LARS Information Note 111573

Application of Machine Processed ERTS-1 Data to Regional Land Use Inventories in Western Colorado

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APPLICATION OF MACHINE-PROCESSED ERTS-1 DATA TO REGIONAL LAND USE INVENTORIES IN ARID WESTERN COLORADO*

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ABSTRACT

The Earth Resources Technology Satellite (ERTS-1) provides timely, good quality data which can be beneficial to regional land use and resource inventory assessment. Analysis of sequential data sets by nominal photointerpretive techniques is time-consuming and limited by the ability of the human interpretation system. Computer processing techniques for analyzing multispectral scanner data have been developed at Purdue University by the Laboratory for Applications of Remote Sensing (LARS) to facilitate handling of large amounts of remote sensor information.

A study area, located near Grand Junction in west-central Colorado, is well suited for testing the capabilities of computer techniques to perform resource inventories at regional scales, and to present these data in forms compatible with management requirements. The ERTS-1 data set collected 27 September 1972 is nearly cloud-free and includes a large number of distinctive natural patterns that are economically significant. Results indicate good capability for spectrally differentiating zones of various naturally occurring vegetational assemblages from the computer compatible data tapes. Cultural patterns, both urban and agricultural, can be identified on the multispectral data. The acreage of irrigated lands can be determined. Data from the near infrared channels of the scanner are useful in identifying and mapping the extent of surface water available for the area. In arid or semi-arid environments the success of this latter capability can be an important factor in influencing land use and management patterns.

After classification, information derived from the multispectral data can be displayed as computer printout comparable in scale to 7 1/2' U.S.G.S. topographic quadrangles, as a black and white image, or as a color-coded image. In addition to map output, information regarding areal extent of the various cover classifications may be obtained in tabular or graphic form, with the output then converted to acreage.

Analysis of satellite data with ADP techniques offers land managers or planners rapid access to data output. It is anticipated that as our ability to interpret these data improves, our understanding of systems required to define resource needs is also enhanced, and man will be able to better utilize this information in the development of regional land use inventory models.

INTRODUCTION

The results described in this paper pertain to automatic data processing of computer compatible tapes of ERTS-1 MSS data

*NASA Contract NAS5-21880 Entitled: "An Interdisciplinary Analysis of ERTS Data for Colorado Mountain Environments Using ADP Techniques".

(Scene I.D. 1066-17251, 27 September 1972) for mapping vegetation and land use associations in arid west-central Colorado. This project is an outgrowth of computer-assisted geologic analysis of an area near Durango, Colorado(1). Analyses were done on an IBM 360 Model 67 computer using programs developed by the Laboratory for Applications of Remote Sensing (LARS) at Purdue University. Results of such analysis imply great utility for inventorying natural and cultural resources. Information in the form of thematic maps, photographs, or tables, as illustrated in this paper, is applicable toward dealing with current and future resource stresses by providing regional assessments in formats compatible with management requirements.

DESCRIPTION OF THE REGION

The study area is centered around the Uncompahgre Plateau and Grand Valley, Colorado, in the transitional zone between the San Juan Mountain section of the Middle Rockies physiographic province and the Canyonlands section of the Colorado Plateau province. Grand Junction, Colorado is the major urban center within the region.

Grant Valley is bordered for the most part by mountainous terrain. From the valley, altitude 4,500 feet, terrain rises northward to the Book Cliffs escarpment at 6,500-7,000 feet and Grand Mesa (10,000+ feet) (Fig. 1). Deep box canyons flank the valley on the south, cut into the dip slope of rock units in terrain that rises gently toward the summit of the Uncompahgre Plateau at 9,700 feet. Farther to the south lies Paradox Valley and the La Sal Mountains, an eroded intrusive mass with central peaks to 12,000 feet. Regional relief exceeds 7,000 feet within the study area. Parts of alluviated Grand Valley are dissected and broken by arroyos, gravel-capped mesas, and rock benches.

The valley is cut into Mancos Shale on the downthrown side of a faulted monocline (Fig. 2). The Mancos Shale of the Book Cliffs is overlain by younger Mesozoic and Tertiary continental sediments capped by Tertiary lava flows on Grand Mesa. The Uncompahgre Plateau is a structural uplift that consists entirely of Mesozoic rocks resting unconformably on a pre-Cambrian basement complex of granite, gneiss, and amphibolite. The north flank of the plateau is only slightly deformed and dips gently towards Grand Valley; the south flank is broken by step faults descending towards the Dolores River. Hunt (1956) provides a comprehensive study of the areal geology and physiography.

Grand Valley is typically arid with long-term annual precipitation of about 9 inches. Rainfall increases with altitude and the high country may receive more than 20 inches. Vegetation is altitudinally zoned, in response to climatic variation, from Upper Sonoran assemblages in the valleys to Subalpine at the crests. This altitudinal zonation of vegetation in the Uncompahgre and Grand Valley area generally follows Middle Rocky Mountain zonation sequences as established by Daubenmire in 1943 (Fig. 3). In the La Sal Mountains, isolation and decreased moisture results in mixing and some inversion of the normal vegetative sequence. Repeated climatic shifts during Quaternary and Recent times have created transition zones between any two adjacent vegetational climaxes, which are the loci of cyclical vertical migration.

The soils tend to directly reflect moisture, cover type, rock type, and slope aspect. Soils range from ariodosols of alluvial groups or series in the valleys regionally upward into alfisols or brown forest soils at higher altitudes (Fig. 4 and U.S.D.A., 1940).

Other than timber harvesting and grazing, the principal land use is agricultural, chiefly in the Grand Junction-Fruita area where local terrain peculiarities permit extensive growth of orchards and row crops subject to irrigation and vagaries of a relatively short growing season (Fig. 5).

ANALYTIC PROCEDURES

Objectives of the analysis were to: 1) implement automatic pattern recognition procedures to derive an accurate and comprehensive classification system for land use and cover types in west-central Colorado, and 2) portray the results of the analysis as maps, graphs, and charts compatible with user requirements.

Data Reduction

Based on Daubenmire's classification of vegetation sequences, the natural vegetation of the study area was separated into seven groups: 1) desert, 2) oak-mahogany savanna, 3) pinyon-juniper forest, 4) Ponderosa pine forest, 5) aspen-meadow complex, 6) dense, subalpine fir forest, and 7) apline tundra. Two land use classes, agricultural and urban were added to the seven natural vegetational classes to essentially complete the classification scheme. Although many different classes of urban and agricultural land use are spectrally separable (Todd, etal, 1973; Bauer, etal, 1973), the small area of man's activity in the Uncompahgre region, compared with the broad expense of natural cover types, made further segregation of land use categories impractical for this study. Small sections on imagery of the study area were masked by clouds, cloud and topographic shadow, and water. Inclusion of these classes within the classification system brought the total number of classes separated to twelve.

Spectral classes were defined in the following manner. For each class, sample areas of approximately 100 acres each were located on a color composite ERTS-1 image by photo interpretation techniques. The bases for determining visual correlation between class name and image pattern were: 1) field reconnaissance in August, 1973, and 2) comparison of a vegetation map of the La Sal Mountains (Richmond, 1962) with the ERTS-1 imagery.

The chance that any arbitrarily selected area of 100 acres will be composed of a completely homogeneous cover is rare, particularly in near-mountain and mountain regions. Thus, each sample area was assumed to possess a dominant cover type and a residual cover type.

Non-supervised* machine clustering into a small number of spectrally separable classes (i.e., twice the number of expected dominants) was performed individually on each sample area. The mean reflectance of each cluster was plotted as a function of the wavelength band of each ERTS-1 channel (channels 4-7) for each of the desired classes (Fig. 6A). In this manner, the "residual" reflectance elements were statistically separated from the dominant cover type within each sample area. Commonly, each "dominant" type was composed of two or more distinct spectral classes, such as the two classes evident for agricultural areas (Fig. 6B). In this manner, subclasses for many of the twelve major classes were extracted from the raw data. Next, each cluster for each sample area was displayed by a particular alphanumeric symbol on a printer image. Training fields were selected from the areas displayed on the printer image as the dominant class or subclasses:

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*A non-supervised classification is obtained by a machine generated statistical separation of a continuum of reflectance values. The classification is based on the mean reflectance value of each data point and its covariance among the four ERTS-1 wavelengths.

the training fields were chosen in areas interpreted as most representative of the dominant cover type. The pattern of dominant and residual classes as displayed on the printer image gave clues that permitted extraction of areas from within a dominant cluster that were more representative of the desired class that were elements along border lines between residual and dominant clusters. The training fields for the desired classes were then processed by a supervised** classification algorithm in order to define the spectral characteristics of each training class (Fig. 6B). The 100-acre sample areas were then reclassified, based on the derived supervised classes, to test the classification system on small areas of known cover type. Patterns discernibly related to topography, and consequently vegetation, as displayed on these test sites were used to further refine the location of training fields until the display patterns seemed sufficient for a regional classification. Final training class statistics thus derived from analysis of approximately 4,500 acres of sampled areas were then applied to a classification of about 4.4 million acres of the Grand Valley-Uncompahgre Plateau region. The ratio of sample areas to classified areas is thus about 1:1,000. The statistics generated for this study are available but for the sake of brevity have been omitted from this paper.

Data Interpretation

One of the advantages of the LARS computer system is the selectivity offered the user in choosing the form of the final product. Depending on the type of interpretation required, the information may be displayed as maps, graphs, charts, or photographs. The geographic distribution of the classified data elements may be displayed and photographed on a digital display television screen. The statistical spectral class of each data element is stored on magnetic tape. Either a grey-scale level or a color may be assigned to each class. Each data point may then be called from the tape and displayed on the television screen as the appropriate grey-scale or color level. The distribution of grey levels or colors on the screen thus represents the associated distribution of spectral classes. If the training method associates known cover types on the ground with accurately located data elements within training fields, a class name can be confidently assigned to each class. However, if training fields cannot be accurately correlated with precisely known ground truth, the geographic distribution of each spectral class, as displayed on the television screen, must be used to infer the identity of the cover type associated with each class.

In analysis of the west-central Colorado region, our confidence in the vegetal and land use class identity of each training site was marginal. The spectral classes were known to be statistically separable, but a "name" for each class was only tentatively assigned, prior to viewing the classification results. Twenty-four separable spectral subclasses were used to obtain the separation necessary to display twelve classes of cover type and land use. Positive identification of each subclass was reserved until its geographic distribution was determined from the map displays of the entire classified area (Fig. 7). For example, areas on the data array used during data reduction and thought to represent surfaces covered by pinyon and juniper assemblages statistically separated into three distinct spectral classes. Therefore, the tentative pinyon-juniper assemblage was assigned to three subclasses, PJ-1, PJ-2, and PJ-3. Geographic distribution of spectral class PJ-3, as represented on the television digital display

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**A supervised classification is obtained through human input which determines the data elements that are to be used in the classification algorithm, rather than purely machine controlled statistical separation of a total range of values as occurs in the non-supervised mode.

screen, identified it as part of a oak-savanna assemblage which dominates at elevations immediately adjacent to but lower than the pinyon-juniper assemblage. The presence of an oak-savanna class within areas dominated by pinyon-juniper indicates the normal transitional nature of boundaries between zones. Thus, the oak-savanna assemblage grows in dry valleys within the lower portion of the pinyon-juniper zone; conversely, in moist valleys the upper zone extends spatially downward into adjacent but lower oak-savanna.

Regrouping the subclasses experimentally achieved desired results, allowing production of a color-coded map that accurately represents the distribution of vegetation zones as described by Baubenmire, and land use features identified by field reconnaissance.

RESULTS

The classification map of the entire area is shown in Figure 7. Each vegetation zone and land use category is shown by a specific grey level. Agricultural areas appear dark grey. A sequence of vegetation zones is clearly visible encircling the Uncompahgre Plateau in the center of the image, the La Sal Mountains in the southwest corner of the picture, and Grand Mesa in the northeast corner. The oak-savanna zone (very dark grey) is immediately above the desert areas (lightest grey). The pinyon-juniper zone is medium-grey tone. These three climax assemblages comprise the Foothill vegetation zone. Above the Foothill zone is a belt dominated by clumps of aspen interspersed with high, grassy meadows and scattered stands of Ponderosa pine. This, the Montane zone, is displayed as a dark grey tone. Above this, the Subalpine zone appears as black. Climax assemblages within this zone include Ponderosa pine, Douglas fir, subalpine fir, and Englemann spruce. Ponderosa pine is widely spread throughout the Montane and Subalpine zones, but tends to concentrate in certain areas as a distinct band between the aspen-meadow and spruce-fir climax assemblages. The spruce-fir shows a very dark grey band along the crest of the Uncompahgre Plateau, as slope dependent groups coincident with drainage lines radiating from the center of the La Sal Mountains, and as a "blanket" covering Grand Mesa. In Figures 8 through 14 each zone has been separated from all other cover types for individual display. A color display of all classes shows the relative distribution of the zones much more clearly than does the grey-scale separation shown here. Water was separated as a statistical class in this study, but its limited surface area with respect to the large area classified rendered it essentially invisible on the visual display.

The relationships of the zones is presented graphically in Figure 15. A transect of overlapping 400-acre fields (Fig. 16) extending from Uncompahgre Butte (9,732 feet) to the base of Grand Mesa (4,500 ± feet) was analyzed for relative percentage of each cover type. The relative proportions of cover types within each field along this transect were plotted as a function of elevation. The appropriate peaks on the resulting graph correlate very well with elevations associated with each cover type in the purely ideal model of Daubenmire (Figure. 3). Transitional areas between various zones are evident where lines on the graph intersect, the surface cover at these points being composed of equal amounts of two adjacent zoned classes. Some secondary "peaks" which appear anomalous on the graph result from the transect crossing major topographic breaks such as valleys where, as expected, the vegetation corresponds with abrupt change in altitude and aspect of exposure. However, the graph clearly demonstrates the arbitrary nature of discrete zonal boundaries. The boundaries are actually non-existent, but their use facilitates classification and communication. Such graphs as given herein may be used to homogenize boundary definition in zones of continual variation.

Similar LARSYS analyses may be performed on similar transects of selected fields within the classified area to obtain density factors for any classified cover type.

Richmond (1962) provides a vegetation map of the La Sal Mountains that serves as a test of accuracy of the machine classification of the Uncompahgre-Grand Valley region. Within the La Sal region the classical vegetation zones are somewhat disturbed, owing to decreasing moisture and slope exposure aspects. Areas of oak-mahogany concentrations lie above the pinyon-juniper zone; distribution of Ponderosa pine appears to be chiefly controlled by lithologic outcrop patterns and subsurface moisture retention rather than by elevation; and the aspen-meadow zone is almost absent on the west side of the La Sal Mountains. Our computer map shows vegetation patterns in the La Sal area as almost identical to those on Richmond's map (Fig. 17). However, the machine-generated map indicates a zone of savanna and desert lands which Richmond's map does not show. Lacking adequate field-based ground truth, the cause of this discrepancy has not been determined.

Figure 18 illustrates the range in scale available to users of the LARSYS digital display screen. All enlargements are performed on the television screen, and then photographed by Polaroid or 35mm camera. Enlargement capabilities of the dark room are not considered here. The smallest scale (Fig. 18A) is obtained by displaying every third line and every third column of the ERTS-1 machine compatible data on the screen, i.e. one-ninth of the data points within the displayed area. This mode of display exaggerates the geographical distortion present in raw ERTS-1 MSS data. Techniques have been developed at LARS and elsewhere (Anuta, 1973) to correct for this distortion, but were not utilized in the present analysis. Problems also arise in the larger scale television images. In Figure 18D, scale 1:125,000, each datum point is represented by 16 television picture elements. This extracts no additional information from the data than Figure 18C, scale 1:500,000, in which each datum point is represented by one picture element, but it does allow easier recognition of small spectral groups. For instance, in the 1:125,000 scale map two classes of urban land use have been displayed. On smaller scale images such separation is useless owing to the neurological threshold constraints of visual perception. Because of the "blocky" character of the data display, certain disadvantages arise in interpretation of the maximally enlarged data.

CONCLUSIONS

Infintely variable data from large areas on the Earth's surface can be statistically transformed into a limited number of discrete displayable categories which, with minimal interpretation, can aid in proper assessment and planning of man's activities. The LARSYS method of manipulation of ERTS-1 MSS data as described herein has applicability toward regional land use planning, forest management, soil science, and cropland assessment. The land use planner has at his beckon new kinds of maps showing regional distribution of cover types and land use. These maps can be helpful in directing development toward areas where the disruptive ecological effects will be minimal in tradeoff with maximized economic benefits. The forest resource manager can quickly assess potential productivity of a region by glancing at vegetation maps showing location of stands of timber species such as fir and Ponderosa pine. The agronomist can accurately locate non-productive areas within large agricultural belts, and perhaps determine the cause of non-productivity. The farmer can better predict his harvest by following maturaton of crops of satellite images collected at regular intervals.

Machine analysis of satellite data may not always provide meaningful maps or other meaningfully reduced data of 80-acre farms or city blocks, but it does and will provide accurate and timely maps of regional or areal scope. In our experiment, 4.4 million acres in west-central Colorado have been classified into twenty-four distinct spectral groups. Statistically regrouping these classes into nine categories allowed determination of the relative percentages of each category (Fig. 19). This pie diagram may easily be converted into acreage covered by each vegetation type and land use (Table 1). As seen from the diagram and table, desert and near-desert areas (pinyon-juniper and oak-savanna) dominate the land surface throughout this arid region. Agricultural production is almost exclusively on converted desert, where irrigation is necessary for water is scarce. Effective management in such areas is essential to future development, and satellite technology, when coupled with machine reduction of the awesome number of data elements, provides a tool for planners and managers to draw upon in achieving their desired objectives.

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LAND USE	% OF TOTAL AREA	ACRES
Pinyon-Juniper	25.7	1,119,497
Oak-Savanna	22.8	993,173
Desert	19.6	853,780
Aspen & Meadow	10.5	457,382
Crops and Masture	8.5	370,262
Ponderosa Pine	6.0	261,361
Spruce Fir	2.7	117,613
Alpine	2.3	100,188
Urban	0.6	26,136
Cloud	0.5	21,780
Shadow	0.4	17,424
Water	0.4	17,424
TOTAL	100.0	4,356,020

Table l. Vegetation type and land use acres in study area of west-central Colorado. Conversion factor is 1.1 acre per datum element of satellite imagery.

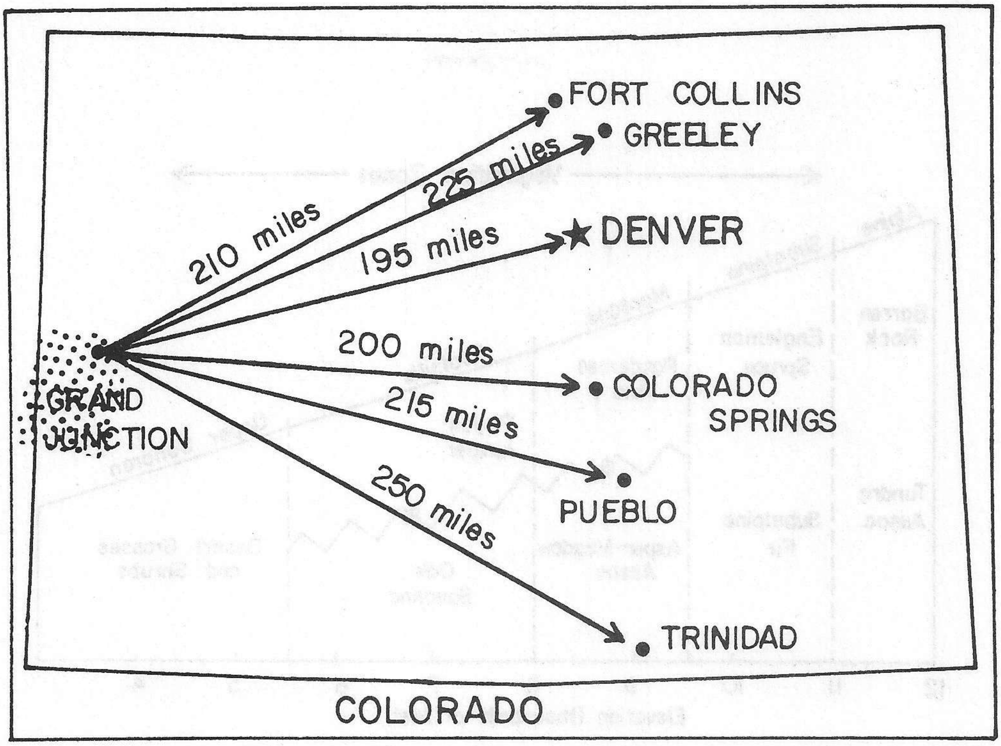

Figure 1. Location map of the study area (stippled) classified by man-machine interaction. Mileages from Grand Junction, Colorado.

Figure 2. Grand Valley irrigated belt, Book Cliffs, and Grand Mesa looking northeast from the Colorado National Monument. Monoclinal fold shown in the Wingate Sandstone cliff marks the northern edge of the Uncompahgre Uplift. Altitude-dependent vegetation zones have developed in response to this uplift. From top to bottom along the left edge of the picture are the irrigated agricultural belt, desert, oak-savanna in the canyon, pinyon-juniper in foreground and along top edge of the cliff.

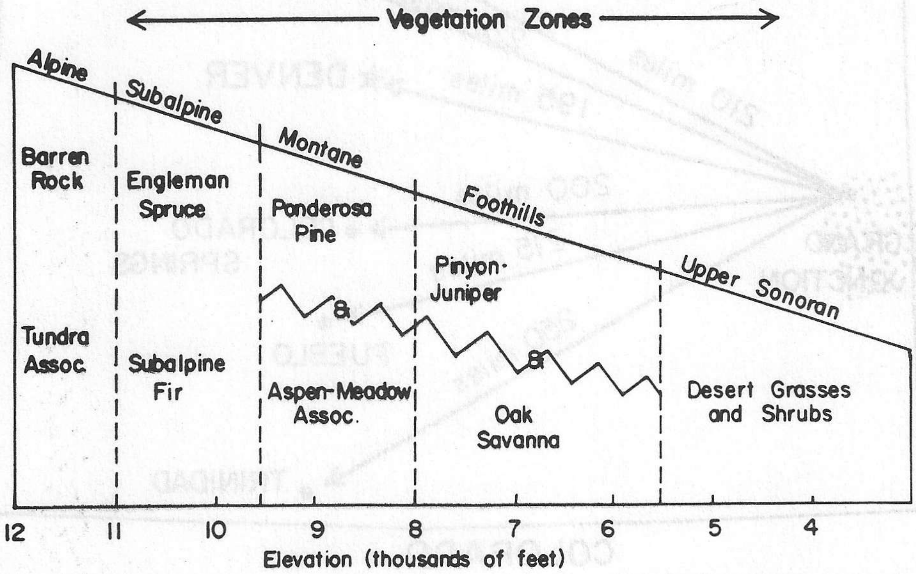

Figure 3. Ideal model of vegetation zones in the central Rocky Mountains (modified from Daubenmire, 1943).

Figure 4. An example of soils developed in Grand Valley. This aridisol is located on Orchard Mesa east of Grand Junction, beneath orchards as shown in the photograph.

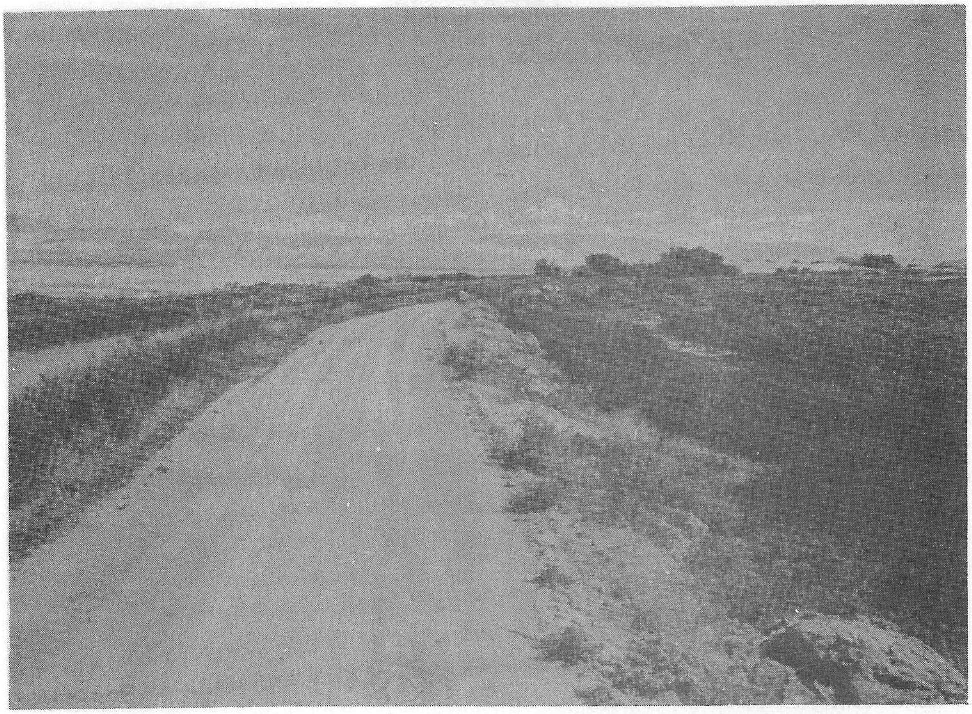

Figure 5. Effects of irrigation on vegetation in Grand Valley, looking east from a point northeast of Fruita. The Government High Line Canal separates the desert grasslands on the left from the irrigated croplands on the right. Book Cliffs and Grand Mesa are in the background.

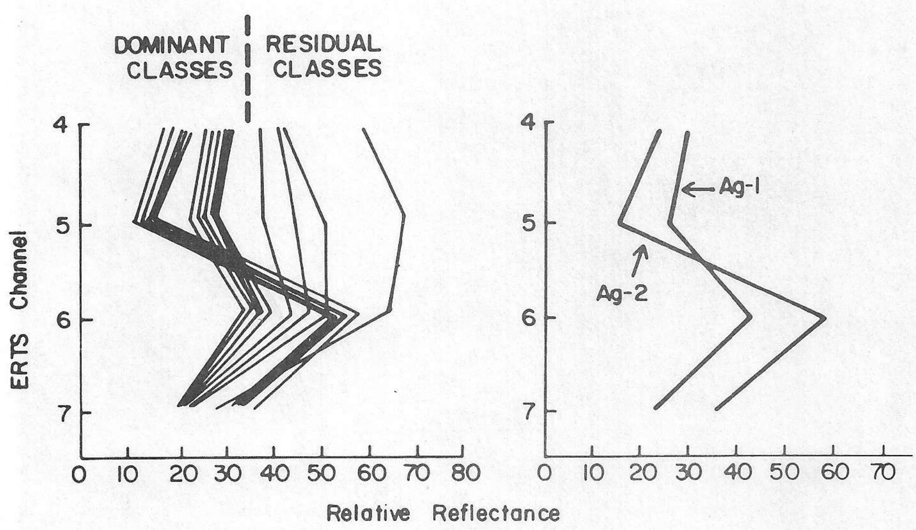

Figure 6. (A) Spectral plots of the non-supervised clustering algorithm performed separately on five known agricultural test areas of approximately 100 acres each. Two "dominant" classes are clearly separable from the "residual" classes.

(B) Spectral plots of the supervised classes, AG-1 and AG-2.

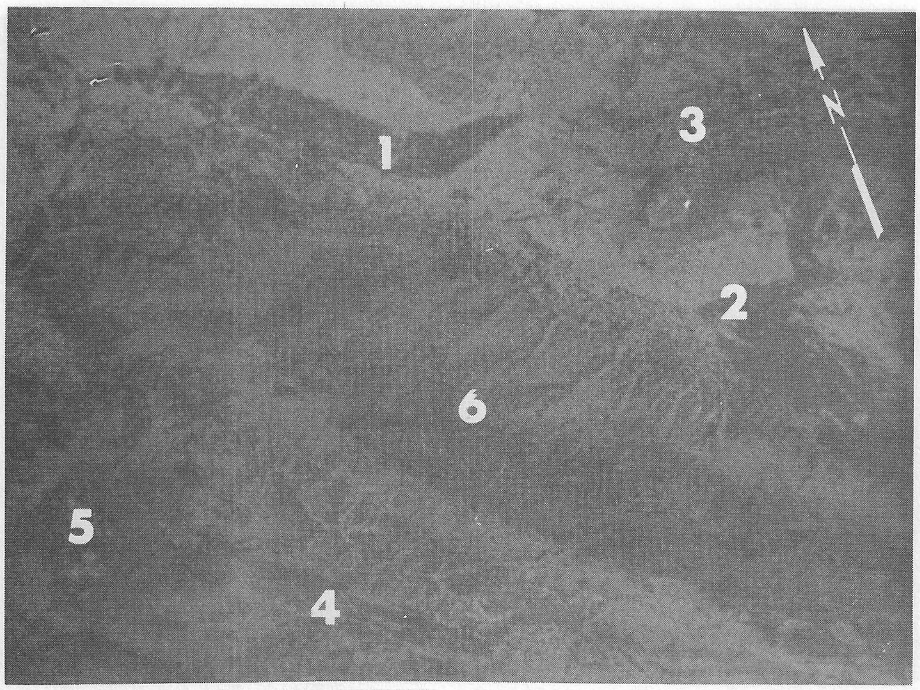

Figure 7. Classification map of vegetation zones in west-central Colorado. Grey-scale separation is poor. See figures 8-14 for separate display of each zoned assemblage. 1 Grand Junction, 2 Delta, 3 Grand Mesa, 4 Paradox Valley, 5 La Sal Mountains, 6 Uncompahgre Plateau.

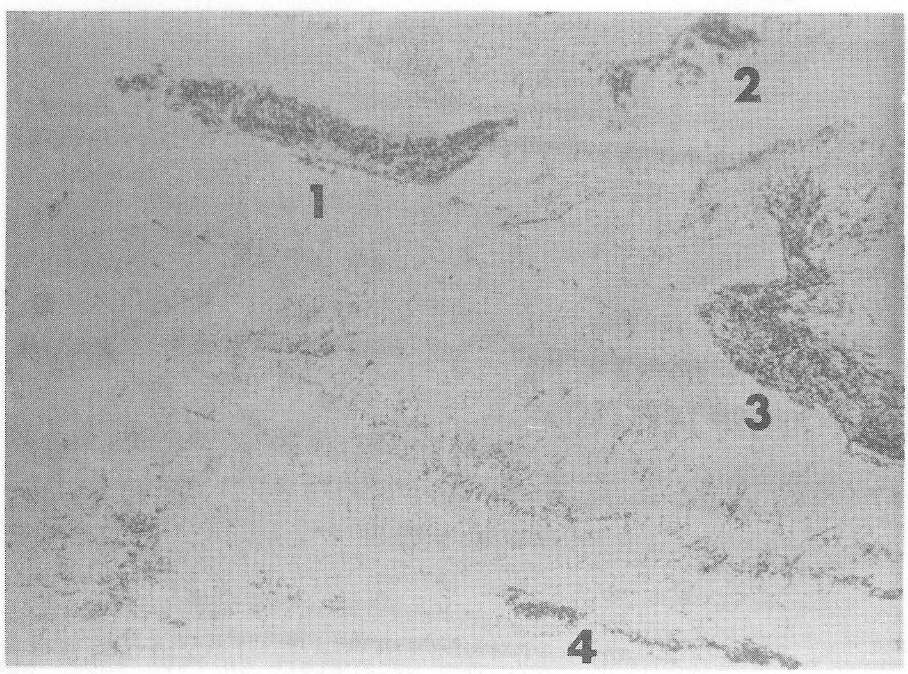

Figure 8. Agricultural areas are dark. Four major agricultural areas are: 1) Grand Valley (cigar shaped area); 2) a three part strip along the Colorado River (upper right); 3) Montrose-Delta-Uncompahgre Valley (right center); and 4) Norwood region (lower right).

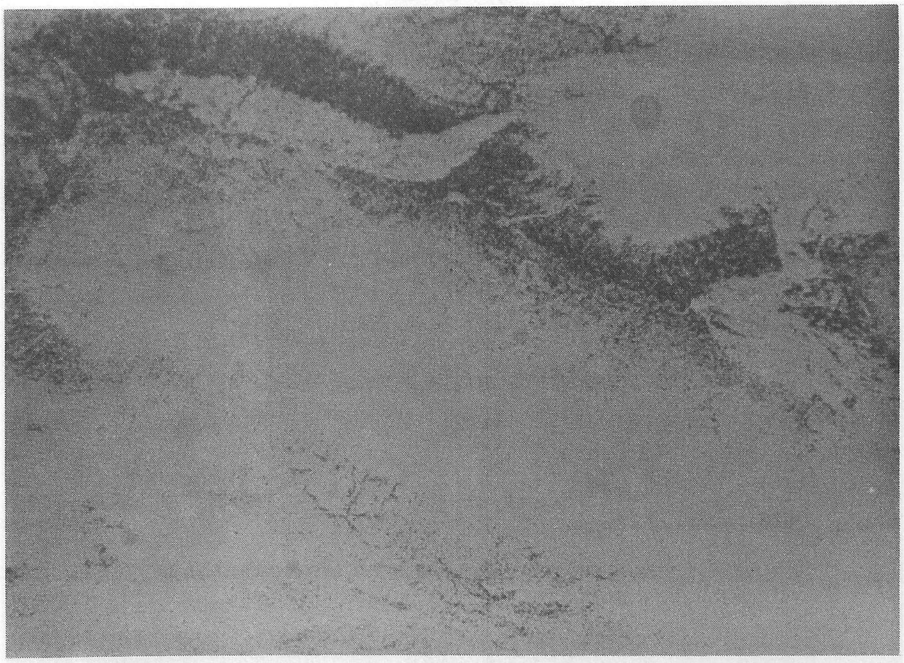

Figure 9. Desert areas are dark. The desert regions follow the broad Grand-Uncompahgre Valley with the irrigated agricultural areas as "holes" in the desert.

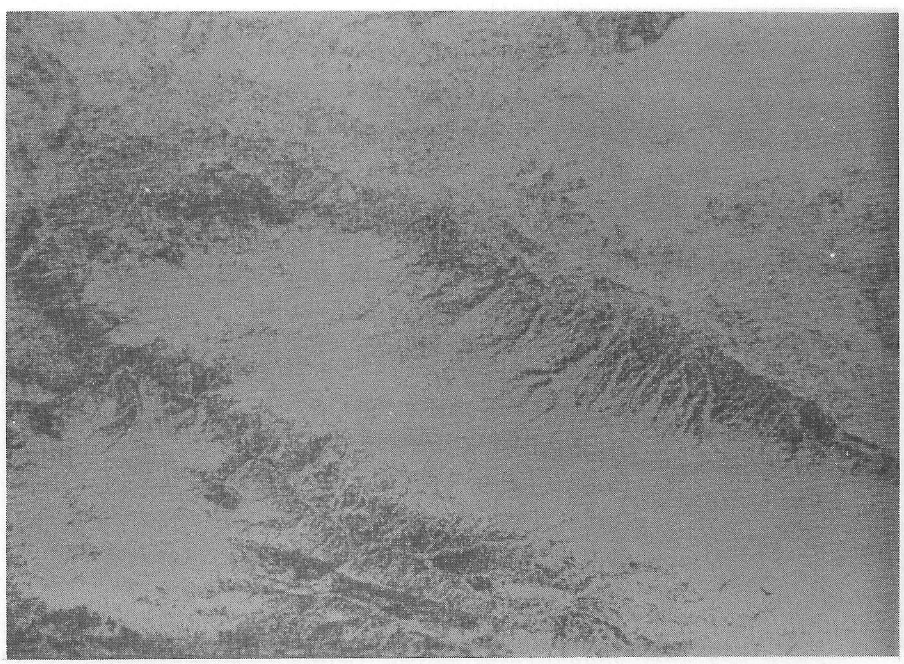

Figure 10. Oak-savanna is dark. This zone rings the Uncompahgre Plateau in the center and the La Sal Mountains in the lower left.

Figure 11. Pinyon-juniper is dark. This zone also rings the Uncompahgre Plateau and La Sal Mountains like the oak-savanna zone but, additionally, outlines Grand Mesa in the upper right portion of the picture.

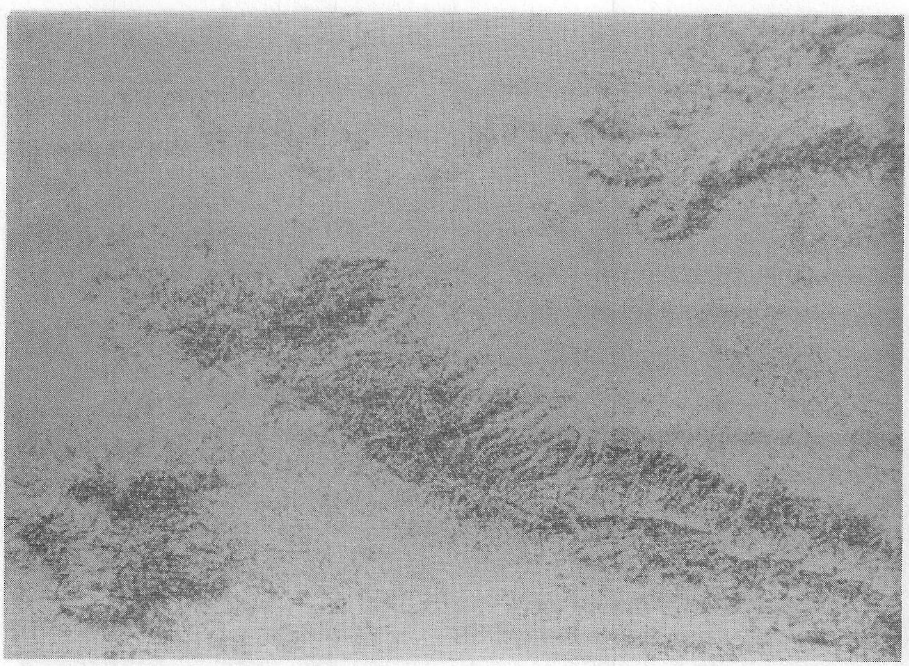

Figure 12. Aspen-meadow is dark. This zone forms an extensive cover in the upper regions of the Uncompahgre Plateau, an asymmetric band around the La Sal Mountains, and a strip on the southeastern flank of Grand Mesa.

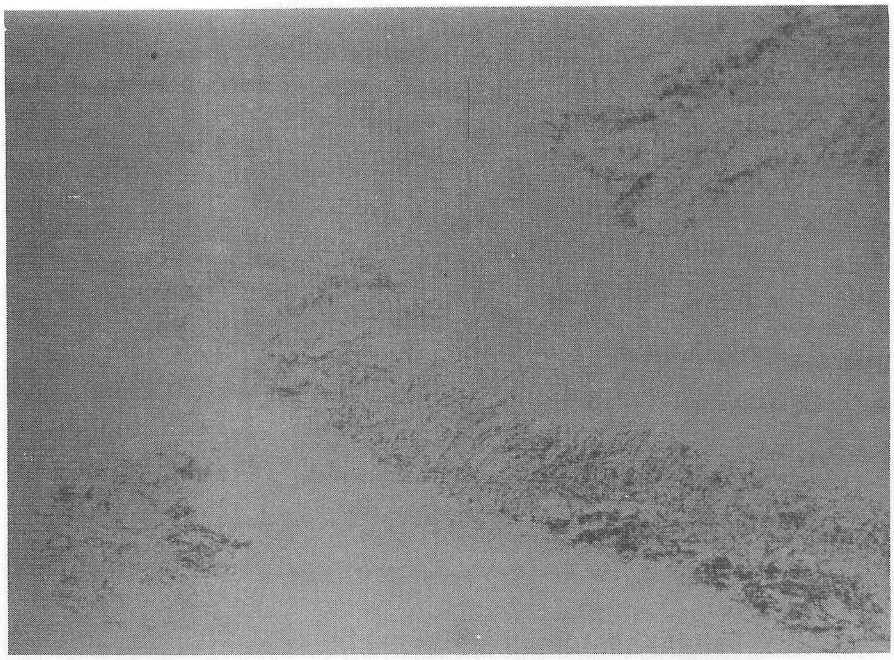

Figure 13. Ponderosa pine is dark. Ponderosa pine is widely distributed atop the Uncompahgre Plateau with concentrations along the southern flank; it displaces aspen-meadow along the northwest flank of Grand Mesa as the dominant species in the mid-altitudes (compare to figure 12), and is found below the aspen-meadow on the east slope of the La Sal Mountains.

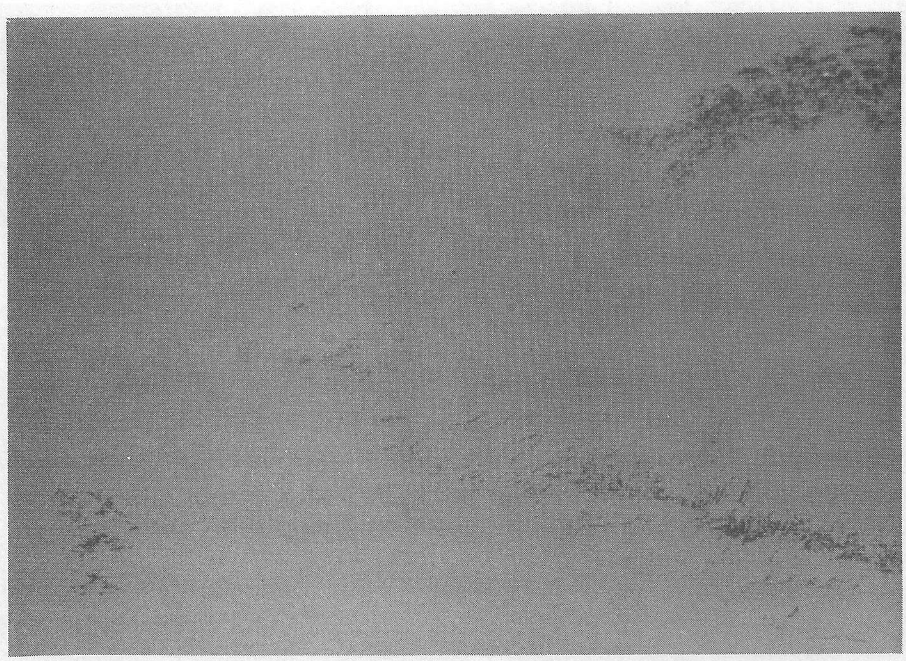

Figure 14. Spruce-fir is dark. This zone occupies a strip along the crest of the Uncompahgre Plateau, blankets Grand Mesa, and radiates from the peaks of the La Sal Mountains.

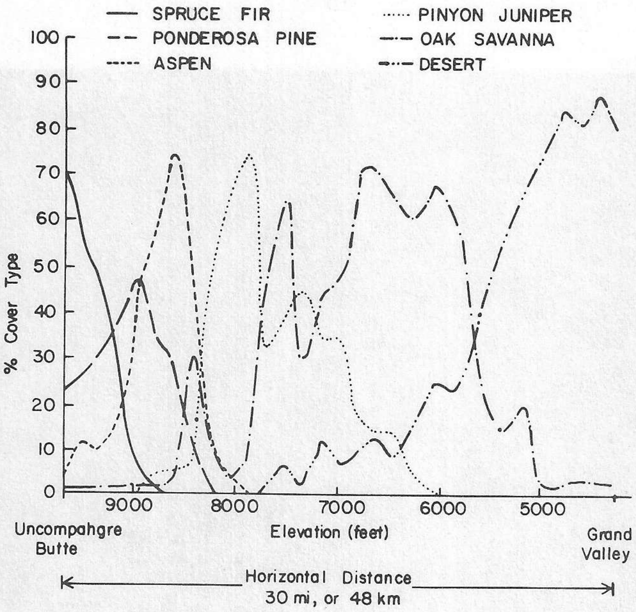

Figure 15. Percentage of cover type assemblage as a function of elevation. The percentage of classified cover type in each of 30 overlapping 400-acre fields (20 x 20 data elements) was calculated by a LARSYS computer program. The overlapping fields defined a transect along an essentially constant topographic slope from Uncompahgre Butte to Grand Valley as shown on Figure 16. The plot of the results shows the dominant assemblage at various elevations and the transitional nature of the boundaries between zones. The secondary peak on the oak-savanna curve at 8,300' represents a misclassification of aspen-meadow-high grassland species as oak-savanna. Compare this graph with the ideal model shown in Figure 3.

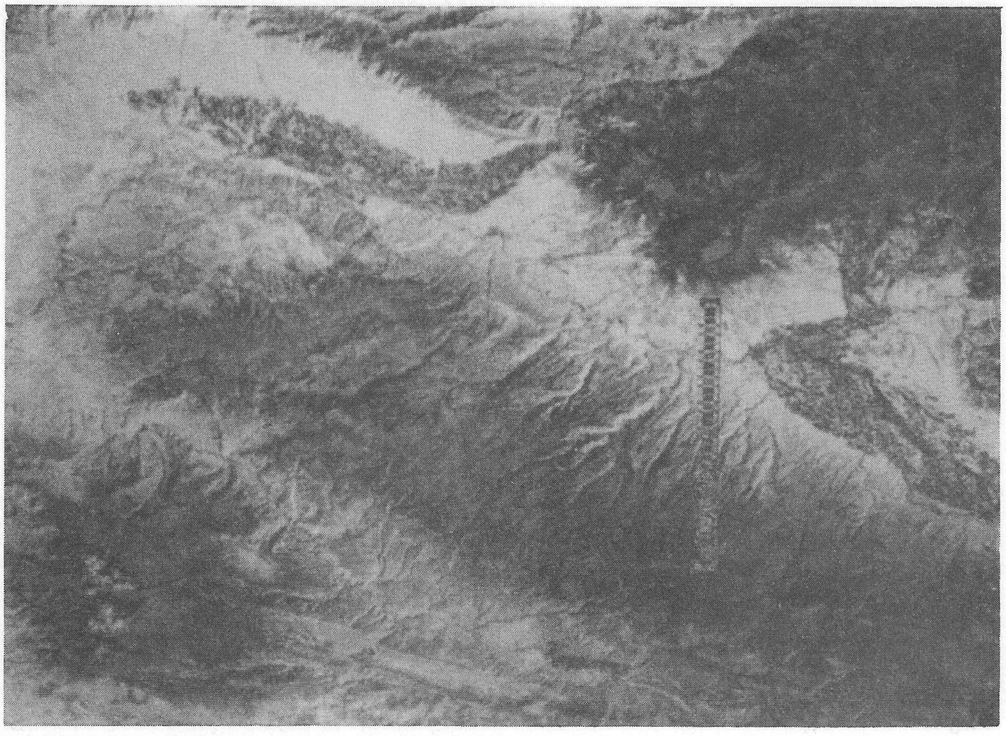

Figure 16. Band 5 image of the study area showing location of a linear transect of overlapping test fields from which data were obtained to construct Fig. 15. Transect extends from Uncompahgre Butte (bottom) to Grand Valley (top).

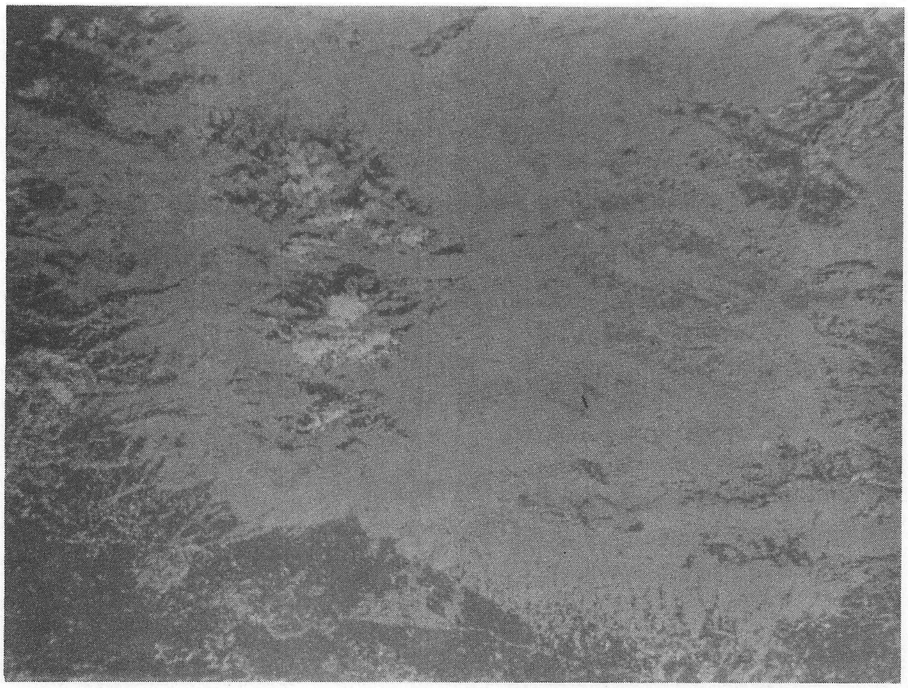

Figure 17. Classification enlargement of La Sal Mountain Region. Light areas in center of the uplift are tundra and bare rock. Spruce-fir is represented by the radial black bands following valleys down the slopes of the high peaks. The medium light grey zone surrounding the peaks is the aspen-meadow complex with medium grey fingers of Ponderosa pine extending into this zone in the right central portion of the area south of Sinbad Valley. The light grey band is pinyon-juniper surrounded by the dark, low lying oak-savanna assemblage bordering the photograph.

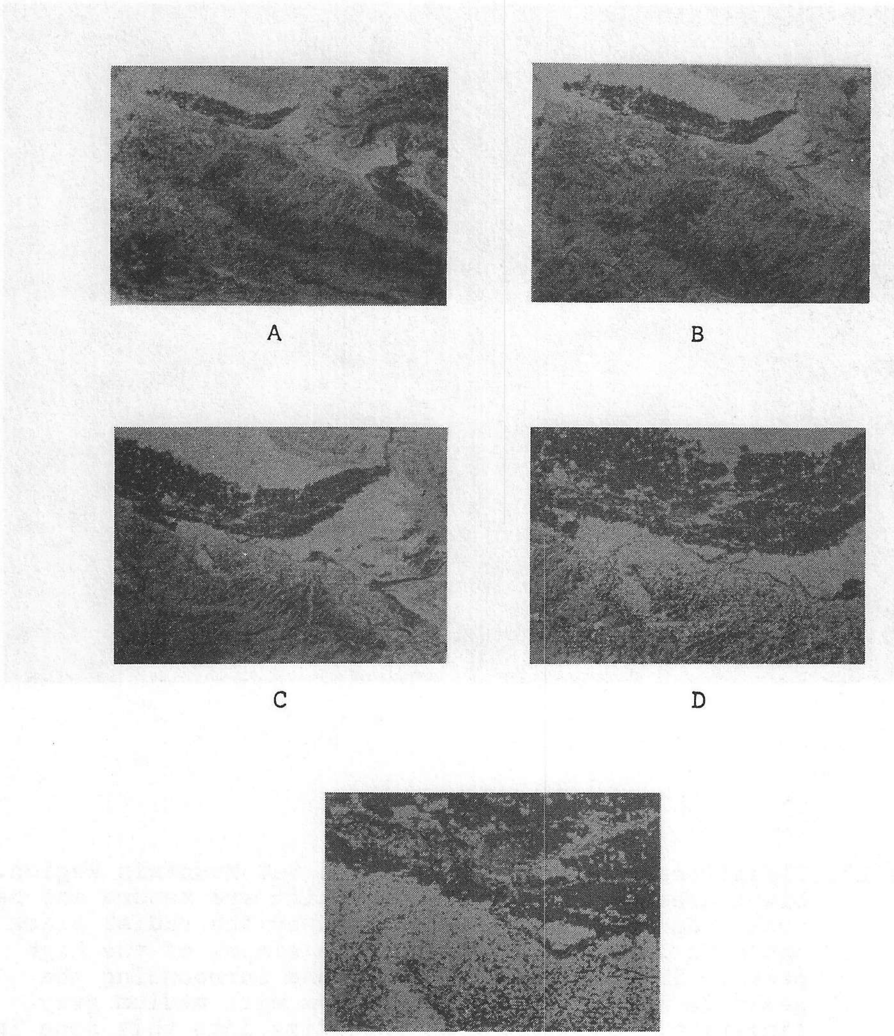

Figure 18. Range in scale available through the use of LARS digital display screen. Original scales of Polaroid photographs of classification results are (A) 1:1,500,000 (B) 1:1,000,000 (C) 1:500,000 (D) 1:250,000 (E) 1:125,000. Grand Junction, Colorado (population ≈ 30,000) clearly shows up on photos (D) and (E). Colorado River is the winding black band on photo (E).

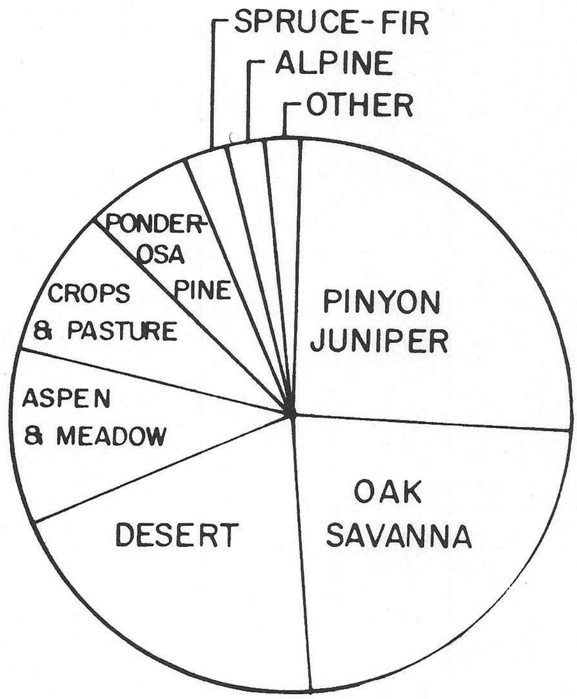

Figure 19. Pie diagram depicting the relative proportions of land use and cover type in 4.4 million acres of west-central Colorado. "Other" includes urban areas, cloud-covered regions, shadow areas, lakes and rivers.