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METROPOLITAN LAND COVER INVENTORY USING MULTISEASONAL LANDSAT DATA

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ILLUSTRATIONS[1]

[1] All illustrations (color for fig. 3, 4, 5, 6, and 7; black-and-white for fig. 1, 2, and 8) in this document are available in 35 mm transparency format from: User Services
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ABSTRACT

As a part of the Pacific Northwest Land Resources Inventory Demonstration Project (PNLRIDP), planners from State, regional, and local agencies in Oregon are working with scientists from the EROS Data Center (USGS), Ames Research Center (NASA), and the Jet Propulsion Laboratory (California Institute of Technology) to obtain practical training and experience in the analysis of remotely sensed data collected from air and spacecraft. A 4,000 km^2 area centered on metropolitan Portland was chosen as the demonstration site, and a four-date Landsat temporal overlay was created which contained January, April, July, and October data collected in 1973. Digital multispectral analysis of single dates and two-date combinations revealed that the spring-summer and summer-fall combinations were the most satisfactory for land cover inventory. Residential, commercial and industrial, improved open space, water, forested, and agriculture land cover categories were obtained consistently in the majority of classification iterations. Census tract and traffic zone boundaries were digitized and registered with the Landsat data to facilitate integration of the land cover information with socioeconomic and environmental data already available to Oregon planners.

INTRODUCTION

In the fall of 1974, the Pacific Northwest Regional Commission (PNRC) started the Pacific Northwest Land Resources Inventory

[1/] Work done under U.S. Geological Survey Contract No. 14-08-0001-16439.

Demonstration Project to show the use of remotely sensed data in the collection of Earth resources data. The PNRC is made up of the Governors of Idaho, Oregon, and Washington, with the addition of a Federal Co-chairman. The commission appointed representatives from each of the three States to administer the project. Working with State, regional, and local agencies in the Pacific Northwest, the PNRC, NASA, and USGS outlined a five-phase project to last from three to four years (Hedrick and others, 1976).

Because resource management agencies have different inventory needs, project activities were divided into several discipline areas, including forestry, agriculture, rangeland, weeds, and urban. Discussions and introductory workshops were held with user agencies in each discipline to establish discipline project objectives and study sites in each state.

Of these State discipline projects, the activities of the Oregon urban group will be the focus of this manuscript. User agencies directly involved in this sub-project include the Oregon Department of Land Conservation and Development, Oregon Department of Transportation, Columbia Region Association of Governments, Multnomah County, and the City of Portland. Specific objectives of the Oregon urban discipline are the following:

- To train local, regional, and State personnel to analyze Landsat data.
- To analyze the potential uses of Landsat data by local, regional, and State agencies.
- To create a regional land use and land cover map using Landsat data, and aggregate the results by census tracts and traffic zones for tabular output.
- To evaluate the cost and feasibility of using various land use classification techniques and systems.
- To comment on the feasibility of determining vacant land, pervious/impervious land, and wetlands.

To accomplish the above objectives, a series of analytical technique workshops was scheduled during 1975 and 1976, in which representatives from the Oregon agencies met with USGS and NASA scientists to perform analysis of digital Landsat data and to interpret supportive aerial photographs. Workshops held at the USGS/EROS Data Center, NASA/Ames Research Center, and the Jet Propulsion Laboratory allowed the Oregon group to utilize a number of different analysis systems, including the General Electric Image 100[1/], Electromagnetic

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[1/] The use of brand names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

Systems Laboratory (ESL) IDIMS, and Laboratory for Applications of Remote Sensing (LARS) Purdue University LARSYS.

A 4,000 km^2 area, centered on metropolitan Portland, was chosen as the urban discipline project area because of the diverse types of urban and nonurban land cover and land use, and because the area contains numerous small urban centers with high growth rates (fig. 1). Parts of five Oregon counties, Columbia, Washington, Multnomah, Yamhill, and Clackamas are included in the project area, as is part of Clark County, Washington.

ACKNOWLEDGEMENTS

Many individuals contributed to the efforts reported herein. In particular, the authors express their appreciation to J. Ralph Shay, Oregon State University, and Dennis R. Hood, EROS Data Center, U.S. Geological Survey, for coordinating urban discipline activities in Oregon within the overall Pacific Northwest Project, and to Anthony J. George, Jr., Oregon Department of Environmental Quality (employed earlier in the project with Oregon Department of Transportation), and Richard W. Hegdahl, Columbia Region Association of Governments, members of the Oregon urban discipline group which participated in the analysis activities. Thanks are also extended to James Jeske, NASA Ames Research Center, for assistance in data analysis and generation of output map products, and to Nevin Bryant, Jet Propulsion Laboratory, California Institute of Technology, for coordinating the post-processing activities involving aggregation of Landsat data by geographic units.

INFORMATION REQUIREMENT

In 1974 the State of Oregon's Land Conservation and Development Commission adopted a comprehensive list of goals and guidelines for statewide planning to "promote comprehensive land use planning to assure the highest level of livability for its citizens" (Oregon Land Commission and Development Commission, 1974). The goals and guidelines pertain to a wide range of land use planning and energy conservation activities, including transportation, agriculture, forestry, recreation, and housing. The goals are regulations to be followed by citizens and local governments. In Oregon, goals are applied and implemented through comprehensive plans. Guidelines are not mandatory, but are suggestions which would aid local governments in achieving the goals.

At the local level, cities, counties, and special districts are required to formulate and compile comprehensive land use plans conforming to the State's planning goals and guidelines. Local governments are urged to consult regional, State, and Federal agencies when preparing their plans, and Federal agencies should make their planning concerns known to the local governments. Comprehensive plans must include factual data to support the policies and other decisions

Figure 1. Landsat image of Portland, Oregon region showing location of project area. Band 7 image collected April 7, 1973 (ID 1258-18331-7).

set forth in the plan. Inventories and data, therefore, are needed of (1) natural resources, (2) manmade structures and utilities, (3) population and economic characteristics of the area, and (4) roles and responsibilities of governmental units.

Planning is not a static process, however, and the State recommends that the plan and implementation measures be reviewed at least every two years. Reviewing the plan involves re-examining the data and problems and continuing through the same basic phases used in preparation of the plan.

Two fundamental elements of inventory and data collection have been outlined above as they relate to Oregon land use planning: (1) baseline inventory and (2) monitoring change. The baseline inventory is the initial inventory of natural resources and other planning data, while monitoring change involves updating the initial inventory. Three important questions must be raised concerning regional, State, and Federal relationships with the local planning process:

1. How much do the resources (budget, manpower, etc.) of local governments vary regarding their ability to conduct comprehensive baseline inventories?

2. Will local governments have adequate resources to monitor change frequently and to update plans?

3. How compatible (that is, in degree of similarity) will the natural and cultural resource inventories be between various local governments?

These concerns are significant in consideration of regional planning problems. Watershed planning, transportation planning, water use studies (surface water and ground water), energy sources and consumption, recreation needs, coastal zone management, hospital planning, and wildlife habitat preservation have two key elements in common: (1) their spatial extent transcends county and municipal boundaries, and planning decisions affect large regions, and (2) planning requires detailed, accurate inventories, such as data collected by local governments for policy and decision making. It is important, therefore, that inventories and plans of local governments have a high degree of compatibility and are kept up-to-date. Large area planning concerns facing the State of Oregon today include the Willamette River Greenway (Oregon Land Conservation and Development Commission, 1975) and urban development in the Portland metropolitan area (Columbia Region Association of Governments, 1976). Planning activities for these areas need to be compatible with the needs of the State as a whole, as well as the entire Pacific Northwest.

Inventory and planning data are not always available at the local level. Baseline inventories supported by extensive field ("on-the-site") investigations require many man-months to complete and may require other resources not available to all local governments. It is not surprising, therefore, that inventory specialists have explored the feasibility of using remote sensing techniques for collecting a wide variety of Earth resources information, including land cover data.

The use of aerial photographs is a well documented tool for collecting land use and land cover data (Alexander and others, 1968; Sellman, 1972). Information about the use of land is derived by association of land cover with land use. Agencies can often justify the cost of acquiring aerial photographs over their area of interest because the photos can be used extensively in preparation of baseline inventories. Agencies may not, however, have the resources to obtain photos every two years (or more frequently) for the sole purpose of updating inventories.

A supplemental source of data for the inventory and monitoring process is data transmitted to Earth from an orbiting satellite. Although the detail of satellite data is coarser than that available using aerial photographs, the former allows quick and efficient inventories over very large planning and resource management areas (Simpson and others, 1973). The regular and periodic collection of generalized land cover information, which can often be correlated with man's use of the land, provides key elements of baseline inventories, as well as fundamental indicators of change, which are large-area compatible.

LANDSAT DATA

NASA has launched two satellites--Landsat-1 in 1972 and Landsat-2 in 1975--which are dedicated to the collection of Earth resources information. Orbiting the Earth at a nominal altitude of 915 km, each Landsat has the capability of recording data over most of the Earth's surface every 18 days. Offsetting orbits allow an area to be imaged twice in this period when both satellites are operating. Data are still being received from Landsat-2, but Landsat-1 became non-operational on January 6, 1978. The swath of the satellites is 185 km wide; individual frames of data measure 185 km on a side (National Aeronautics and Space Administration, 1976).

Of the three Earth resources data collection devices aboard the Landsats (Return Beam Vidicon (RBV) camera system, Data Collection System (DCS), Multispectral Scanner (MSS)), only the multispectral scanner data were used in the Oregon urban investigations. The MSS system collects data from four parts of the electromagnetic spectrum: Band 4, 0.5 to 0.6 μm (visible green); Band 5, 0.6 to 0.7 μm (visible red); Band 6, 0.7 to 0.8 μm (reflective infrared); and Band 7, 0.8 to 1.1 μm (reflective infrared). The data are transmitted to ground receiving stations and from there to NASA Goddard Space Flight Center.

Landsat data are available in two formats, computer compatible tapes (CCTs) and photographic imagery. A Landsat scene stored on a CCT contains 2,340 scan lines with 3,240 columns (samples) each, an aggregate of over 7.5 million data elements, or pixels. Each pixel has a numerical reflectance value in each of the four bands. The nominal area of a pixel is 0.45 ha (57 by 79 m).

Landsat photographic imagery (film or paper) is derived from the CCT data. Relative reflectance values are assigned gray levels for the production of Bands 4, 5, 6, and 7 scene images. Enlargements may be made of individual bands, or two or more bands may be composited to produce false color composite images. Imagery is commonly analyzed at scales ranging from 1:1,000,000 to 1:250,000.

There are three key elements which must be considered together when mapping metropolitan areas using Landsat data, namely, (1) the relative reflectance of Earth surface features in (2) different spectral bands, resulting from (3) integration of various Earth surface reflectance values within the resolution cell (0.45 ha) of the system. To illustrate the three concepts, consider the single-family residential area. The photointerpreter can identify a residential area on an aerial photograph by the characteristic pattern of closely spaced streets and regularly spaced house rooftops. Between houses and streets are lawns or a tree canopy (or a mixture of both), depending upon the age and type of residential area. On Landsat data, these individual residential area components cannot be detected; a relatively uniform, integrated spectral response is obtained from combining and integrating the reflectance values within 0.45 ha cells (Ellefsen, 1974). Some texture does remain, however.

Residential areas display significant variation in their visible and infrared reflectance patterns, according to pixel components. Older areas with a mature tree canopy have a low to medium reflectance in the visible wavelengths, while newer areas (except exurban development) have relatively high reflectance because of the rooftops and streets. In the infrared bands, however, reflectance patterns are similar, but for a different reason. Older areas have lower reflectance than newer areas because of the greater proportion of impervious material in the former (Todd and Baumgardner, 1973). Infrared reflectance is highly dependent upon the proportion and type of vegetation cover.

On Landsat CCTs, land cover tone variations (relative brightness, or reflected electromagnetic radiation) are stored as numerical values; darker land cover types have low values and lighter types have relatively high values. Land cover types are distinguished in digital analysis by noting differences in digital values. Consideration of the multispectral characteristic of Landsat data allows separation of more land cover types than if a single band is used. Analogous to the image interpreter's use of several Landsat bands simultaneously (or using color composites), the digital analyst uses computer algorithms which can examine digital values of all four bands simultaneously (or more, if a temporal overlay is used).

ANALYSIS ACTIVITIES

Landsat data analysis and training efforts were conducted concurrently. Oregon personnel travelled to the EROS Data Center, NASA Ames Research Center, and the Jet Propulsion Laboratory for several week-long analysis/training sessions which entailed "hands-on" experience with computer data analysis systems. While they did not participate in data preprocessing (data preparation) and postprocessing (output product generation), they did perform all intermediate analysis activities (actual information extraction from the Landsat data). Personnel training was a major project objective, and it was determined that the Oregon representatives should become as familiar as possible with principal analysis techniques.

Vegetation is a primary component of most land cover types in the Portland metropolitan area, and knowledge of regional phenological changes in vegetative cover is critical in selection of one or more Landsat scenes for analysis. In 1973, four scenes collected January 7 (ID 1168-18323), April 7 (ID 1258-18331), July 24 (ID 1366-18321), and October 4 (ID 1438-18305) over the project area afforded an ideal opportunity for the Oregon personnel to examine spectral differences between land cover types in different seasons (fig. 2). To facilitate the comparative analysis, a temporal overlay was created, in which Landsat digital data from the project area from each season were spatially registered and stored on a single computer tape (Anuta, 1970). All four bands from each of the four dates were used resulting in an overlay containing 16 channels of data. The objective then was to determine which dates or combination of dates was best for land cover inventory.

To check the results of each computer categorization of the project area into land cover categories, and to provide a quantitative means of comparing results between seasons, three test sites (ranging in size from 13 km^2 to 39 km^2) were established (fig. 3). One site was located in the center of the City of Portland (Portland test site), while two were located on the urban-rural fringe of the metropolitan area (Canby and Gresham test sites). The test site aggregate included all of the analysis-defined land cover categories presented in the project area. Land use and land cover maps and area summary tables were prepared for each site by photo interpretation of 1973 and 1974 small-scale, color-infrared aerial photographs (fig. 4), supplemented by local knowledge of the area.

Parallel analyses of the multidate Landsat data were performed using three remote sensing analysis systems, LARSYS (Purdue University), Image 100 (General Electric Company), and IDIMS (Electromagnetic Systems Laboratory, Inc.). Because analysis functions, procedures, and algorithms are different on each system, the Oregon personnel had the opportunity to apply various analysis techniques. While the Image 100 system employs a comparatively elementary categorization

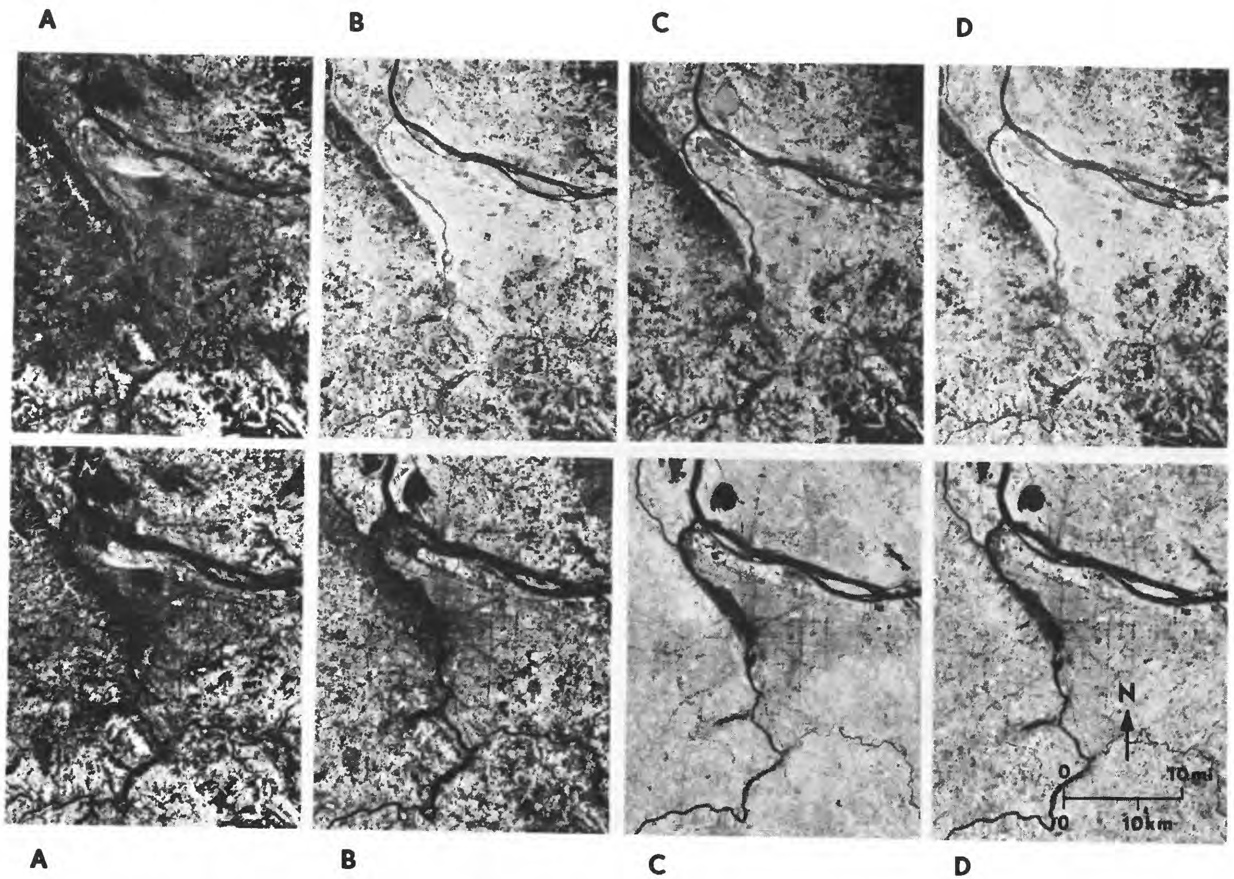

Figure 2. Multiseasonal Landsat data collected in 1973 over the Portland metropolitan area; A. Jan 7 (ID 1168-18323), B. Apr. 7 (ID 1258-18331), C. July 24 (ID 1366-18321), D. Oct. 4 (ID 1438-18305). Upper tier of images shows Band 5 (visible red); lower, Band 7 (reflective infrared).

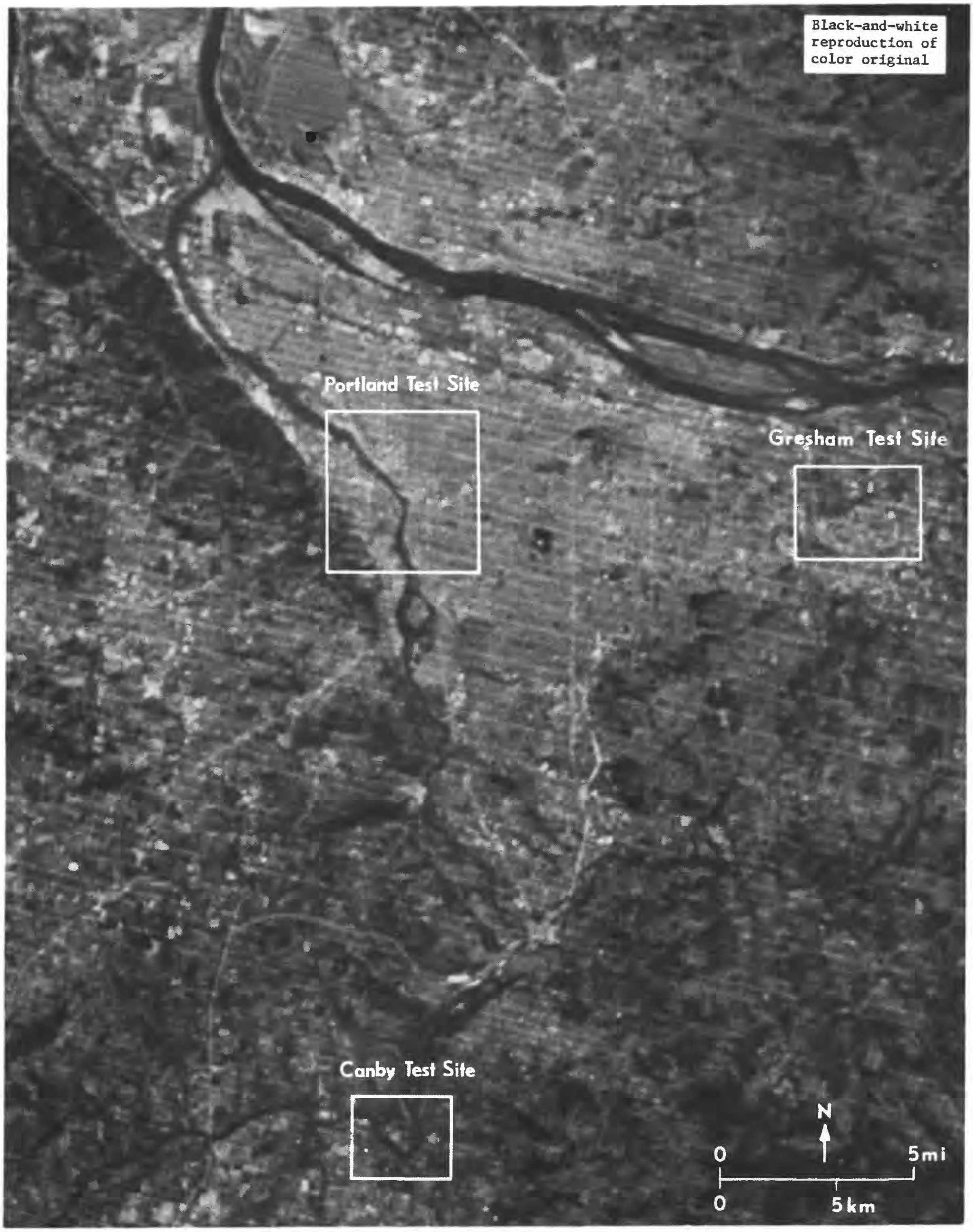

Figure 3. Landsat color composite image collected April 7, 1973 (ID 1258-18331), showing location of three test sites.

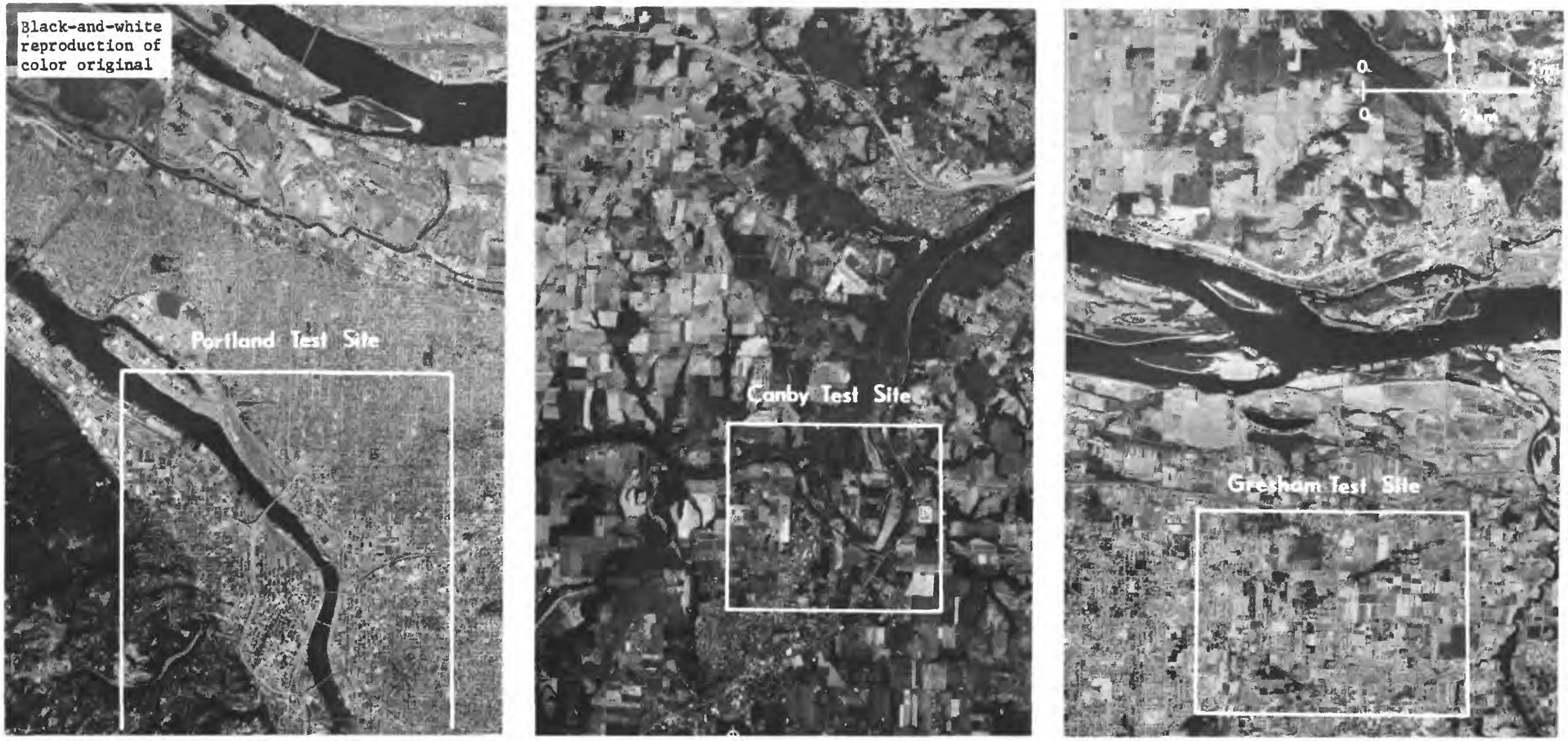

Figure 4. Portions of three small-scale, color-infrared aerial photographs of test sites.

(classification) algorithm, using upper and lower reflectance values of land cover classes, the LARSYS and IDIMS systems employ a decision rule which uses a probability density function to characterize (and discriminate between) classes.

Image 100 Analysis

The analysis procedure which was used on the Image 100 system is often referred to as a supervised approach to classification because the analyst uses (1) information about the area (local knowledge, aerial photographs, and other data), and (2) image interpretation to locate representative training sites for each desired land cover category.

Individual Landsat scenes of the four-date temporal overlay were analyzed before attempting multidate analysis. To facilitate training site selection, a small area (14.6 by 14.6 km) was chosen which contained representative sites of all land cover types in the project area. The 214 km^2 area was viewed as a color composite (or as individual bands, displayed in black and white) on a standard sized television screen, a Cathode Ray Tube (CRT). Using a joystick to move a cursor around on the screen, the analyst located representative training areas for a chosen land cover type. The algorithm calculated the upper and lower reflectance values (of the pixels located within the training areas) for each of the Landsat bands, in effect defining a four-dimensional spectral signature for the class. Reflectance values of all pixels in the 214 km^2 subscene were then examined; pixels which had the same spectral signature as the training area pixels were displayed as green on the CRT, superimposed on the color composite. Examination of the spatial distribution of pixels revealed whether the displayed class did, indeed, represent the desired land cover category.

The first attempt at defining the land cover class rarely, if ever, produced the desired result. Too much or too little of the class area was shown as green on the CRT. A number of programs, including frequency histogram displays, Boolean algebraic functions, and two-dimensional scattergrams were used to adjust the signature ranges of the class. At each step in this refining procedure, the analyst checked the spatial distribution of the class on the CRT. After the analyst was satisfied with the results, the class was stored in a designated sector of the Image 100 memory and assigned a color to facilitate comparison with subsequently developed land cover classes.

Using the above approach, the analyst proceeded, class by class, to develop land cover signatures. As multiple class development proceeded, the analyst had to take precautions that signatures (and resulting distribution maps) did not overlap. Many of the same procedures and algorithms used to create and modify individual classes were also used to resolve problems of signature overlap.

Upon completion of the 214 km^2 area classification, two milestones were reached: (1) all desired land cover categories had been accounted for and were assigned to an Image 100 class, and (2) most of the pixels in the area had been assigned to a land cover class. To test the classification results at that point, the analyst classified the three test sites (using the final signatures developed in the 214 km^2 area) for which acreage summary tables had been prepared. Landsat-derived acreage summaries and land cover maps were compared with those obtained from photo interpretation. If acreage summaries were satisfactory, the analyst would apply the signatures over the entire project area. For production of a final land cover map for display purposes, results were not used from the Image 100 analyses, and such signature extension was not performed. Notwithstanding, analyses of each of the four dates (except January - see results discussion) were performed, and test site acreage summaries were prepared for comparative purposes.

Analysis of multidate Landsat data required special consideration on the Image 100 system, which allows analysis of only four bands at a time. Working with single dates posed no problems, but two-date analysis required a selection of bands to be used. Several different combinations were attempted, but it was concluded that using Bands 5 and 7 (both a visible and infrared band) from each date afforded the best classification results. Two-season analysis with four bands proceeded in the same manner as working with individual dates.

LARSYS and IDIMS Analysis

A semi-unsupervised method of classification was used on the LARSYS and IDIMS systems, versus the supervised approach used on the Image 100. The semi-unsupervised method is also known as the guided clustering or controlled clustering technique, because the analyst uses knowledge of the project area to select representative sites from which a computer algorithm can determine a set of land cover class signatures (Fleming and others, 1975). While analysis procedures and software are different on the LARSYS and IDIMS systems, the analysis concept and key algorithm are similar enough that they are discussed together below.

Initially, the analyst located sites (cluster plots) throughout the project area to be submitted to the clustering algorithm. Twenty-one small, rectangular cluster plots, averaging 230 ha in size (a 1.2 percent sample of the total project area), were selected to represent all of the land cover classes in the project area. It must be noted that a particular cluster plot was not, for example, a homogeneous forested area or a commercial/industrial area, but that an adequate proportion of the cluster plot aggregate contained residential and commercial/industrial sites. Similar to the Image 100 analysis sequence, individual Landsat dates were analyzed before attempting multiseason analysis.

The clustering algorithm examined all four bands of the cluster plot aggregate and separated the cluster plot into a number of homogeneous spectral (land cover) classes. Clustering is an iterative procedure, whereby the algorithm begins with one cluster, then separates it into two clusters, and continues until an analyst-specified number or cluster variance threshold is reached. With the LARSYS system, 25 cluster classes were requested of the algorithm, a number which was decided upon after a degree of experience had been attained working with the data. With IDIMS, however, the algorithm calculated the variance of each cluster after each iteration, and continued to split clusters until 80 percent of the clusters had a variance below the analyst-specified threshold.

The principal output from the cluster program was a set of statistics for the spectral classes which included arithmetic means for each band and covariance matrices. Cluster class statistics from all four Landsat bands were used to classify the three test areas using a Gaussian maximum likelihood decision rule (Swain, 1972). Each pixel in each test area was classified into one of the 25 cluster classes according to the probability (likelihood) of assignment. The task of the analyst was then to interpret the resulting test area cluster class maps. Comparing those maps to the land cover maps prepared by photo interpretation, the analyst decided which cluster classes belonged to which land cover classes. The cluster classes are spectral classes and not necessarily information classes. Most desired land cover classes were represented by two or more cluster classes. For example, variations in the spectral reflectance patterns of the single information class, agriculture, frequently required several spectral classes, which included one or more types of mature growing crops, fallow area, stubble, and burned fields.

After interpretation of all cluster classes, the analyst checked the pixel area totals with those developed by photo interpretation. The clustering technique is an iterative procedure, and several cluster runs (applying different algorithm parameters) were needed before the cluster classes matched the information classes satisfactorily. Various statistical, analytical programs were also used (similar to those available on the Image 100), including two-dimensional plots of data points, two-dimensional plots of class means and standard deviations, and class frequency histograms. The analyst could then examine the statistical relationships among the spectral classes in order to determine problems involving excess overlap or non-accountance of data for which spectral classes were needed.

Even after a number of clustering iterations, the analyst was not satisfied with certain information class pairs, i.e., residential classes still overlapped the agricultural classes too much. The analyst then resorted to manual selection of training fields, not unlike the procedure used on the Image 100. Small training areas were located for the troublesome classes. Means and covariance matrices were calculated and combined with the classes obtained from clustering, and the four test areas were classified once again. After completing the spectral class refinement and obtaining satisfactory test classification results, the entire project area was classified.

Two-season analysis on LARSYS and IDIMS is different from that performed on the Image 100, because more than four Landsat bands can be analyzed simultaneously. In analysis of two-date data, the same 21 cluster plots were submitted to the clustering algorithm, but all eight bands were used to determine the cluster classes. It was determined, moreover, that the 25 cluster classes requested with single date data would not be enough; consequently, 40 classes were requested. Statistics from the 40 classes could have been used to classify the test sites using all eight bands, but excessive amounts of computer time would have been required (Coggeshall and Hoffer, 1973). The eight-band statistics were submitted to an algorithm which calculated separability coefficients for pairs of classes and for all possible combinations of four, five, and six bands. The algorithm calculated the degree of statistical separability between classes for those band combinations and printed a table showing the best overall combination to use for classification. A small degree of accuracy was lost using a subset of the available bands for classification but the savings in computer time were substantial.

Inventory Results

Overall classification results between the three systems--Image 100, LARSYS, and IDIMS--were similar for the majority of classification tests. The January data were not useful because of the low degree of contrast between land cover types and the presence of snow cover (fig. 1). Individual classifications of the April, July, and October data revealed that October was the best single month for land cover classification. Comparable two-season results were obtained from using a combination of April and July data, as well as the July and October combination (table 1). Classification results from combining April and October data were less accurate. Forested areas, water, and commercial/industrial areas were consistently identified with relatively high accuracies. Acreage of agricultural land was usually underestimated, while residential areas were overestimated. Identification of improved open space (parks, golf courses, other large urban grassy areas) was inconsistent, but the total improved open space acreage relative to the entire Portland metropolitan area is small.

For production of the final land cover map, the two-date, April-July classification from the LARSYS analysis was selected. The iterative clustering procedure described above was used to obtain cluster classes, which were then matched with the desired land cover classes. Residential areas, improved open space, clear water, forested, and agricultural land were identified satisfactorily, but confusion existed between commercial/industrial areas and shallow sediment-laden

Table 1.--Comparison of ground data with three Landsat two-season land cover classifications using LARSYS system

	Commercial/ Industrial	Residential	Water	Improved Open Space	Forested	Agriculture
Ground Data (test site hectares)	1595	1907	367	173	679	1499
April & July (hectares)	1496	2596	312	274	601	941
Hectares high (+), low (-)	-99	+689	-55	+101	-78	-558
Percent high (+), low (-)	-6.2	+36.1	-15.0	+58.4	-11.5	-37.2
April & October (hectares)	1469	2473	716	378	700	484
Hectares high (+), low (-)	-126	+566	+349	+205	+21	-1015
Percent high (+), low (-)	-7.9	+29.7	+95.1	+118.5	+3.1	-67.7
July & October (hectares)	1928	2372	318	50	614	938
Hectares high (+), low (-)	+333	+465	-49	-123	-65	-561
Percent high (+), low (-)	+20.9	+24.4	-13.4	-71.1	-9.6	-37.4

water. Manually selected training fields were developed for these two classes, which were successfully separated. Using the separability algorithm, Landsat bands 4, 5, and 7 from April and 5, 6, and 7 from July were selected to classify the project area by the Gaussian maximum likelihood function.

A 1970 land use map published by the Columbia Region Association of Governments (CRAG) (fig. 5) may be compared with the 1973 April-July Landsat land cover categorization (fig. 6). Enlargements of the center portion of both maps are illustrated in figure 7. The two maps are similar, but are not directly comparable because of the differences in source material and data, and differences in classification procedure, including class definition and minimum-size mapping unit. The residential classes (yellow on figure 5, blue on figure 6) are comparable in both cases. The Parks and Golf Courses class (green on figure 5) is comparable to the Improved Open Space class (orange on figure 6), although the latter includes scattered fields of vigorously growing crops we might have preferred to include in the Agriculture class. The Commercial and Industrial classes (red and blue, respectively on figure 5) are roughly comparable to the Commercial and Industrial class (red on figure 6). The minimum mapping unit for the Landsat map is the pixel, 0.45 ha (1.1 A). At this resolution, commercial and industrial use areas are not spectrally separable because they both have extensive impervious surfaces (rooftops, streets, parking lots, and bare ground), and relatively little vegetation-covered surface (Todd and others, 1973). Consequently, distinctive land use/land cover areas classified as Commercial and Industrial land cover on the Landsat map are classified as Public-Quasi Public on the CRAG map. These areas include airport runways and terminal facilities as well as the parking lots and structures of churches, schools, and governmental institutions. Conversely, grassy areas of larger institutional sites and greener industrial parks were assigned to the Improved Open Space or Agriculture classes on the Landsat map. The minimum mapping unit for the CRAG map appears to be as small as the Landsat pixel in discrete instances, but generally it is considerably larger.

Some of the misclassification problems could be solved using prior knowledge of the spatial distribution of land use types. Although not used in this study, procedures used to implement this additional type of information are available on various data processing systems.

The differences noted above in classification schemata are, of course, related to the fact that Landsat analyses yield land cover data, which can often, but not always, be associated with existing land use. Outside of the urban and built-up portion of the project area, only one category, Agriculture-Forest and Other Open Space, is mapped (white) on the CRAG map, but the category Water is separated in acreage summary tables for counties, census tracts, and traffic zones. Three such categories were developed as a result of the Landsat analysis, Agriculture, Forest, and Water (yellow, green, and gray on maps).

Figure 5. Land use map of the Portland urban area, Oregon, 1970. Land uses shown in color: Residential (yellow), Commercial (red), Industrial (blue), Parks and Golf Courses (dark green), Agriculture, Forest and other open space (white); terrain features (brown); hydrologic features, major roads and county boundaries (black); Urbanized Area boundary, U.S. Census, 1970 (gray). Source: Columbia Region Association of Governments.

Figure 6. Land cover map of the Portland urban area, Oregon, 1973. Land cover classes shown in color: Residential (blue), Commercial and Industrial (red), Improved Open Space (orange), Agriculture (yellow), Forested (green), Water (gray), Seasonal change related to water (black). Source: LARSYS April-July Landsat analysis.

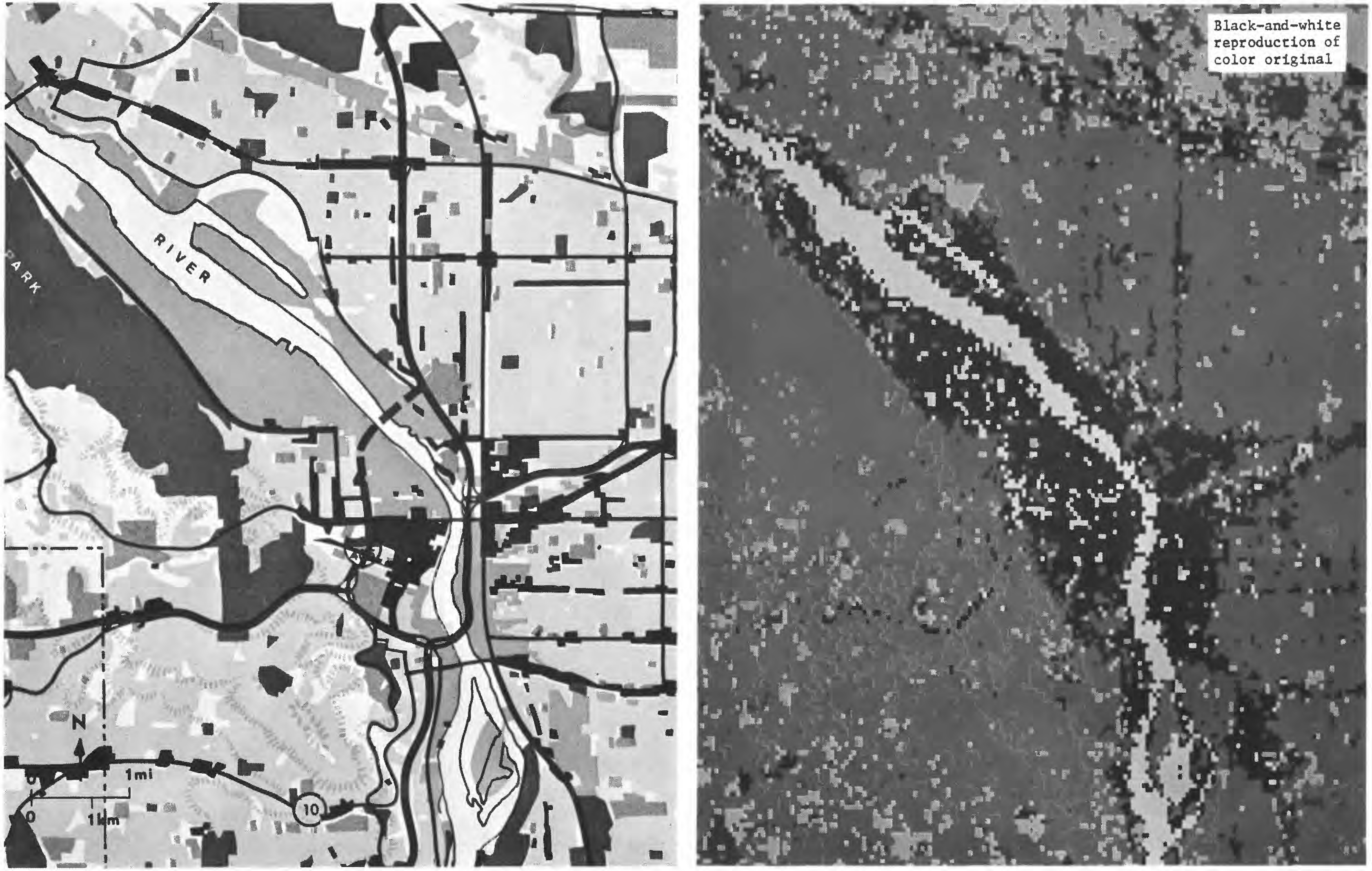

Figure 7. Comparison of 1970 land use (left) and 1973 land cover (right) maps of a portion of the Portland urban area, Oregon. For map descriptions and sources, see captions for Figure 5 and 6.

The CRAG and Landsat schemes can be compared with the scheme developed by Anderson and others, 1976 (table 2). Level I categories of the Anderson system are typically obtained from "Landsat (formerly ERTS) type of Data", Level II (shown in table 2 only for Urban or Built-up Land), from "high-altitude data at 40,000 ft (12,400 m) or above (less than 1:80,000 scale)" (Anderson and others, 1976). The Anderson Level I categories may be approximately by category aggregation with either the CRAG or Landsat data, although the latter would include twice the number of categories than the former (4 versus 2). Level II categories, however, within the Urban or Built-up Land category are more closely associated between the Anderson and CRAG systems.

Aggregation and Use of Land Cover Data

One of the most useful applications of the resultant classification is combining the digital land cover data with socioeconomic and environmental data available for the Portland area. Population, housing, employment, school enrollment and natural resources data have been collected for census tracts and traffic zones. The boundaries of these units were digitized and then overlayed with the digital land cover data by the Jet Propulsion Laboratory (fig. 8). This allowed generation of summary tables of each cover class acreage within all census tracts and traffic zones (Bryant, 1976). When land use information is available in a quantified form, comparison with a wide range of socioeconomic and environmental data is more feasible than if available only in a visual format. Land use and land cover data are only one input into a complex process of modelling and decisionmaking, yet it is an important addition to a dynamic data base for land cover, transportation, and environmental impact modelling.

Test site data, such as listed in table 1, can be incorporated into the tabulation of land cover acreages by geographic units. Comparison of the "actual" land cover acreages (obtained from photo interpretation and local knowledge) with Landsat-derived acreages indicates whether the latter estimate was high or low. Correction factors may then be calculated, using the ratio of the "actual" to the Landsat acres, for each land cover class. Landsat acreages generated for geographic units are then corrected using the appropriate ratios.

COMMENT

The Pacific Northwest Project was still underway at the time of this writing, and overall evaluation of the urban discipline activities in Oregon still needs to be done. A cost-effectiveness analysis will be incorporated into a future phase in the project. Moreover, Oregon agencies need to evaluate the role that Landsat-derived information can play in local, regional, and State inventory and planning tasks.

The generalized land cover categories obtained from Landsat analysis can serve a significant supportive function in the preparation

Table 2.--Comparison of Anderson, CRAG, and Landsat classification schemes

Anderson and others[1/]	CRAG[2/]	Landsat (LARSYS April - July map)
1 Urban or Built-up Land		
11 Residential	1 Residential	1 Residential
12 Commercial & Services	2 Commercial	2 Commercial & Industrial[5/]
13 Industrial	3 Industrial	
14 Transportation, Communication, and Utilities	4 Streets[4/]	
15 Industrial and Commercial Complexes		
16 Mixed Urban or Built-up Land		
17 Other Urban or Built-up Land	5 Parks & Golf Courses	3 Improved Open Space
	6 Public-Quasi Public	
2 Agricultural Land[3/]	7 Agriculture-Forest & Other Open Space	4 Agriculture[5/]
3 Rangeland[3/]		
4 Forest Land[3/]		5 Forest[5/]
5 Water[3/]	8 Water[4/]	6 Water[5/]
6 Wetland[3/]		
7 Barren Land[3/]		
8 Tundra[3/]		
9 Perennial Snow or Ice[3/]		

[1/] Anderson, J. R., Hardy, E. E., Roach, J. T., and Witmer, R. E., 1976, A land use and land cover classification system for use with remote sensor data: U.S. Geological Survey Professional Paper 964, p. 8.

[2/] Columbia Region Association of Governments, no date, Existing land use 1970 (map): Portland, Oregon, Map 1.

[3/] Level 2 categories not listed.

[4/] Categories not shown on land use map, but used in acreage summary tables for county, census tract, and traffic zone breakdowns.

[5/] Subcategories were mapped for certain classification interations.

Figure 8. Census tracts registered to Landsat data. Left: census tract mask. Right: boundaries of 1970 census tracts overlaid onto April 7, 1973 (ID 1258-18331-7) Landsat image. Source: Jet Propulsion Laboratory, California Institute of Technology.

of local baseline inventories. State agencies, counties, and municipalities undertaking extensive resource inventories (for example, preparation of comprehensive land use plans) will need very detailed information. If a Landsat land cover map has been prepared, however, it can provide important knowledge of those areas which require more intensive investigation.

Over large planning areas, such as the Portland metropolitan area or the Willamette River valley, it is difficult to obtain land resources data which are both current and compatible over the entire region. Landsat-derived data can be obtained at a relatively low cost, over very large areas, and within a short time frame. Important region-wide development patterns can be ascertained through time-sequential analyses, such as conversion of cropland and/or forested areas to urban and built-up uses, population growth (estimated by measuring acreage of new residential areas), and increases in specific cropland acreage.

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