and makes possible the generation of digital data base tapes and a wide array of graphic and statistical output products.

An essential requisite to better use of the Nation's land is current information on land use and land cover and on the rates and trends of changes—hence, the need for a program of map update. Before embarking on such a program, however, a systematic approach to monitoring and mapping changes in land use and land cover must be developed. A program to update the USGS land use and land cover maps must portray an appropriate level of information, relate to and build upon the existing USGS land use and land cover digital and statistical data base, incorporate the elements of timeliness, cost-effectiveness, and standardization, and meet the varying needs of data users at regional, State, and other agency levels. An evaluation of the various considerations in the updating of land use and land cover maps is requisite to the establishment of a nationwide program of map update that will best achieve these objectives.

The major considerations in planning a nationwide program for updating USGS land use and land cover maps are the following:

- How often should maps be updated?
- What remotely sensed source materials should be used for detecting and compiling changes in land use and land cover?
- What base maps should be used for presenting data on land use and land cover changes?
- What maps or portions of a map should be updated?
- What methods should be used for identifying and mapping changes?
- What procedures and what formats should be used for updating maps?

Options within each of these categories must be evaluated in terms of advantages and limitations in the task of map update in order to recommend the optimal alternatives for implementation in an operational nationwide program of land use and land cover map update.

HOW OFTEN SHOULD MAPS BE UPDATED?

Since land use and land cover changes occur at highly variable rates from place to place, there is a need to establish differing intervals for monitoring and mapping changes. Frequency of update, in the ideal sense, is not only a factor of the dynamics of land use and land cover change but also is related to the type of change, the relative importance of the change, and to the location, concentration, and amount of change. In reality, however, such factors as priorities, schedule capacities, cooperative agreements, map scales and data level may make a difference in the decisionmaking process involving frequency of update determinations. In addition, one must remember that the ability to update is also dependent upon the availability of suitable remotely sensed source materials.

THE NATURE OF LAND USE AND LAND COVER CHANGES

Before attempting to establish a frequency for map update, an understanding of the nature of land use and land cover change is required. Changes take place at variable rates in different locations and at different times within the same area. Anderson (1977) cites some examples of the dynamics of land use and land cover change. The reversion of Cropland and Pasture to Forest Land in New England is occurring slowly while in parts of the South Cropland and Pasture are converting to planted pine (Forest Land) at a much faster rate. In central Florida during the 1950's, citrus acreage expanded rapidly and changes in land from other uses to the Orchards, Groves, and Vineyards category were numerous and frequent. By the 1960's, the citrus grove expansion had stabilized and land use and land cover changes involving this category had decreased significantly.

Residential subdivision development, highway construction, and land use and land cover changes involving most other Urban or Built-Up Land uses take place in very short periods of time. Although the land area involved may be considerably less than for nonurban categories, the number and frequency of the changes and their far-reaching impact on the landscape make changes in these "dynamic" urban categories important to identify as frequently as possible. Other categories of land use and land cover may undergo little or no change over long periods of time. In some areas, there is a pronounced absence of economic or environmental conditions for change. For example, in many parts of the arid Southwest having extensive areas of Barren Land and desert vegetation, very little change occurs. Areas characterized by tundra or perennial snow and ice cover are relatively unchanging. These areas are characterized by certain types of land use and land cover categories and can be termed as "stable" land environments because of their resistance to change.

Finally, regional variations based on historical patterns are likely to affect land use and land cover change. The kind and the magnitude of the changes experienced in an area in the past may not be the same as those likely to occur in the future. For example, urbanization is slowing down in the Northeast and Midwest parts of the Nation, while the Southeast and Southwest are experiencing considerable growth in urban land use and land cover categories. Thus, even though the land use and land cover categories involved in change have the same dynamics, the rate of change varies with region and time.

There are other considerations affecting the frequency of map update in addition to and apart from those already discussed. These considerations include obsolete specifications and classification system compilations, errors, map scale, classification level, or cooperative arrangements with certain users. These considerations are, however, incidental determinants of update frequency since they would most likely affect update only on a one-time basis.

PROCEDURES FOR DETERMINING UPDATE FREQUENCY

Determining the frequency for updating land use and land cover maps can be approached from two distinct viewpoints, each yielding a different approach for frequency determination and a different interval of update. In the first, update frequency is determined according to elapsed time. In this approach, a map is updated at a predetermined time interval regardless of the amount and type of changes that have actually taken place.

The second approach is based on criteria of change, where the amounts and the types of change dictate the frequency of update. Each land use and land cover map is updated according to certain predetermined land use and land cover change criteria concerning amount and type of change, regardless of the time elapsed. This approach could result in the update of maps with the same or similar general land use and land cover features at different frequencies and also in subsequent updates for the same map at varying intervals.

The approach chosen for frequency determination at this stage—either based on elapsed time or on change criteria—will dictate the procedures to be followed. If map update frequency is based on elapsed time, specific time intervals need to be established for map update. This could be accomplished by stratifying the land use and land cover maps according to a ranking of Level II land use and land cover categories (see table 1), into areas of high and low national priorities, areas of high and low change potential (dynamic versus stable land environments), by regions, by age of compilation source material, and by other considerations concerning the nature of land use and land cover change mentioned previously. Each of these groups of maps would be assigned a preferred update interval. Three other time factors can also be considered in establishing update intervals for selected maps under the elapsed time approach. One is to tie-in update frequency with the census for urban areas. This census, once taken decennially, is planned to be updated every 5 years beginning in 1985. A second consideration is to plan updates that coincide with the acquisition and availability of aerial photographs. A third factor, budget and manpower constraints, would establish a minimum practical time interval for map update. Within the USGS nationwide mapping program, 5 years from the date of the compilation source material has been established as the minimum time for the scheduling of land use and land cover map update. Given the scale and the level of land use and land cover detail mapped under this program, a minimum 5-year update cycle is compatible with the expressed goal to maintain current land use and land cover information.

A procedural advantage to the time interval approach to map update frequency is that no routine review or inspection of candidate land use and land cover maps is required prior to updating. Since the need for map update is based solely on the age of the land use and land cover data, a map need not be reviewed to satisfy any other criteria or conditions of land use and land cover change for update selection.

The second approach to the determination of map update frequency, in which frequency is dictated by specified change criteria, requires a different procedure. Since the amount and type of land use change determines the need for update, each land use and land cover map must be reviewed periodically with more current remotely sensed source materials to identify the changes. Thus an additional step—photoinspection—is required to determine update frequency.

The photoinspection process establishes a cycle for the periodic review of maps to determine the need for update. This cycle designates a minimum or maximum time interval for the photoinspection of land use and land cover maps. A cycle could range anywhere from 1 year to 5 years or more. The same strategy developed for selecting maps for update based on elapsed time criteria can be used to target maps for photoinspection and to determine likely routine time frequencies for photoinspection with available remotely sensed source materials. On this basis, photoinspection is done at constant predetermined time intervals.

The frequency of photoinspection would not automatically correspond to the frequency of actual map update. Due to the nature of land use and land cover change, not all the maps would meet the change criteria for update selection at the given photoinspection time. Thus, although photoinspection is conducted routinely on a prescheduled frequency, map update is performed only as often as necessary.

RECOMMENDATIONS

If a map update program is to be effective, it must incorporate the element of time together with an understanding of land use and land cover dynamics in the determination of update frequency. It is recommended, therefore, that update frequency be structured on the basis of need as determined by criteria of land use and land cover change and that elapsed time be considered an important, supportive input to update planning. The overall approach to establishing a frequency for land use and land cover map update should encompass two stages:

1. A photoinspection procedure should be established to periodically review land use and land cover maps in order to identify the changes that justify updating the maps. Routine photoinspection for selected areas should be conducted on predetermined cycles based on elapsed time.
2. A map update procedure should be established in which maps are selected for update primarily on the basis of land use and land cover change, where the amounts and types of changes identified in the photoinspection phase determine the need for map update. The frequency of actual map update cannot be predetermined since it is dependent on the outcome of photoinspection.

In establishing a routine cycle of photoinspection for the purpose of determining the need for map update, two considerations should be taken into account: (1) The dynamics of the land use and land cover categories with respect to change over time and (2) the relative importance of the land use and land cover changes with respect to their cultural, economic, and environmental impacts. With these two factors in mind, a hierarchical arrangement of Level II land use and land cover categories can be made on the basis of change potential, in terms of the relative rate at which changes might occur in the respective land use and land cover categories and in terms of the potential impact of the changes. In a second stratification, these Level II land use and land cover categories can be grouped into the general land use and land cover environments for which they are likely to represent the dominant land use and land cover condition (see table 2). These general environments can, in turn, be ranked according to probable rates of land use and land cover change and the relative importance and impact of the change taking place on the landscape. To each of these groups, a target time frame can be assigned which represents an optimum photoinspection or update cycle based on the likely rate and impact of the changes to be encountered. A suggested frequency of update resulting from such a stratified matrix approach is shown in table 2.

TABLE 2.—*Suggested update cycles for land use and land cover data based on stratification of Level II categories*

Land use and land cover environment	*Level II category*	*Update cycle (years)*
SMSA's, urban and built-up areas, and other dynamic change areas.	11–17, 76	5–7
Critical environment areas	51–54, 61, 62, 72	7–10
Energy resource areas	75, 76	7–10
Agricultural, Rangeland, and Forest Land areas.	21–24, 31–33, 41–43	10–15
Stable land areas	71, 73, 74, 77, 81–85 91, 92	15–20

WHAT REMOTELY SENSED SOURCE MATERIALS SHOULD BE USED FOR DETECTING AND COMPILING CHANGES IN LAND USE AND LAND COVER?

A land use and land cover map update program should be designed to make maximum use of remotely sensed data. Present remote-sensing technology offers a wide selection of sensors and capabilities. From past experience in land use and land cover mapping, some general guidelines have been established by Loelkes (1977) for the selection of remotely sensed source materials. These guidelines are the following:

1. The format of the remotely sensed data must be such that it is or can be rectified, if necessary, to a tilt-corrected format.
2. The scale should be no larger than 1:60,000.
3. Source photographs for the winter season (leaf-off condition) should be used, if available.
4. There must be no snow cover.
5. The photographs should contain no more than 10-percent cloud cover.

In addition to these guidelines, two additional criteria should be considered. The resolution of the remotely sensed source should be sufficient for interpretation of Level II land use and land cover categories accurately and consistently. Comparability with the past or future land use and land cover data should be provided in that the level and class of information extracted from the update source is the same as that contained in the earlier map data base.

There are several kinds of remotely sensed data that can be used to update land use and land cover maps. They are large-scale, low-altitude aerial photographs; small-scale, high-altitude aerial photographs; Landsat multispectral scanner (MSS) imagery; Landsat MSS digital data; and Landsat return beam vidicon (RBV) imagery. Given the present technology, each has certain advantages and limitations for land use and land cover change detection and map update. Some of the more pertinent characteristics of each are described below.

LARGE-SCALE, LOW-ALTITUDE AERIAL PHOTOGRAPHS

These photographs range in scale from 1:20,000 to 1:40,000 and are taken from aircraft at altitudes of 10,000 to 40,000 ft. They have the following advantages for land use and land cover map update: They can be rectified to a tilt-corrected format for mapping; the resolution is sufficient for interpreting Level II categories; and they often provide more frequent coverage for some areas than is provided by higher altitude sources. Large-scale, low-altitude aerial photographs possess, however, several limitations for map update. Since land use and land cover map update is of a nationwide scope, the land area involved precludes extensive use of large-scale remotely sensed data due to the lack of complete coverage needed over some large areas. In addition, the costs associated with low-altitude aerial photograph acquisition and data utilization and integration over large areas are excessive. Finally, the scale and resolution of large-scale photographs far exceed that required for efficient Level II land use and land cover mapping on a nationwide basis, thereby lessening the comparability of updated data with the existing land use and land cover data base developed from high-altitude source materials. There is a tendency when using larger scale photographs to see and therefore extract more detailed land use and land cover information. Generally, the structure of the mapped Level II categories derived from large-scale sources is somewhat different from the same Level II categories derived from small-scale sources. With the low-altitude, large-scale photographs, the classification is derived from an aggregation or building up of more detailed information; with high-altitude, small-scale photographs, more general information is broken down into its component parts in cases where this information conforms to the classification system and mapping specifications in USGS Open-File Report 77-555 (Loelkes, 1977).

SMALL-SCALE, HIGH-ALTITUDE AERIAL PHOTOGRAPHS

Small-scale, high-altitude photographs have nominal scales between 1:80,000 and 1:120,000 and are obtained from aircraft flying at altitudes of 40,000 to 60,000 ft. They are principally NASA high-altitude RB-57 and U-2 photographs and photographs acquired for USGS topographic mapping. Such photographs are usually black-and-white panchromatic or color-infrared. They have been used successfully in compiling nearly all past land use and land cover data.

Small-scale, high-altitude photographs have the following advantages for map update: They can be rectified to a tilt-corrected format for mapping; the resolution and scale are sufficient for interpreting and mapping Level II categories accurately and efficiently for large areas at 1:250,000- and 1:100,000-scales; and they provide data comparability with the existing land use and land cover data base. The limitations are that the available or existing source may not be the optimal source for land use and land cover mapping based on the guidelines mentioned previously and the coverage is often nonrepetitive or infrequent thereby limiting the selection of areas that can be updated.

LANDSAT MULTISPECTRAL SCANNER (MSS) IMAGERY

Much research has been conducted on the use of Landsat imagery for land use and land cover mapping and change detection. However, to date, the potential value of Landsat MSS imagery for consistent measuring and mapping of spatial and temporal changes in land use and land cover has not been fully demonstrated. Clearly, Landsat MSS imagery presents several advantages over conventional aerial photographs. It affords synoptic coverage of land use and land cover as frequently as every 18 days. In addition, coverage for nearly all parts of the country is readily available at relatively low cost and fills in the gaps left by conventional aerial photographs in providing the necessary source for land use and land cover update maps where and when needed. Its repetitive capability makes possible the routine monitoring of areas for changes in land use and land cover. Landsat MSS imagery can also be used to "target" specific areas, having extensive Level I-type land use and land cover change, which may then be updated using higher resolution sources.

The outstanding advantages of frequency of coverage, repetition, availability, and low cost make Landsat MSS imagery a uniquely appealing source for land use and land cover map update. However, it does possess certain formidable limitations for operational use. Studies undertaken in southern Arizona (Place, 1974) and elsewhere (Fitzpatrick-Lins, 1978) using Landsat MSS imagery have shown that Landsat imagery is not wholly appropriate for Level II land use and land cover mapping. Several USGS Level II land use and land cover categories cannot be identified and mapped from the Landsat imagery alone. Particularly, the resolution of the MSS imagery does not permit accurate and consistent separation of those land use and land cover categories most likely to undergo temporal changes. As a result, Landsat imagery would be least suitable as a source of land use and land cover change information in those very areas where most of the changes are occurring. The inability of Landsat to replicate the same Level II categories contained in the baseline land use and land cover maps, as well as from one Landsat scene to the next, limits its use as source material for detailed map update since comparability with the existing baseline data cannot be realistically achieved.

LANDSAT MSS DIGITAL DATA

A somewhat more promising application of Landsat data for land use and land cover mapping and change detection is offered by computer-aided analysis of Landsat MSS digital data. Ongoing research and development activities conducted by the USGS (Milazzo and others, 1977) suggest the potential for using Landsat digital data for land use and land cover change detection in an operational map update program. Landsat digital data afford the same currency of information as the MSS imagery. In addition, computer processing makes possible the examination and classification of large amounts of data quickly. Since the data are already in a digital format, they form the basis of a geographic information system capable of providing simultaneous area measurement tabulations. Thus, the need to convert a graphic land use and land cover map into digital format to derive area statistics is eliminated.

In computer processing of Landsat digital data for land use and land cover change detection, changes are derived by comparing the relative spectral responses occurring over time. Georectified and reformatted tapes from two time periods are overlaid in the computer and the spectral differences between the two scenes print out as possible areas of change. These areas are then grouped in a specialized classification and related to corresponding USGS Level I and (or) Level II categories. In this technique, the mapping of change is accomplished by comparing two data sets, not two separate maps or interpretations. In theory, this technique seems quite workable for change detection. However, in practice there are several significant problems which, given the present technology, may or may not be resolved.

One problem lies in converting spectral differences into valid land use and land cover category changes. It is unrealistic to expect a specialized land use and land cover classification developed from computer-classified Landsat data to match category for category or to merge with the USGS Level II classification system which is designed for human compilers using other remotely sensed sources. Due to the incompatibility of these two systems, the detection of either "from" or "to" changes in each of the USGS Level II categories cannot be accomplished. Hence, a direct update of land use and land cover maps derived from other remotely sensed sources with Landsat digital data is not feasible.

Another formidable problem in using Landsat digital data for change detection and map update is that such a map of "changes" is likely to contain considerable noise, or false changes—areas that appear different spectrally, but their use or cover category has not changed. The identification of false changes is due to a number of factors including misregistration of pixels in the Landsat scenes being compared; comparison of data from different seasons, particularly involving crop rotation cycles, where the rotation causes the same agricultural activity to be erroneously identified as a land use and land cover category change; identification of differences in soil moisture content or other environmental anomalies that result in different spectral signatures for the same land use or land cover category; and misclassification of land use and land cover due to poorly grouped spectral classes. One way to reduce the occurrences of false change identification is to raise the threshold level. Differences as small as one picture element (pixel), 1.1 acres, can be identified from the Landsat digital data. By raising the threshold, one can sample larger groupings of pixels, for example 8-pixel by 8-pixel windows, in which only changes of approximately 64 acres or greater are mapped. Although this approach significantly reduces the amount of "salt and pepper" type false changes, it also results in a loss of sensitivity to many valid land use and land cover changes, which often occur in small areas. There is also a loss of comparability with the Level II classification system in which land use and land cover is mapped at 10- and 40-acre minimums. Therefore only a few gross Level I category changes such as Forest to Agriculture are identified.

LANDSAT RETURN BEAM VIDICON (RBV) IMAGERY

The newly acquired NASA Landsat RBV imagery appears to be a promising source for land use and land cover mapping and update roughly equivalent to the small-scale, high-altitude aerial photographs used in past mapping. Although no thorough evaluation has been conducted, the imagery viewed thus far suggests promise for use as either a photographic source for direct updating of maps in cases where the resolution permits reliable discrimination of discrete Level II land use and land cover categories or for targeting those areas where enough Level I changes have occurred to justify update using higher resolution materials.

RECOMMENDATIONS

The level, amount, and accuracy of land use and land cover data that may be obtained from remotely sensed data depend on the altitude and resolution of the sensor and, to some extent, on the scale of the derived product. Anderson and others (1976) recommend the use of high-altitude source data from altitudes of 40,000 ft or more, with scales of 1:80,000 or smaller for the extraction of Level II land use and land cover information. In keeping with this recommendation, the principal remotely sensed sources used for the mapping of Level II land use and land cover data have been NASA high-altitude U-2 and RB-57 photographs and photographs acquired for USGS topographic base mapping. Small-scale, high-altitude photographs have been used successfully for compiling nearly all past land use and land cover information and are capable of meeting the seven recommended guidelines for remotely sensed data selection previously enumerated. It is expected that small-scale, high-altitude photographs will continue to be the mainstay of future land use and land cover map compilations, and it is recommended that they continue to be one of the primary photographic sources for updating land use and land cover maps.

In addition to the use of small-scale photographs for updating maps, it is also reasonable to consider using large-scale photographs in a limited and complementary way when more suitable smaller scale sources do not exist or when a more detailed land use and land cover classification is required for special applications.

The use of Landsat digital data in updating land use and land cover maps relies on the development of new and improved digital data analysis techniques and on continued improvements in computer technology. At present, Landsat digital data are most appropriate for monitoring gross land use and land cover changes and for assisting in the update selection process for manually compiled land use and land cover maps. The data do not constitute a primary source for such an update, but may rather function in a complementary role.

WHAT BASE MAPS SHOULD BE USED FOR PRESENTING DATA ON LAND USE AND LAND COVER CHANGES?

There are three primary USGS map bases that can be used in the mapping of land use and land cover data. These are the 1:250,000-scale topographic maps, the 1:100,000 intermediate-scale quadrangle maps, and the intermediate-scale county maps at 1:100,000 and 1:50,000. Each of the map bases is considered in terms of at least five factors: (1) costs to produce, (2) impact on existing statistics, (3) amount of information portrayed, (4) usefulness to users, and (5) versatility, or number and types of products that can be derived.

1:250,000-SCALE TOPOGRAPHIC MAPS

The 1:250,000-scale topographic map possesses the following general advantages as a base in updating land use and land cover maps: It has proven to be a satisfactory base and scale for the presentation of Level II land use and land cover data in a standardized, nationwide program of land use and land cover mapping; it is available nationwide—maps are complete for all 50 States; the scale is adequate for mapping Level II land use polygons at 10- and 40-acre minimum sizes; most baseline land use and land cover and associated data mapping has been keyed to the 1:250,000-scale base map; and most baseline land use and land cover maps and associated data have been digitized using the 1:250,000-scale map base control.

The 1:250,000-scale topographic map has certain limitations in its use as a base for updating maps. The positional accuracy does not meet National Map Accuracy Standards (NMAS) in most cases, even though maps are revised periodically; bases for some areas, and hence planimetric data, are often out-of-date; and the scale does not satisfy the needs of many land use and land cover data users.

1:100,000 INTERMEDIATE-SCALE QUADRANGLE MAPS

The use of the 1:100,000 intermediate-scale topographic quadrangle map as a base for updating land use and land cover has the following advantages: It has good positional accuracy—it meets NMAS; it provides relatively up-to-date planimetric base data; the scale is well-suited to Level II land use and land cover mapping and data presentation at 10- and 40-acre minimum mapping units; it permits easy readability of Level II polygons and identifiers, particularly in congested areas; and it allows the flexibility of mapping polygons at lower minimum mapping sizes since 10- and 40-acre mapping units are well above the threshold of clarity and readability at this scale.

There are disadvantages to the use of the 1:100,000-scale maps: Almost 2,000 maps are required to cover the conterminous United States at 1:100,000-scale, as compared to 473 for the 1:250,000-scale series; there is incomplete coverage nationwide—bases are generally not available for those areas where updates may be needed most; land use and land cover compilations on the 1:100,000-scale base offer the same information to the user as does the 1:250,000-scale map when the same classification level and the same minimum mapping units are used; and, it is more costly to compile and produce the 1:100,000-scale map than the 1:250,000-scale map. In addition, a mixture of baseline land use and land cover maps at 1:250,000-scale and updated land use and land cover maps at 1:100,000-scale creates confusion for users and makes cross-sheet boundary land use and land cover data utilization difficult, which diminishes the range of usefulness of the map product for many State and regional applications. In the geographic information system, comparability between the merged graphic and statistical data generated from land use and land cover polygons digitized using 1:250,000-scale base control and those polygons digitized using 1:100,000-scale base control may not be achieved due to positional accuracy differences between the two bases.

1:100,000 AND 1:50,000 INTERMEDIATE-SCALE COUNTY MAPS

The advantages and limitations described for the 1:100,000-scale quadrangle series apply to the 1:100,000-scale and 1:50,000-scale county map series as well. In addition, use of this base for land use and land cover map update deviates even further from the goal of standardized map products in the national mapping program. This map series can function more appropriately as a supplement to the standard land use and land cover map series and is quite appropriate for special applications.

RECOMMENDATIONS

Most land use and land cover maps that have been digitized thus far have been concentrated in those areas mapped on the 1:250,000-scale base. These are usually the older maps and are therefore the ones more likely to be among the first selected for update. For these maps, revised 1:250,000-scale topographic base maps have become available, or new 1:100,000 intermediate-scale topographic quadrangle maps have been or will soon be completed. In both cases, the use of a map base in the update phase that is different from that used in the initial mapping of land use and land cover will impact the statistical data base already developed from the digitized map. Misregistration of land use and land cover polygons could occur due to differences in positional accuracy. Hence, the integrity of the statistical data being built upon and added to the data base may be affected adversely. This is especially so in the case of the 1:100,000-scale series map versus the 1:250,000-scale map.

An additional input to the selection of a map base for land use and land cover update involves regional considerations. In some parts of the Nation, the land use and land cover patterns are less complex than in other parts. For example, many areas in the Central United States, as well as many parts of the West and Southwest, have extensive acreage in a few stable land use and land cover categories such as Rangeland and Barren Land. In such areas where rapid or numerous land conversions are unlikely, or overall map content and detail are minimal, the 1:250,000-scale base remains adequate for the presentation of land use and land cover information. In other parts of the Nation, where land use and land cover patterns are more dense and complex and where changes in land use and land cover occur with greater number and frequency, it is desirable to map land use and land cover on the 1:100,000-scale bases. Given these considerations, it seems reasonable to continue the use of two bases for nationwide land use and land cover mapping.

The following approach to the selection of a map base for first-round land use and land cover map update is suggested:

- The 1:250,000-scale bases should be used for land use and land cover map update in those areas where 1:100,000-scale bases are not available and should continue to be used for map update in those areas where, given the nature of the regional land use and land cover patterns, it is desirable to continue the presentation of updated map data at that scale, even if 1:100,000-scale bases are available.
- Update of existing 1:250,000-scale land use and land cover maps should be on the 1:100,000-scale bases if such bases are available at the time of update and if the regional location and nature of the land use and land cover patterns and expected changes make it advantageous to convert to the larger scale base.
- For those land use and land cover maps already compiled at 1:100,000-scale, update should be continued on the 1:100,000-scale bases.

The approach to map update outlined here tries to balance the blend of old and new. It attempts to maintain the much needed and used digital and statistical data base already developed for the 1:250,000-scale map while allowing the gradual incorporation of and eventual conversion to the 1:100,000-scale base on a regional basis for land use and land cover mapping.

WHAT MAPS OR PORTIONS OF A MAP SHOULD BE UPDATED?

Once a map has been selected for updating, a determination of the exact areal extent of the required update must be made. The maps, or parts of maps, should be chosen where, upon inspection, the amount, concentration, and type of changes are sufficient to justify an update. The map may be updated by either the full map sheet or by partial map sheet.

FULL MAP-SHEET UPDATE

Full map-sheet update involves updating an entire map (at any scale) at one time. This approach has the advantage of providing continuity with the former baseline map, in that a completely updated version of the old map is released in the same form. This leaves the user with no question as to what parts of the map have been updated. Also, all of the land use and land cover data contained on the map are from the same source and time. The disadvantages, however, in the full map update approach are significant for small-scale maps such as the 1:250,000-scale map. Suitable photographic coverage for the entire map is usually difficult and costly to procure. Even so, updating the full map sheet is appropriate in cases where changes in specifications or classification system necessitate complete recompilation and revision of the map or where the changes are in fact extensive enough to cover most of the map area.

PARTIAL MAP-SHEET UPDATE

In this approach, only those parts of a map are updated where a significant amount of change has occurred, is likely to be found, or where user interest or needs are greatest. These map parts may be defined by geographic coordinates, quarter-map sections, SMSA's, political boundaries such as those for counties or States, designated regional, environmental, or administrative areas, selected land use and land cover categories, or other criteria. This approach has the advantage of providing the user with an updated map product quickly, efficiently, and inexpensively. However, a limitation exists in that the release of a full map for which only specific parts have been updated creates the need for additional map legend explanations, such as a coverage diagram, to tell the user what parts of the map have been updated and to what date. Another disadvantage is that the user must obtain supplemental material for identifying the exact boundaries of the updated areas on the map. The need for supplemental data could be increased by successive rounds of map update when update is undertaken for different parts of the map at different times. This would ultimately decrease the comparability and usability of the data.

Another disadvantage of partial map update is that it creates innumerable internal edge-joining difficulties between the polygons at the boundaries of the updated area and those (either extensions of the same polygon or different land use and land cover polygons) outside the updated area. To effect a proper internal joining, the limits of the update area must become the arbitrary or artificial boundaries between the new and the old adjoining land use and land cover polygons. If this joining procedure is followed through successive rounds of partial map sheet update, a series of artificial boundaries may be set up on the map. These boundaries could create a visible pattern of land use and land cover polygons that follow the outline of each updated area thereby segmenting the map on this basis. This adversely affects the attempt to portray land use and land cover polygons by natural boundary delineation.

RECOMMENDATIONS

One of the more difficult decisions concerning the update of land use and land cover maps deals with recommending the areal extent of map update. Because both 1:250,000- and 1:100,000-scale maps have been used as bases for initial data compilation in the USGS land use and land cover mapping program, a different decision concerning what maps or portions of a map should be updated is required in each case. The following recommendations for the areal extent of map update are proposed:

- For existing 1:250,000-scale land use and land cover maps that are to be updated at the same scale, update should be done for the complete map sheet.
- For existing 1:250,000-scale land use and land cover maps that are to be converted to the 1:100,000-scale bases for map update, update should be done on 1:100,000-scale bases covering either the complete 1:250,000-scale map sheet or selected quadrants.
- For 1:100,000-scale land use and land cover maps and all other maps to be updated on 1:100,000-scale bases, update should be done for the complete map sheet.

Thus, whatever the map scale for the presentation of updated land use and land cover information, it is generally recommended that the complete map be updated at one time. Since land use and land cover data are compiled and formatted by full map sheet, it should likewise be updated on that same basis. This approach maintains continuity in mapping design and eliminates the hazards associated with over-customizing the map product to the point where it serves a decreasing number of users.

WHAT METHODS SHOULD BE USED FOR IDENTIFYING AND MAPPING CHANGES?

Change detection is a separate and distinct step in the land use and land cover map update process. It deals with the detection and identification of temporal changes in land use and land cover from a comparison of remotely sensed and (or) map source materials from two or more time periods and the mapping of those changes in accordance with established land use classification standards and map compilation specifications. There are four basic methods for detecting land use and land cover changes: original source material-to-new source material, original map-to-new source material, original map and source material-to-new source material, and original map-to-new map comparisons.

ORIGINAL SOURCE MATERIAL-TO-NEW SOURCE MATERIAL

In the original source material-to-new source material change detection technique, changes are derived from a comparison of the original compilation photographs with the new photographs. In this approach, one compiler determines the land use and land cover categories from the old photographs and makes the change assessments from the new photographs at the same time. This technique has certain advantages in that the compiler can see the actual land use and land cover features as they appeared at both times, and errors in the original compilation, either of commission or omission, can be identified if they are involved in change. This technique thus allows for a limited correction of the data base.

There are at least five limitations of the original source-to-new source procedure for detecting changes in land use and land cover. First, the costs of storing or reacquiring all of the original compilation materials are high. Second, in an original source-to-new source comparison, the compiler is looking at only the areas involved in change on the two sets of photographs. Since no reference is made to the land use and land cover information on the original map, the compiler is likely to miss original compilation mapping errors that are not involved in change. The third limitation of of an original source-to-new source change detection procedure is that it tends to add more land use and land cover detail in an update because the compiler intentionally focuses on small, discrete land use and land cover categories in order to search out every possible change that might meet minimum mapping unit sizes. This results in a tendency to rearrange the more generalized existing boundaries of the land use and land cover polygons in order to accommodate many small polygons of change.

A fourth limitation of the original source material-to-new source material method is that it generates an undue number of interpretation and delineation "disagreements" between the original data and the data interpreted during update. The disagreements usually involve indefinite categories and boundaries which must be subjectively interpreted and delineated. The individual conducting the update, who has access to both sets of sources, may not make the same decisions as were made by the original compiler. The end result may be an update fraught with unnecessary data base corrections. Finally, the detection of valid land use and land cover changes by direct visual comparisons between two or more remotely sensed sources acquired in different years is cumbersome, time consuming, and difficult because the sources are frequently of different film types, film quality, seasons of year, and scales. The first three variables may be selectively controlled. Scale differences can be minimized, but this usually requires costly rescaling of the photographs by either optical-mechanical methods or by laboratory processing.

ORIGINAL MAP-TO-NEW SOURCE MATERIAL

In the original map-to-new source material procedure, land use and land cover changes are identified by comparing the original compilation with the new photographic source materials. In this technique, a transparency is made of the old land use and land cover compilation. The transparency could be a matte-positive base with land use and land cover polygons and identifiers shown in blue-line or a negative scribecoat guide of the old land use and land cover data. This transparency, which serves as the compilation base for the mapping of land use and land cover changes, is then overlain on the new photographic base film which has been rectified and (or) scaled, either photomechanically or photo-optically, to the scale of the compilation base. Using either the scaled base film or the new source in its original form as viewing film, each delineated polygon on the base map is compared with the corresponding land use and land cover feature appearing on the new source photographs. Any changes in land use and land cover between the photograph and the map are recorded on the compilation base; only the actual areas of change are mapped. The base photographs are used to help locate and position the new land use and land cover polygons on the compilation base. Each polygon of land use and land cover change can be labeled by a four-digit "from-to" code (fig. 1) which identifies the former (from) Level II land use and land cover category (as mapped in the old compilation) and the new (to) Level II land use and land cover category (appearing on the new remotely sensed source). This is the least costly, the easiest, and the most expedient method of detecting land use and land cover change and maintains an overall accuracy level commensurate with the established standards for USGS land use and land cover mapping.

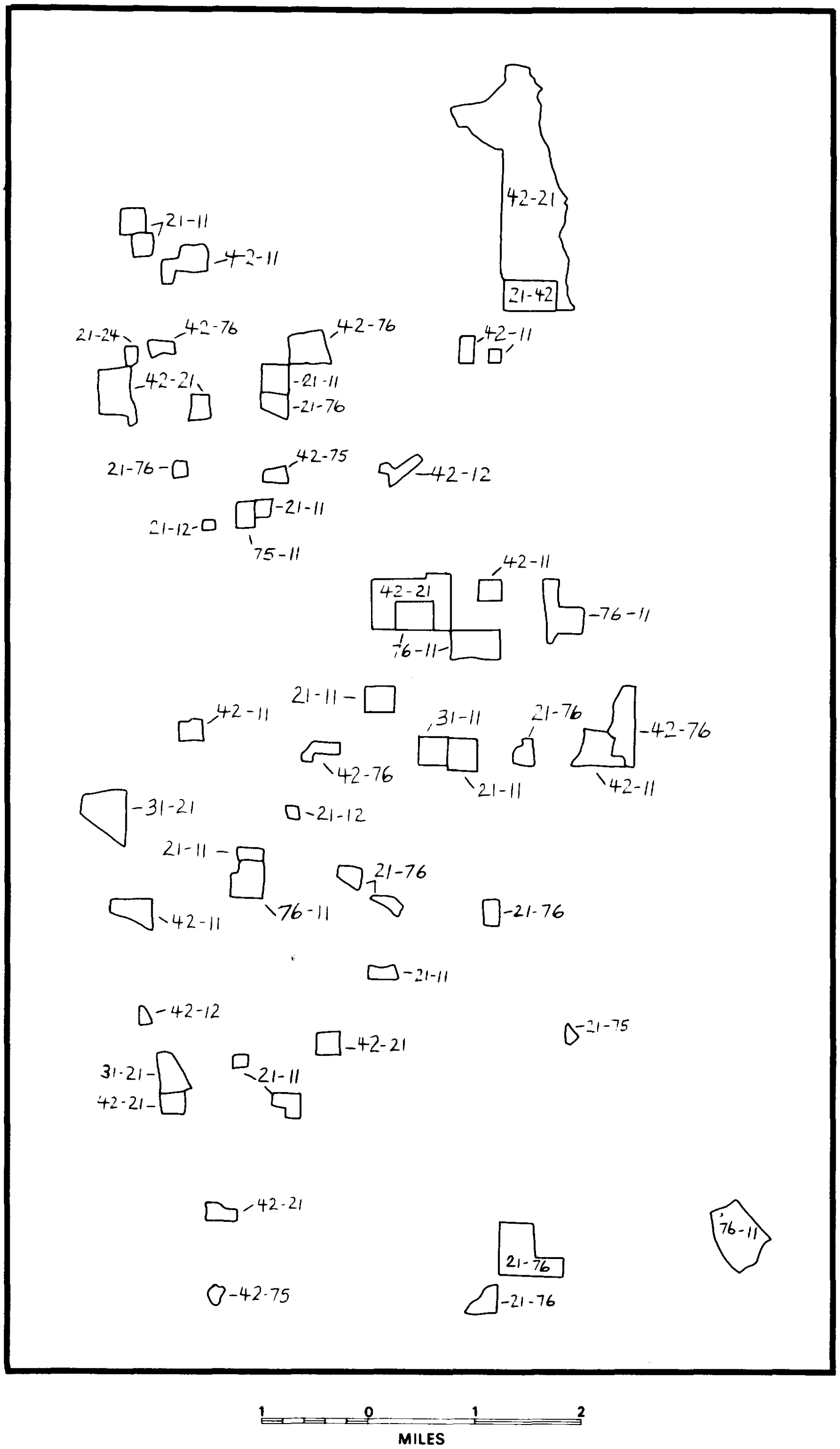
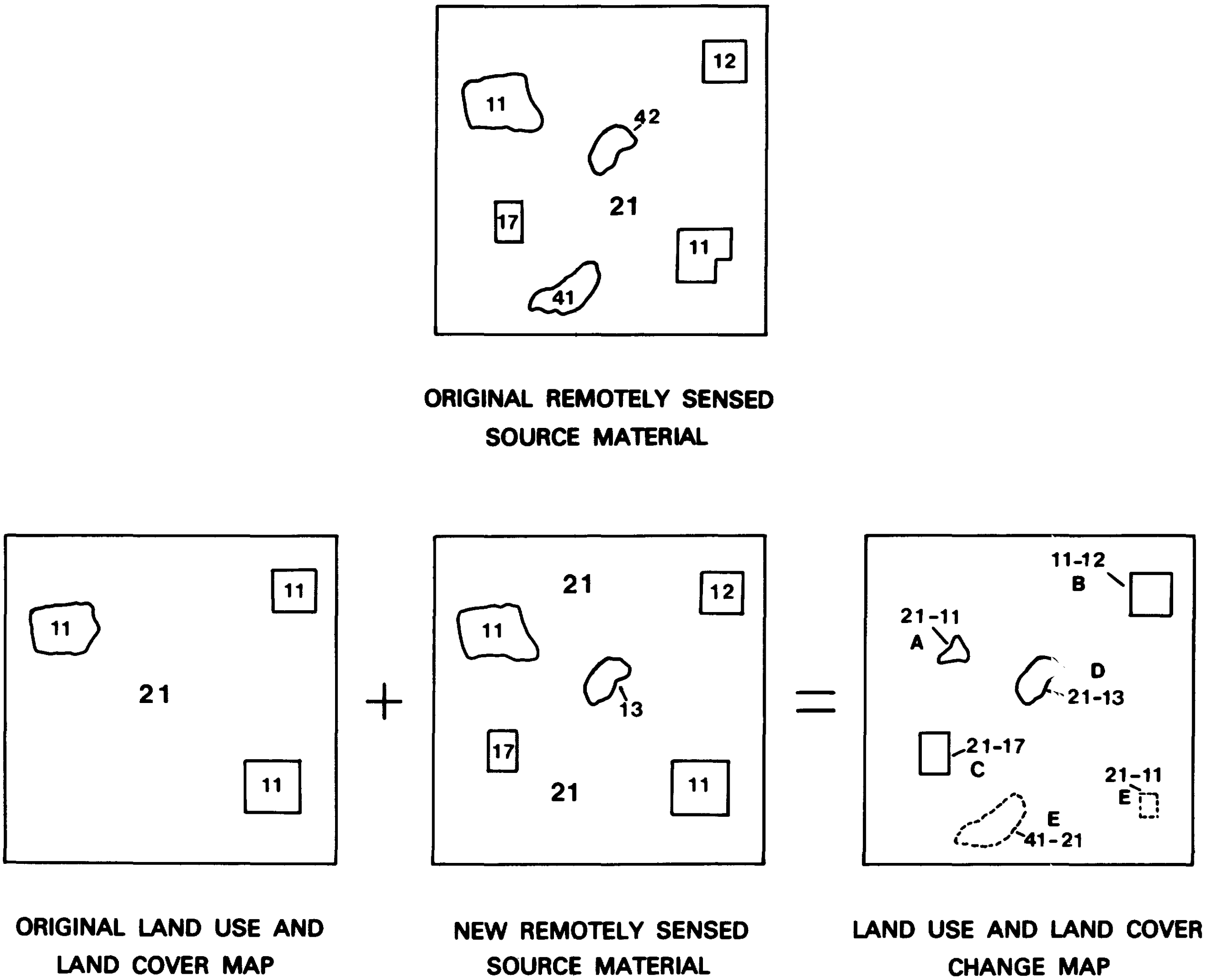


FIGURE 1.—Example of a land use and land cover change map showing only the polygons of land use and land cover change occurring between 1972 and 1978 for a portion of the Ocala, Fla., 1:100,000-scale topographic map. Changes were derived from a comparison of the 1972 land use and land cover map with 1978 aerial photographs. Polygons are identified by two Level II land use and land cover codes indicating the former and the new categories, respectively (See table 1 for identification of Level II category codes).



EXPLANATION FOR FIGURE

- A – False change polygon mapped due to boundary delineation error in original map compilation
- B – False change polygon mapped due to interpretation error in original map compilation
- C – False change polygon mapped due to polygon omission in original map compilation
- D – True change polygon mapped falsely due to polygon omission in original map compilation
- E – True change polygon not mapped due to error in original map compilation (dashed lines indicate valid change polygon not delineated on change map)

FIGURE 2.—Possible land use and land cover change mapping errors resulting from an original map-to-new source material change detection approach.

However, in the original map-to-new source material approach to change detection, there is an inherent danger that errors in the original compilation may go undetected. Figure 2 shows examples of five types of errors that can occur. These errors are more easily identified and corrected if the old compilation source material and the original map are compared with the new remotely sensed source. The differences in the final maps of land use and land cover change that result from the original map-to-new source and the original map and source-to-new source change detection methods are also illustrated in figure 2.

ORIGINAL MAP AND SOURCE MATERIAL-TO-NEW SOURCE MATERIAL

Perhaps the most thorough and comprehensive technique for detecting land use and land cover change is provided by the original map and source material-to-new source material method. It combines the elements of the two change detection techniques described previously. In this procedure, the land use and land cover map is scaled to the new remotely sensed source material which is then compared simultaneously with both the original map and the original source materials. This procedure has the following advantages: The compiler is able to see the actual land use and land cover features as they appeared at both times as well as to see how they were originally mapped; the original land use and land cover map can serve as a base control for measuring and mapping all land use and land cover changes; the same general level of detail in land use and land cover mapping used in the original compilation is retained in the update; and all errors in the original compilation can be identified thus permitting complete correction of the data base.

There are also two limitations associated with the original map and source material-to-new source material change detection procedure. The costs to store or reacquire the original compilation sources are high, and the detection and assessment of land use and land cover change by direct comparison between two or more photographs can be a difficult and time-consuming procedure owing to differences in film type and quality, season of the year, or scale.

ORIGINAL MAP-TO-NEW MAP

A final change detection method is the original map-to-new map procedure. In this technique, a new map is compiled using new source material. Polygons of land use and land cover change can be derived from a comparison of the original map with the new map. This procedure possesses one advantage in that the original compilation source material is not needed.

There are also several disadvantages to using this method for land use and land cover change detection. First, after the new land use and land cover map is produced, an extra step is required to isolate the polygons of land use and land cover change. Second, some of the land use and land cover changes identified may be a result of purely subjective differences in category interpretations and boundary delineations between the two compilations and do not necessarily reflect valid sequential changes. Third, the time and cost to manually compile a new land use and land cover map are excessive and seldom warranted. A final disadvantage to this method is that the remotely sensed source materials used to compile the new map may not be as good as the source materials used in the original compilation (In this case, the original map is replaced by one that is indeed more current but does not achieve the same quality or accuracy level.).

RECOMMENDATIONS

Of the four change detection methods, it is recommended that maps be updated whenever possible by using the original map-to-new source material method. However, since the changes mapped by the original map and source material-to-new source material approach are likely to be more correct, it is strongly recommended that the old compilation photographic source material if still readily available be used to supplement the basic original map-to-new source material method for detecting changes.

WHAT PROCEDURES AND WHAT FORMATS SHOULD BE USED FOR UPDATING MAPS?

The final considerations in a land use and land cover map update program deal with map update procedures and product formats. Procedures for updating land use and land cover data include complete or partial map recompilation, the incorporation of detected changes in an updated original map, the mapping of detected changes on a separate map overlay, or the separate generation of statistical data.

MAP RECOMPILATION

If the map recompilation procedure is selected, all or parts of a map are recompiled from new remotely sensed source materials. In a complete recompilation approach, a whole new land use and land cover map is produced from new remotely sensed source materials. This is the most drastic of the alternatives—a "start from scratch" approach. The new map has the same product format as the original. In this approach, all data are changed or corrected as necessary, and no attempt is made to keep previously mapped land use and land cover boundaries or categories.

A partial recompilation is a less drastic approach to map update than the complete recompilation alternative. In this approach, only specified portions of the original map, or selected map content, are corrected or updated by recompilation. The result is a complete land use and land cover map in the same format as the original compilation that combines parts of the original with the revised or new compilation. Again, the partial recompilation approach could be used most practically when parts of the original compilation need extensive reworking, for example, where Forest Land or Forest/Wetland delineations are significantly inaccurate due to poor quality sources or where inappropriate seasonal coverage was used in the original mapping phase. Any parts of the old map, however, known to be of acceptable quality and accuracy and meeting specifications are retained.

UPDATED ORIGINAL MAP

In an update of the original compilation, only the changes that have occurred over a specified time period are delineated and these changes (new polygons) are incorporated with the original compilation. In this approach, the original compilation is preserved as the base. The previous land use and land cover boundaries and categories are held as mapped, and only appropriate corrections, additions, and deletions are made. In this procedure, a separate overlay registered to the original map is used to record only the polygons of change. The land use and land cover polygons on the old map that correspond to these areas of change are deleted on the original base. The overlay is then composited with the original compilation, either photographically or digitally by computer. The result is an updated map in the same format as the old compilation.

MAP OVERLAY SHOWING CHANGES

In this approach, the changes in land use and land cover over a specific time period are isolated and mapped on a separate overlay keyed to the original compilation. A single map or overlay is produced, either by photographic laboratory processing or by computer, showing only the polygons of change. Each polygon is labeled by a four-digit change code which identifies both the prior Level II land use and land cover category (from the original map) and the new land use and land cover category (from the new photographic source). An example of a prototype map showing land use and land cover changes for a part of the Washington, D.C., metropolitan area is shown in figure 3.

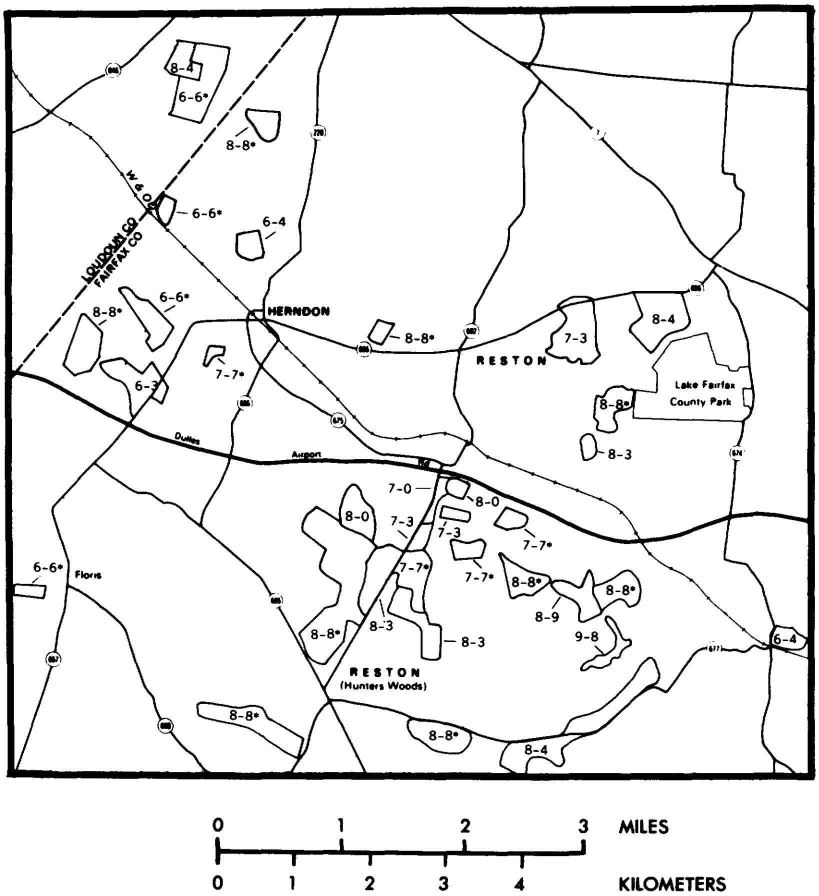
GENERATION OF STATISTICAL PRODUCTS

In this approach, a new map product is not provided. The land use and land cover changes between the original map and the new remotely sensed sources are recorded on an overlay in manuscript format only, solely for the purpose of digitizing. Once the new data are digitized, updated statistics are released in computer printout format, which provide information concerning the prior and new land use or land cover and the areas of change. The original land use and land cover map remains unchanged; only the statistics reflect the changes.

RECOMMENDATIONS

The products of an update program should be (1) maps showing complete land use and land cover information to the date of the most recent source materials, (2) updated statistics, and (3) overlays showing only the changes that have occurred until the time of update.

It is recommended that the updated original procedure be used whenever possible to generate a map product showing complete land use and land cover information. In the updated original approach, changes are incorporated into the original compilation to create a new map showing the current land use and land cover information at the time of update. Except for a written explanation in the legend of the map identifying the updated area(s) (if it is less than the full map sheet), no provision is



EXPLANATION FOR FIGURE

Land use change, 1970-72

Commercial and services	0-0
Industry	1-1
Transportation	2-2
Multifamily residence	3-3
Single-family residence	4-4
Strip and cluster development	5-5
Agriculture, with residence	6-6
Improved open space	7-7
Unimproved open space	8-8
Water	9-9

Change polygons are identified by numbers separated by a hyphen; the first digit indicates the land use in 1970, and the second digit indicates the land use in 1972. For example, a change polygon coded 6-4 means that the land use changed from Agriculture (6) in 1970 to Single-family residence (4) in 1972. Land use in transition is shown by an asterisk (*) following the use code.

FIGURE 3.—Selected area within Fairfax County, Va., modified from the map of Washington urban area, District of Columbia, Maryland, and Virginia (I-858-D), showing land use and land cover changes between 1970 and 1972 (Wray 1975).

made to distinguish between the old land use and land cover polygons and the new ones.

Another product, updated statistics, should accompany the complete land use and land cover map. The statistics reflect the amount and type of change and its location in terms of selected data associated by drainage basin, county, census tract, or other associated map data.

A separate overlay showing the "from-to" polygons of land use and land cover change for a given period also should be provided, either in the form of a manually-compiled or computer-derived map, for those users whose applications require the specific polygon data on change. It is recommended that the change overlay be made a part of the standard set of associated maps and data which supplement the land use and land cover maps. Since a change overlay can be produced quickly and with very little additional preparation and expense, it probably will be the first product of the map update program.

It is recommended that map recompilation be undertaken only in cases where there were significant changes in the classification system and (or) mapping specifications, or other situations where it is infeasible or impractical to build upon the established land use and land cover map base.

SUMMARY

In the review and evaluation of various considerations in accomplishing map update within the framework of the present USGS land use and land cover mapping program, recommendations for updating land use and land cover maps in accordance with the goals of the USGS land use and land cover mapping program have been offered. In summary, the recommendations are as follows:

- Initiate periodic inspection of land use and land cover maps using available remotely sensed source materials to identify changes, with inspection scheduled at a 5-year minimum interval and actual frequency of map update dependent on the amount and type of land use and land cover change.
- Continue to use small-scale, high-altitude photographs as the principal remotely sensed source material for updating land use and land cover maps.
- Use the 1:250,000-scale base maps for updating land use and land cover maps of those areas where either 1:100,000-scale bases are not available or for those regions where it is desirable to continue the presentation of map data at 1:250,000-scale. Use the 1:100,000-scale base maps for updating those maps already compiled at that scale or for updating existing 1:250,000-scale land use and land cover maps for which 1:100,000-scale bases are available and the regional location or the nature of the land use and land cover data make conversion to the larger scale base desirable.
- For existing 1:250,000- and 1:100,000-scale land use and land cover maps which are to be updated at their respective scales, update the complete map sheet. For existing 1:250,000-scale land use and land cover maps that are to be converted to the 1:100,000-scale bases, update should be by whole 1:100,000-scale map sheets covering either the full 1:250,000-scale map area or selected quadrants.
- Use the original map-to-new source material method as the principal land use and land cover change detection technique. Supplement this method by using the original compilation remotely sensed source material where needed and when available.
- Update maps using the updated original approach in which only the outdated portions of the original map are replaced with new data. Present data in a complete land use and land cover map format. Provide updated statistics on land use and land cover. Provide a separate overlay showing only the polygons of land use and land cover change as an optional associated map supplement. Conduct recompilations only when necessary.

These recommendations do not necessarily represent the only approaches to updating land use and land cover maps. They are suggested as a foundation for the development of a strategy for updating maps in the nationwide land use and land cover mapping program. We hope that the recommendations will stimulate users to consider and express their requirements for updated land use and land cover information.

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