NASA
Technical
Paper
2137

March 1983

Wildland Inventory and Resource Modeling for Douglas and Carson City Counties, Nevada, Using Landsat and Digital Terrain Data

James A. Brass,
William C. Likens,
and R. Ronan Thornhill

NASA

NASA
Technical
Paper
2137

1983

Wildland Inventory and Resource Modeling for Douglas and Carson City Counties, Nevada, Using Landsat and Digital Terrain Data

James A. Brass
and William C. Likens
Ames Research Center
Moffett Field, California

R. Ronan Thornhill
Nevada Division of Forestry
Carson City, Nevada

National Aeronautics
and Space Administration

Scientific and Technical
Information Branch

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

WILDLAND INVENTORY AND RESOURCE MODELING FOR DOUGLAS AND CARSON CITY COUNTIES, NEVADA, USING LANDSAT AND DIGITAL TERRAIN DATA

James A. Brass, William C. Likens, and R. Ronan Thornhill*

Ames Research Center

SUMMARY

This pilot forest inventory project was a joint effort of the National Aeronautics and Space Administration and the Nevada Division of Forestry, Division of State Lands, the Governor's Planning Office, and the University of Nevada-Reno. The overall goal of the project was to demonstrate the potential of using Landsat satellite imagery to map and inventory pinyon-juniper desert forest types in Douglas and Carson City Counties, Nevada. Specific map and statistical products produced include land cover, mechanical operations capability, big game winter range habitat, fire hazard, and forest harvestability. As a result of this project, the Nevada Division of Forestry has determined that Landsat can produce reliable and low-cost resource data. Added benefits become apparent when the data are linked to a geographical information system (GIS) containing existing ownership, planning, elevation, slope, and aspect information.

INTRODUCTION

This pilot forest inventory project describes a use of Landsat digital analysis to inventory vegetative types in western Nevada. The pilot study was a cooperative effort among the Nevada Department of Conservation and Natural Resources (Division of Forestry and Division of State Lands); Governor's Office of Planning Coordination; the University of Nevada-Reno (UNR); and the National Aeronautics and Space Administration (NASA) (Ames Research Center) during May 1979 through August 1980.

From 1975 through 1980, a growing demand was generated by state resource agencies to evaluate and monitor the natural resources under their jurisdiction. With this demand in mind, a joint project was initiated between the State of Nevada and Ames Research Center (ARC). Through the efforts of the UNR, Renewable Natural Resources Department, a meeting was organized to introduce many state agencies to the benefits of Landsat digital data for resource monitoring. During that meeting, Dr. Dale Lumb and Susan Norman (ARC) discussed the possibility of a cooperative effort (Nevada Division of Forestry (NDF) and ARC) to investigate the application of Landsat in inventorying and mapping pinyon-juniper (P. monophylla Torr. and Frem and Juniperus osteosperma (Torr.)) desert forest types in Nevada. At that time, both ARC and NDF were uncertain as to how successfully Landsat could map this desert forest type.

Managerially speaking, the State of Nevada is in a unique position compared to most other states. Approximately 60.8 million acres (86.3% of Nevada) is under the

*Nevada Division of Forestry.

direct management of the federal government. Currently, the management policies and practices concerning this vast resource area are strictly federally controlled, with little input by various state resource agencies. However, many state resource agencies are interested in acquiring resource information to monitor present management practices or update old resource information. Through the use of Landsat digital data, the Nevada Department of Conservation and Natural Resources hoped to map forest densities of timber types in Douglas and Carson City Counties, Nevada.

Accurate and timely resource information is necessary in making the best possible decision concerning Nevada's resources. To arrive at this information, the use of Landsat data is just one solution. Landsat imagery could fill a basic need which is now being reflected by the many resource issues in Nevada. Reforestation, urbanization, and fuels management are only three of the issues facing resource agencies in the state. To address these needs the state requires timely information on a large scale. Previous resource studies have been done with a large ground survey component. As funding decreases, costly ground inventories must also be decreased. To fill the void left by decreasing field work, Landsat data will be used to stratify areas for more efficient use of ground surveys and to provide synoptic coverage of the land cover.

LANDSAT REMOTE SENSING

Remote sensing may generally be defined as the observation of objects or scenes without direct contact. Aerial photography has long been used in forest management planning and represents proven remote sensing technology; it was therefore natural for NDF to be interested in the feasibility of technologically advanced remote sensing inventory methods. Specifically, forestry and other state agencies were ready to evaluate Landsat, a NASA satellite series, as a potential source of resource information.

The first Landsat satellite was launched in 1972. Landsat, formerly called the Earth Resource Technology Satellite (ERTS), is an Earth-viewing satellite operating in a near-polar orbit approximately 917 km (570 miles) above the Earth's surface. Landsat images cover a square geographical area approximately 184 km (115 miles) on a side, or approximately 3.5 million hectares. The image is recorded in four wavelength regions (bands) of the electromagnetic spectrum, two in the visible portion and two in the near-infrared. Photographic film is not carried in the satellite because of the difficulty of transporting it back to Earth. Instead, the satellite records data with an electro-optical device called a multispectral scanner (MSS). The amount of light reflected from the Earth is recorded in each wavelength band numerically. Signal strength can vary from 0 to 127 digital numbers (dn) in three bands and from 0 to 63 in the remaining band.

Landsat data basically provides point source information. The satellite sensors scan in 183.5-km swaths perpendicular to the Landsat orbital track. Six lines of data are scanned simultaneously in each of the four spectral bands. Each detector produces an analog output, which is encoded as a six-bit digital word, each word corresponding to one picture element (pixel). Although each detector imaging area is 79 by 79 m, the sampling by each detector during any particular instant represents only 55 m of new information in the cross-track direction. Therefore, in practice, the nominal pixel area is 56 by 79 m at the nadir. Each pixel covers approximately 0.45 ha (1.12 acres) on the ground, resulting in the nominal one-acre resolution.

A Landsat scene is composed of a grid of 1.1-acre data cells (pixels). This 1.1-acre resolution results in more than one object measured per observation, a pronounced difference from traditional aerial photography. In addition, Landsat records only two of the colors recorded by color film, red and green. However, two additional bands are sensed by the satellites. These bands record reflected infrared radiation to which normal color film is not sensitive. Landsat data are digital (a series of numbers rather than tones or colors on a photograph) and therefore can be processed by computers.

This numerical aspect of the data is the most interesting to the resource agencies. Image processing enables the grouping of pixels of similar reflectance patterns (spectral signatures) into unique categories. This process is somewhat analogous to what a photointerpreter accomplishes with delineating regions of similar color on aerial photographs. Because of the nature of these unique categories of Landsat, information can be printed as alphanumeric symbols at 1:24,000 scale for overlay on United States Geological Survey (USGS) base maps. In addition, summary statistics such as the number of acres occurring within each Landsat category are easily available.

Anyone experienced with type-mapping using aerial photographs undoubtedly sees several limitations to Landsat data at this point. Landsat, which does not image individual trees, cannot record the subtle changes in tree size, tree shape, and canopy texture noted by photointerpreters. However, three important aspects of Landsat data do compensate for these limitations.

1. Landsat sensors record light reflectance values much more uniformly, objectively, and consistently than do photographic emulsions. In addition, imaging problems such as scale differences between images and flightpath precision (usual problems in aerial photography) are minimized with imagery taken from satellite platforms.

2. While forest or canopy texture (an important factor in species identification) is not easily measured with Landsat digital data directly, texture does influence the average light reflectance of the forest canopy. Canopy spectral signatures are a function of tree color, shape, size, density, structure, and texture. Except for density, which can be well characterized within limits, Landsat measures all other factors indirectly.

3. Finally, Landsat measures reflectance in the infrared portion of the light spectrum above that recorded by color aerial photographs, or even color infrared photography. Therefore, increased vegetative information is acquired by the multispectral scanner.

It is a well known phenomenon that different vegetation types display greater differences in their infrared reflectance level than they do in the visible spectrum. Discriminant analysis of Landsat data makes use of this fact by recognizing differences in the infrared reflectance, which has been shown to contain more discriminatory information than visible light reflectance. In spite of these compensating strengths, the early research information from Landsat data seemed to be very discouraging (Heller, 1975). In the field of remote sensing it was felt that Landsat might only be able to discriminate forest land from nonforest land. However, image analysis routines were greatly improved in the 1970s (Fleming et al., 1979; Gaydos and Newland, 1978), and a potential for increased information content from Landsat is now indicated. In light of these results, NDF personnel felt that Landsat computer processing technology had advanced to a point where a Landsat pilot forest inventory demonstration project was both feasible and desirable.

OBJECTIVES OF THE PROJECT

The overall goal of this pilot project was to demonstrate the potential of using Landsat to map and inventory pinyon-juniper desert forest types in Douglas and Carson City Counties, Nevada. The specific objectives were to:

1. Obtain and geometrically correct the four-band Landsat digital image of Douglas and Carson City Counties, Nevada. Develop data in a digital format on magnetic tape. Produce black and white false color photographs of the Landsat raw data.

2. Produce a raster format digital representation of the terrain in the study area using Defense Mapping Agency/National Cartographic Information Center (DMA/NCIC) terrain (elevation) data. Register elevation data to Landsat data and record on magnetic tape. Derive digital slope data from the elevation data, register to Landsat data, and record on magnetic tape.

3. Classify Landsat spectral data into general categories: agriculture, urban, brush, pinyon-juniper forest, Sierra Nevada forest, and water. Emphasis would be placed primarily on the pinyon-juniper forest in the Pine Nut Mountains. Produce color thematic maps of the classified data.

4. Provide state personnel with training and experience in remote sensing techniques. Specifically, provide training in aerial photointerpretation (small and large scale) and Landsat digital analysis techniques for forest resource monitoring and mapping. (See Western Regional Applications Program under "Training.")

5. Generate summary strata statistics by county and ownership.

6. Evaluate the value, suitability, and utility of the pilot project and the possible continuation of Landsat analysis by state agency personnel. Address such questions as, Can Landsat be used to accurately map pinyon-juniper forests throughout Nevada? What information can be derived from remote sensing techniques? How can Nevada state agencies use this tool?

In addition, final products were to be developed in digital and photographic form. Those products include

1. A general land cover map of Douglas and Carson City Counties, Nevada.

2. Sierra Nevada forest maps, including fire hazard, forest cover and densities, wildlife habitat, and big game winter range.

3. Pine Nut Mountain Range maps, including fire hazard, forest cover and pinyon-juniper densities, accessibility or harvestability of pinyon-juniper forest, mechanical operations, and big game winter range.

4. Tabulation of acreage features and products by county and ownership classes.

PROGRAM OBJECTIVES

The first question to arise in the planning phase was, Where does one conduct a pilot forest inventory project in Nevada? NDF suggested the Douglas and Carson City Counties area (fig. 1) for several reasons:

1. Diverse vegetative types exist in both counties (east slope of the Sierra Nevada Range, Carson Valley agriculture areas, and the pinyon-juniper forest of the Pine Nut Range.

2. All three major ecological areas contain distinct vegetation zones.

3. Ancillary data that were important to NDF (ownership and terrain information) was readily available for this area.

Researching several different aspects of using digital information was a prime concern in the study. To investigate the possibilities of correlating vegetation with other data sources, NDF chose management problems they were presently addressing: Concerns such as wildlife habitat evaluation, wildland fire hazard, and timber harvestability mapping would be used to test the applicability of using Landsat in conjunction with other data layers.

Testing Landsat remote sensing techniques to inventory various vegetative species common to Nevada's arid climate was the major thrust of the pilot study. If principle plant communities within Nevada could be adequately mapped, NDF, as well as other state agencies, would have a valuable tool for resource management. The techniques applied to Douglas and Carson City Counties could be adapted to other regions of Nevada. A realization existed, however, that spectral characteristics developed from this study might require modification from one part of the state to the next (ecozone changes). However, these same spectral characteristics could still be used in their spatial context to develop specific resources statistics.

PARTICIPANTS

Participants in the study included the State of Nevada's Department of Conservation and Natural Resources Division of Forestry and Division of State Lands; Governor's Office of Planning Coordination; University of Nevada-Reno Renewable Natural Resource Department; and the National Aeronautics and Space Administration's Ames Research Center.

NEVADA DIVISION OF FORESTRY'S RESPONSIBILITIES

There were several responsibilities that NDF would address to ensure the fulfillment of the pilot study.

The State Forester Firewarden, as NDF administrator, is charged by law to supervise and coordinate all forestry and watershed work on state, county, and privately owned lands. This work deals primarily with fire control, working with federal agencies, private associations, counties, towns, cities, and private individuals in administering all forestry and fire control laws in Nevada. In addition to the fire protection responsibilities, the State Forester Firewarden is responsible for resource management programs on nine million acres of state and privately owned forest and watershed lands throughout Nevada.

Under Nevada Revised Statutes NRS 527.310, the State Forester Firewarden is required to inventory all nonfederal forest and range lands in Nevada, and to prepare a report for the legislature. To comply with this law, NDF can use remote sensing techniques to inventory resource lands in Nevada.

For this study, NDF was responsible for

1. Providing a project manager to make general plans and to supervise the NDF staff.

2. Developing a forest resource classification theme.

3. Participating in all workshops to establish thematic classification.

4. Participating in training workshops.

5. Preparing map products as mutually agreed.

6. Developing and planning specialized applications.

7. Designing and implementing evaluations and verifications.

8. Assisting to prepare the final report.

9. Preparing cost and personnel activity summaries.

TECHNICAL PROCEDURE

The following section describes the technical procedures used. A flow diagram covering the steps is shown in figure 2.

1. *Data Selection*

Following delineation of the study area by NDF personnel, a list of potential Landsat scenes were obtained from Earth Resources Observation Systems (EROS) Data Center (EDC), Sioux Falls, South Dakota. Requirements for the scene included most recent coverage, less than 10% cloud cover, and May-through-September time period. The season of imagery was considered important because of the varied elevations throughout the study area. The data, having to cover the Sierra Nevada and Pine Nut Mountain Ranges and the Carson Valley (elevation ranging from 32,800 m (10,000 ft) to 13,120 m (4,000 ft) had to be somewhat free of snow, which mandated scenes being selected no earlier than July as snow still is present at higher elevations in June.

After a study of many dates and images, a July 30, 1978, scene #E-30147-18003 was selected (fig. 3). This scene was chosen for two reasons: (1) the study area was free of cloud and snow, and (2) forest and brush species were still at their "green peak" for good spectral definition. EDC provided the raw data (multispectral scanner bands 4, 5, 6, and 7) in a 9-track, 1600-bpi format. A false color composite print at 1:250,000 scale was also procured from EDC to be used for data analysis and ground truthing.

Terrain data were obtained from USGS-NCIC, Reston, Virginia. A 9-track 1600-bpi tape containing digitized elevation data was ordered for use as collateral information during the project. This tape contained digitized 200-ft contours and interpolated 40-ft contour information that would be used to describe elevation, slope, and aspect within the study area.

In support of the project, a U-2 mission (high-altitude aerial reconnaissance flight) was requested by NDF to be flown by the High Altitude Missions Branch at ARC. These data would be used to update the land cover information in the NDF Office in Carson City, Nevada, as well as to support the verification portion of the Landsat demonstration.

The aerial photography required to accomplish the project goals needed to be of a scale to allow photointerpretation to a species or plant community level and acquired at the same plant maturation point as that found in the Landsat data. If the growth stage of the plant materials were similar in both types of imagery (Landsat versus aerial photography), the relationships between satellite data and aerial photography would be evident.

Since the demonstration was primarily concerned with vegetation — specifically forest vegetation — color infrared film best met these needs. Two scales of photography, 1:32,500 and 1:63,000 (normal scale), covering the entire Douglas and Carson City Counties area would be used to provide an overall examination of the land cover within the region. All aerial photography was to be completed in one 5-hr mission.

Additional data collected included ownership information and USGS 1:250,000, 15 minute, 7-1/2 minute quadrangles. The USGS data were used primarily in the field for geographic referencing and noting vegetation information. Ownership information was important in final product generation. Acreage tabulations by ownership class of all land cover types was produced to indicate responsibility and potential for Nevada state agencies.

2. Training

The Western Regional Applications Program is a means by which Landsat technology and other resource-monitoring, remote sensing techniques can be transferred to state and local governments. As technology transfer was one of the goals for the Nevada project, extensive training of state personnel was accomplished.

Training workshops held at NDF Headquarters, UNR, and ARC were used to familiarize NDF personnel with basic remote sensing techniques. The first workshop, at UNR, was conducted jointly by Dr. Paul Tueller and staff, and ARC. Introduction to satellite data and principles of aerial photointerpretation were discussed. Workshops continued throughout the project to review all aspects of the analysis with the NDF staff. Workshops held in Carson City were supported by the mobile analysis and training extension (MATE) van to provide hands-on analysis experience to state personnel.

The basic approach in the training workshops was to teach the participants basic skills of (1) resource identification using low-, middle-, and high-altitude aerial photography; (2) Landsat digital analysis including registration, digitization, and classification; (3) software manipulation on the computer systems used at ARC for the analysis (Interactive Digital Image Manipulation System and TENEX System); and (4) field training and verification techniques.

Staffing during the workshops was done by the UNR, the Renewable Natural Resources Department and ARC personnel. UNR added valuable local expertise in photo-interpretation and resource identification skills. ARC staff provided skills in digital analysis techniques; manipulation of hardware/software; and general remote sensing theory.

3. Product Development

The user-defined products were developed to more effectively present the data derived from the project. To evaluate the data, thematic maps of the entire demonstration area were produced. These color representations of the data illustrated (1) land cover, (2) elevation, (3) fire hazard, (4) wildlife habitat, (5) harvestability, and (6) mechanical operations. Acreage figures were tabulated from these maps on a county-wide and ownership basis and were developed in tabular format as requested by NDF.

All digital data produced by the project were made available to NDF for further study in a tape format compatible with the IBM 370/158 system requirements.

4. Equipment and Computer Systems Utilized

Below is a list of the Ames computers and other equipment used during the period, and a brief description of the tasks done on each:

1. IBM 360/67 - Used for data reformating, pre- and post-analysis processing.

2. PDP-10 Tenex - EDITOR software used for clustering and classification of images, and for digitization of map information.

3. ILLIAC - Used for clustering and classification of large images.

4. HP-3000 - Interactive Digital Image Manipulation System (IDIMS) - Used for image display. Capable of clustering and classification.

5. Mobile Analysis and Training Extension (MATE) - A mobile (road capable van) IDIMS System.

6. Dicomed film recorder - A device used for producing photographic negatives and prints of image data.

4.1 Preprocessing the Landsat Image: Data Reduction, Rotation, Deskewing, and Reformatting

The image contained on the Goddard format Landsat computer-compatible tape (CCT) covered an area much larger than the study area. To reduce processing time, a subsection covering only the study area was extracted from the full-size image. The coordinates of the area extracted were determined by visual examination of a photographic print of the Landsat image.

The extracted image was rotated and deskewed in order to make the line and sample axes of the image run east/west and north/south, respectively, rather than 11° clockwise of north, which is the natural image geometry. The rotation and deskewing was done so the project analysts would more easily relate the image to existing USGS topographic maps. The degree of rotation applied was derived from a first-order polynomial relating the image surface to latitude and longitude. This polynomial was developed from the image line and sample and corresponding latitude and longitude coordinates for 12 control points.

The extraction of the image subsection, its rotation, and deskewing were carried out on the ARC IBM 360/67 computer. An area-preserving algorithm that did not create or delete, but only shifted pixels, was used to accomplish the rotation and deskewing. During this process the output was reformatted into the EDITOR image format acceptable to other computers used by the WRAP program at Ames.

4.2 Developing a Polynomial Surface Relating Rotated and Deskewed Landsat Coordinates to Latitude and Longitude

The previously developed polynomial surface could, using latitude and longitude information, predict the line and sample locations of pixels in either the unprocessed or preprocessed Landsat images to within ±3 pixels (about ±180 m) of their actual locations. A higher order polynomial was needed to allow accurate location of user-defined polygons, and to allow accurate registration of ancillary data to the Landsat image. The line and sample locations for 20 control points were obtained using a color video display for image examination. These control points were plotted on 7-1/2- and 15-minute topographic maps. The line and sample coordinates, along with latitude and longitude information obtained from the topographic maps, were used to establish a second-order polynomial relating latitude and longitude to line and sample coordinates in both the unprocessed and preprocessed Landsat images. Despite the fact that the 20 control points used for calibration had been selected from the preprocessed image, the second-order polynomial could be used to describe both the unprocessed and preprocessed image. Since the nature of the preprocessing was well known and could be used to define the relationship between the two images, one control point file could be used for the calibration.

4.3 Guided Clustering and Image Classification

The guided clustering process combined the unsupervised and supervised clustering analysis procedures. Both of these procedures use the spectral characteristics of the data, and do not use spatial information.

In the unsupervised process, spectral space is partitioned into compartments, or "spectral clusters," based upon spectral separation parameters supplied by the analyst (the specific parameters used varies). Land cover informational names for unsupervised spectral clusters cannot be well developed until after a classification of the Landsat image is completed.

In the supervised clustering process, the analyst delineates polygons containing a known set of land cover features. Spectral clusters for the land cover features contained within these polygons can be developed. Land cover names can be assigned to the spectral clusters developed by clustering because the cover types contained in the input polygons are known.

Normally a classification is developed after an unsupervised or supervised clustering. The classification process uses a maximum likelihood algorithm to calculate the probability that a given pixel belongs to each cluster, and then assigns that pixel to the spectral class with the highest probability. The classified image is then examined using a color video display or line printer map and compared with aerial photography and ground survey data.

Unsupervised clustering allows the incorporation of the full range of spectral values into the clustering process, thus generating more comprehensive output clusters. Use of the full range of data, however, can result in distorted, or "junk," clusters that emphasize the confusion boundaries between features, rather than emphasizing the desired features. The supervised process allows the computer to find only those features for which spectral clusters have been developed, thus leaving the possibility that some features will be missed. The supervised approach, however, does allow development of customized spectral clusters that can be more accurate than unsupervised clusters at describing desired features. Combining the unsupervised and supervised approach into the guided clustering method is beneficial because the supervised approach can be used to develop optimized spectral clusters for high-interest features whereas the unsupervised approach can be used to yield adequate clusters via a more automated (and therefore less labor intensive) process for those features not of prime interest.

4.3.1 Unsupervised Clustering and Classification

The first analysis carried out on the Landsat image after completion of the preprocessing was an unsupervised classification. A 35-class unsupervised clustering, followed by a classification, was generated by using EDITOR image analysis software present on the ARC ILLIAC computer. The classification was then taken to a computer having a color video display so that the spectral classes could be identified according to land cover type. A plot of the spectral clusters was also produced to aid the analysts in identifying spectral classes (fig. 4). The process of class identification was carried out jointly by ARC and NDF personnel comparing the location of occurrence and spectral characteristics of the computer-generated spectral classes with the appearance of those features on color infrared (CIR) aerial photography. This analysis served both to familiarize the training analysts with the data and to train the Nevada project participants in analysis techniques; it also provided some of the spectral clusters that would be needed in the final classification. The unsupervised clusters developed for the more general cover types such as water, bare ground, and agriculture were later to be used in the final classification. More detailed cover types, such as crown-closure classes by species type, required the more optimized clustering that could be obtained through the supervised process.

4.3.2 Supervised Clustering and Classification

The preliminary step in the supervised classification process was to delineate polygons of known land cover type. The ARC staff located about 65 sites on the CIR photography of the area, and transferred the locations of these polygons to topographic maps. Several sites were selected for each feature of which detailed spectral clusters were desired, including polygons containing (1) pinyon-juniper forest, (2) Jeffrey pine forest, (3) white fir, (4) great basin big sage, and (5) low sage. Ground checks were then done by ARC, NDF, and UNR of each of these polygons, with a site evaluation form recording the vegetation present, degree of ground cover, and other miscellaneous information completed at each site. A total of 58 sites were checked, with about 7 selected in the field. A number of the sites originally planned for investigation were deleted because of inaccessability or time constraints.

At ARC the locations of the polygons were entered onto the TENEX computer using a digitizer (a device that allows map information to be transferred into digital computer format). It was then possible to extract the digital spectral information for each ground site from the Landsat image so that spectral clustering analysis could be done. The spectral information of all polygons tagged as containing a given cover type (based upon information developed during the field work) were merged on a cover-type by cover-type basis. This yielded a separate file of spectral information for each of the cover types for which clusters were to be developed. A period of reiterative clustering of these spectral files followed until it was determined that an optimized set of spectral clusters had been obtained for each of the cover types (fig. 5). In this process a tentative mapping scheme was developed that consisted of a compromise of what NDF wished to map and what the ARC analysts determined was separable based upon the spectral separability of the clusters developed during the unsupervised and supervised processes.

4.3.3 Pooling Statistics and Generating Classification

The spectral clusters produced during the supervised clustering, and those retained from the unsupervised clustering, were grouped, or "pooled," into a new computer file containing all clusters (fig. 5). The comprehensive statistics file thus generated was then used to classify the Landsat image.

4.3.4 Classification Assessment

The guided classification was assessed by ARC and NDF analysts using a color video display, correlating the classification results with features evident on the project's U-2 photography. The analysts found that a small number of the spectral classes developed did not properly identify the land cover features intended. This misidentification resulted largely from occurrences of spectral confusion between some of the cover types. The analysts determined on a class-by-class basis whether it was possible to relabel the problem classes, or to delete them from the final classification run.

There was some problem in separating forest types in the Sierra Nevada from those in the Pine Nut Range. Some areas within the Sierras were incorrectly identified as containing pinyon-juniper forest, a type which does not occur there (at least not in Douglas County). Also, there were similar problems between some of the area's brush species. A stratification approach based upon the ecological zone concept was chosen to eliminate these cases of spectral confusion. Three separate regions (fig. 6), or "ecozones," of clearly different vegetation composition (this being subjectively determined by the ARC and NDF analysts) were delineated and digitized to be used with the digital Landsat data. These areas were (1) the Sierra Nevada mixed coniferous forest, (2) the Pine Nut Range, containing pinyon-juniper forest and sagebrush, and (3) the Carson Valley, an area with agriculture and sagebrush. A new cluster statistics file was created for each of these ecozones using subsets of the previously generated statistics file (fig. 7). Each of the new statistics files excluded clusters for vegetation types that should not be occurring in that region.

Some thought was given to eliminating some of the classification inaccuracies through using elevation or aspect breakpoints to split confusion classes into parts, so that each part could be named separately. The analysts decided, however, that (1) the vegetation in the area was not sufficiently elevation or aspect dependent and (2) the means described earlier for addressing these problems were more straightforward.

4.4 Generation of Final Land Cover Classification

The classification was rerun on the ILLIAC upon completion of the delineation and digitization of the ecozone stratification boundaries and compilation of final statistics files for each of the ecozones. The result was that a separate classification was carried out upon each of the three ecozones. The boundary delineation, statistics file generation, and final classification were accomplished over a two-week period by two ARC analysts working parttime on these tasks.

Once generated, one NDF and two ARC analysts spent one or two days examining the classification. They determined that the final classification improvements had been effective, and that no additional work was required to generate the land cover data (fig. 8).

5. Elevation Data Reformatting and Registration to Landsat Image

The DMA digital elevation data were received from the USGS-NCIC in two portions, one covering the western half of the Reno 1:250,000 standard series topographic map, and one covering the western half of the Walker Lake map. These data were in a format not readily usable by ARC (variable block, 16-bit half-word, north/south profile data — a nonimage format), and as a result required some reformatting. New software had to be written because this type of information had not previously been used in this form at ARC.

Douglas and Carson City Counties straddle the boundary between the Reno and Walker Lake maps. It was thus necessary to mosaic the bottom of the Reno West map to the top of the Walker Lake West map. This was done at ARC using the IDIMS image analysis system. Once the maps were mosaicked, the data were registered to the rotated Landsat image's geometry, this being done on IDIMS utilizing, in part, data obtained from the Landsat calibration file developed during the classification process (Fig. 9). At this point, some holes resulting from an imperfect abutment of the two elevation images during mosaicking were fixed using an averaging algorithm.

5.1 Generation of Slope Image

The slope image was derived from the 16-bit/half-word elevation image, rather than from the 8-bit/byte image. While the 8-bit/byte elevation image is easier to use in conjunction with the land cover image by using it in creating the slope data some information may be lost. An algorithm that examines the 8 adjacent pixels and computes the maximum drop was used to generate slope. This was done on the ARC IBM 360/67 using ISRI geographic information system software. The output consisted of 8-bit/byte data compatible with ARC image processing programs.

6. Ownership Image Creation

NDF delineated polygons for the following ownership classes onto 15-minute maps of the study area: (1) private, (2) Indian trust, (3) Bureau of Land Management, (4) U.S. Forest Service, (5) county, and (6) state lands. ARC and NDF used the ARC digitizer to encode the boundaries and ownership information into a computer format. EDITOR software present on the TENEX computer system was used to generate run-length encoded representations of the ownership recorded from each of the ownership maps. Information for each map was converted on the ARC IBM 360/67 into an image format, and each was sequentially burned into a blank background image that was the base for the output ownership image (fig. 10). The result was a single image showing the ownership information extracted from all of the input maps.

7. Derivative Map Products

The land cover and slope data developed in the project were used to derive four applications maps. These maps were designed to provide resource management data needed by the State of Nevada.

7.1 Mechanical Operations Map

NDF specified mechanical capability ratings for various slope categories. This information was used with the digital slope data to produce the mechanical operations map (table 1, fig. 11).

7.2 Big Game Habitat

A habitat map was derived from the land cover data by ranking the big game (mule deer) habitat potential of each of the land cover types mapped by Landsat. This ranking took into account the carrying capacity of various cover types, and the degree of cover offered by the vegetation. Bitterbrush provides excellent mule deer forage, and was the most highly ranked cover (table 3, fig. 12).

7.3 Forest Harvestability

A model using land cover and slope data was developed for use in creating a forest harvestability map (table 4, fig. 13). Forest stands on moderate slopes were rated more harvestable than equivalent stands on steep slopes. The type and density of the forest was also used in rating harvestability. The Sierra Jeffrey pine and fir types were rated separately from equivalent stands of pinyon and juniper. Areas not containing forest were excluded from the model.

7.4 Fire Hazard

A fire hazard model was developed and used with the land cover and slope data to develop a fire hazard map (table 5, fig. 14). The steeper slopes tend to carry fires most rapidly and were weighted with a higher hazard level than were gentler slopes. Each land cover type was rated as a function of the value of the cover and the fire carrying capacity. Agricultural and riparian areas, lush grass, and water were rated as having the least hazard. Dense forest was moderately ranked, with the highest hazard rankings assigned to brush and sparse forest.

8. Statistical Data

Acreage summaries of the land cover, mechanical operations, habitat, fire hazard, and forest harvestability mappings were obtained by both county and ownership category (tables 6 through 16).

VERIFICATION

Evaluation of the classification developed in Douglas and Carson City Counties was based primarily on the comparison of ground inventory/photointerpretation with Landsat data. To successfully sample all 24 resource classes, a random sample of 100 primary sample units were located throughout the study area. The sample units were nominally 40.5 ha (100 acres) in size (a 10- by 10-pixel area).

Geographic locations (latitude and longitude) were found for the centerpoint of all sample units using the precision calibration file developed during the Landsat analysis. The points were then plotted on USGS 7-1/2- and 15-minute maps. Each sample was then visited, and an ocular estimate of the area was made, as was an inventory of all vegetation present.

Those sample units which could not be inventoried because of terrain restrictions were located on CIR photography (1:32,500 nominal scale). A 100-element grid was overlayed onto the photo and a percent composition was developed using the resource hierarchy produced from the Landsat classification. To determine the accuracy of the photointerpretation, sample units that had been ground checked were interpreted first. After the interpreters felt confident of their ability (90%+ accurately interpreted on known sites), the additional areas which could not be reached by ground survey crews were photointerpreted. As an aid in photointerpretation, those areas which could not be reached were inventoried by sight (a list of plant species for the area was provided by the survey team). This additional input was valuable to the overall process of photointerpretation. The "ground truth" and photointerpretation were assumed to be correct as all verification is based on this data.

The classification evaluation was generated on a per sample unit basis (100-acre cell). No consideration for spatial orientation within the 100-acre cells was given in the comparison of ground survey and Landsat data.

Statistical evaluations of ground truth versus Landsat data were developed utilizing MINITAB (a statistical software package available on an HP 3000 Series III computer). Evaluation of correlation coefficients between ground data and Landsat data within the 100 primary sample units was used to determine how well the Landsat classes were predicting the ground condition (table 17).

The overall ability of Landsat classes to describe the variability of the ground conditions within the study area was generally good. A few classes (the barren class) were not found to adequately describe the ground conditions. Much confusion existed between barren and those classes which attempted to predict low-density vegetation in the high-desert (sagebrush) plant communities. Soil is one factor that would explain the confusion evident in the barren class. Soil coloration in low-density vegetation certainly would add to the vegetation signature, causing a degradation of vegetative reflectance.

Additional classes that did not adequately describe the ground condition were hardwood/cottonwood and aspen. As both classes were not prevalent in the study, lack of data caused problems in developing spectral statistics for each class. In addition, the natural growth characteristics of these two classes in the study area were such that only small linear areas were found. This type of growth caused the MSS sensor to generalize the spectral reflectivity (most areas were not a pixel wide), recording the vegetation surrounding the hardwood areas.

It is important to note that all coniferous land cover classes (Sierra and Pine Nut Mountains) were relatively well explained by the Landsat data. Correlation coefficients between the ground truth and MSS data were all above the 0.9 level. As NDF's primary concerns were with mapping the coniferous forests in the study area, such verification illustrates that Landsat did provide enough information to accomplish agency goals.

GENERAL COMMENTS FROM THE NEVADA DIVISION OF FORESTRY

NDF considers the use of Landsat data for forest inventory projects a reliable and low-cost method which can produce accurate resource data. Landsat information alone is valuable for many purposes, but its real worth becomes apparent when it is linked to a geographical information system (GIS). A GIS will link ownership, existing county planning maps, zoning maps, slope, elevation, and aspect data together, thus providing users with a wide variety of interrelated information sources. For this project, the NDF touched just a few possibilities concerning the combination of a GIS and Landsat inventory; results were very positive.

NDF considers the training provided by and the constant cooperation of ARC a vital part of this project. The many hours devoted to the project by a number of ARC personnel added greatly to the high-quality results of the effort.

Because of the great differences in vegetation types within Douglas and Carson City Counties, the area was a particularly difficult demonstration project. To decrease the amount of misclassification for county-wide projects, the area was divided into three separate ecozones, which were then classified after boundary lines between all three were digitized. Ownership data were produced and vegetation classes were tabulated per ownership. Desert vegetation may be easier to classify using the remote sensing techniques of Landsat because of the similarity of brush species, forest types, agricultural areas, and riparian vegetation.

The final products of the demonstration project have created much interest among state and federal resource agencies in Nevada. These agencies can see the potential value of such data for their own purposes. The forest harvestability map, big game habitat map, fire hazard map, and the land cover map provide valuable information sources for planners and resource managers.

FUTURE OUTLOOK

Through the efforts of the Governor's Office of Planning Coordination, NDF, and Division of State Lands, a resource group has been formed to study the possibility of a new project covering several million acres. Each participating resource agency will assist with their particular data needs for the project. Most of the processing will be handled by the State's IBM 360-VICAR/IBIS software.

NDF foresees the potential use of such resource information as a great asset to all planning departments and agencies. It is a low-cost alternative which can be updated periodically and which can use existing data sources as overlays to the Landsat data base.

The program has been a benefit for the Division and the other agencies cooperating in this initial demonstration project.

ACKNOWLEDGMENTS

Funding for this pilot forest inventory project was provided by all the agencies involved with the study. The National Aeronautics and Space Administration provided the greatest contribution by providing aerial photographs of the study area, training for the participants, use of the mobile analysis and training extension van for demonstrations of the project, and by continued assistance. We wish to thank the many individuals who gave us support at the Ames Research Center throughout the project, including Dr. Dale Lumb, Sue Norman, and David Peterson, who served as administrator coordinators.

We would especially like to thank Dr. Paul Tueller (University of Nevada-Reno, Renewable Natural Resources Department) and his staff for introducing the state agencies to remote sensing, and the Nevada State Forester Firewarden, L. V. Smith, and the Administrator of State Lands, Jack Shaw; without their constant support, this project would not have been possible.

Ames Research Center
National Aeronautics and Space Administration
Moffett Field, Calif. 94035, September 26, 1982

BIBLIOGRAPHY

General

California Department of Forestry. 1980. California's Forest Resources Preliminary Assessment. Sacramento, California.

ESL, Inc. 1979. IDIMS User's Guide, Sunnyvale, California.

Institute for Advanced Computation. 1978. EDITOR Users Handbook. Mountain View, California.

Moesner, Karl. Preliminary Aerial Volume Tables for Pinyon-Juniper Stands. Intermountain Forest Range Experiment Station, U.S. Forest Service, Ogden, Utah.

Ryan, T., B. Joiner, B. Ryan. 1975. Minitab II Reference Manual. Pennsylvania State University. University Park, Pennsylvania.

State of Nevada. 1979. Assembly Bill 413 of 1979 Session.

Strahler, A. H., J. H. Estes, P. F. Maynard, F. D. Mertz, and D. A. Stow. 1980. Incorporating Collateral Data in Landsat Classification and Modelling Procedures, Proceedings of the 14th International Symposium on Remote Sensing of Environment, San Jose, Costa Rica.

U.S. Geological Survey. 1979. Landsat Data User's Manual. Arlington, Virginia.

References

Heller, Robert C.: Evaluation of ERTS-1 Data for Forest and Rangeland Surveys. USDA Forest Serv. Res. Paper PSW-112, Pacific Southwest Forest and Range Exp. Sta., Berkeley, Calif., 1975, 67 p.

Fleming, M. D.; and Hoffer, R. M.: Machine Processing of Landsat MSS Data and DMA Topographic Data for Forest Cover Type Mapping. Proceedings, ±979 Machine Processing of Remotely Sensed Data Symposium, LARS/Purdue University, West Lafayette, Indiana, 1979.

Caydos, Leonard; and Newland, Willard: Inventory of Land Use and Land Cover of the Puget Sound Region Using Landsat Digital Data. USGS Journal of Research, vol. 6, no. 6, 1978, pp. 807-814.

TABLE 1.- LAND COVER FOR SPECTRAL CLASSES USED IN FINAL CLASSIFICATION

Carson Valley		Pine Nut Range		Sierra Nevada Range	
Spectral class	Cover	Spectral class	Cover	Spectral class	Cover
1	1 Water	40	7 PJ +75%	83	1 Water
2	15 Riparian	41	7 PJ +75%	84	3 Jeffrey pine +50%
3	18 Dense sage	42	7 PJ + 75%	85	3 Jeffrey pine +50%
4	21 Sparse sage	43	9 PJ 30-50%	86	5 Jeffrey pine less than 30%
5	17 Agriculture	44	10 S. PJ less than 30%	87	6 Pine/fir +50%
6	14 Hardwood/cottonwood	45	8 PJ 50-75%	88	6 Pine/fir +50%
7	14 Hardwood/cottonwood	46	9 PJ 30-50%	89	6 Pine/fir +50%
8	17 Agriculture	47	9 PJ 30-50%	90	22 Manzanita/sage mix
9	12 Cured grass	48	10 PJ less than 30%	91	22 Manzanita/sage mix
10	12 Cured grass	49	26 Mt. mahogany	92	16 Aspen
11	12 Cured grass	50	16 Aspen	93	5 Jeffrey pine less than 30%
12	17 Agriculture	51	16 Aspen	94	16 Aspen
13	17 Agriculture	52	8 PJ 50-75%	95	2 Barren
14	17 Agriculture	53	26 Mt. mahogany	96	5 Jeffrey pine less than 30%
15	21 Sparse sage	54	7 PJ + 75%	97	11 Lush grass
16	17 Agriculture	55	2 Barren	98	16 Aspen
17	17 Agriculture	56	26 Mt. mahogany	99	22 Manzanita/sage mix
18	12 Cured grass	57	16 Aspen	100	22 Manzanita/sage mix
19	12 Cured grass	58	16 Aspen	101	5 Jeffrey pine less than 30%
20	19 Medium density sage	59	26 Mt. mahogany	102	5 Jeffrey pine less than 30%
21	12 Cured grass	60	10 S. PJ less than 30%	103	11 Lush grass
22	12 Cured grass	61	26 Mt. mahogany	104	22 Manzanita/sage mix
23	17 Agriculture	62	12 Cured grass	105	22 Manzanita/sage mix
24	20 Bitterbrush/sage	63	17 Agriculture	106	22 Manzanita/sage mix
25	19 Medium density sage	64	12 Cured grass	107	2 Barren
26	2 Barren	65	12 Cured grass	108	5 Jeffrey pine less than 30%
27	2 Barren	66	2 Barren	109	25 Sparse brush
28	21 Sparse sage	67	2 Barren	110	24 Sage/manzanita mix
29	21 Sparse sage	68	8 PJ 50-75%	111	22 Manzanita/sage mix
30	15 Riparian	69	9 PJ 30-50%	112	23 Manzanita Bitterbrush mix
31	15 Riparian	70	9 PJ 30-50%	113	25 Sparse brush
32	20 Bitterbrush/sage	71	9 PJ 30-50%	114	4 Jeffrey pine 30-50%
33	19 Medium density sage	72	10 S. PJ less than 30%	115	4 Jeffrey pine 30-50%
34	21 Sparse sage	73	8 PJ 50-75%	116	4 Jeffrey pine 30-50%

TABLE 1.- CONTINUED

Carson Valley		Pine Nut Range		Sierra Nevada Range	
Spectral class	Cover	Spectral clsss	Cover	Spectral class	Cover
35	21 Sparse sage	74	9 PJ 30-50%	117	2 Barren
36	15 Riparian	75	10 S. PJ less than 30%	118	21 Sparse sage
37	20 Bitterbrush/sage	76	18 Dense sage	119	5 Jeffrey pine less than 30%
38	21 Sparse sage	77	18 Dense sage	120	22 Manzanita/sage mix
39	19 Medium density sage	78	21 Sparse sage	121	25 Sparse brush
		79	21 Sparse sage		
		80	10 S. PJ less than 30%		
		81	21 Sparse sage		
		82	1 Water		

TABLE 1.- CONCLUDED
NEVADA GROUPED CATEGORIES AND COLOR CODE

Group category number	Color	Title	Supervised classification category numbers
0	black	Background	0
1	dark blue	Water	1,82,83
2	white	Barren	26,27,55,66,67,107,117
3	dark green	JP + 50%	84,85
4	green	JP 30-50%	114,115,116
5	light green	JP less than 30%	86,93,96,101,102,108,119
6	olive	Pine/fir + 50%	87,88,89
7	dark green	PJ +75%	40,41,42,54
8	olive	PJ 50-75%	45,52,68,73
9	green	PJ 30-50%	43,46,47,69,70,74
10	color 1 (orange)	PJ less than 30%	44,48,68,72,75,80
11	color 5 (maroon)	Lush grass	97,103
12	pink	Cured grass	9,10,11,18,19,21,22,62,64,65
13	no color	Unused class	None
14	color 6 (red)	Hardwood/cottonwood	6,7
15	red	Riparian	2,30,31,36
16	light red	Aspen	50,51,57,58,92,94,98
17	yellow	Agriculture	5,8,12,13,14,16,17,23,63
18	aqua	Dense sage	3,76,77
19	brown	Medium sage	20,25,33,39
20	peach	Bitterbrush/sage	24,32,37
21	sand	Sparse sage	4,15,28,29,34,35,38,78,78,81,118
22	orange	Manzanita/sage mix	90,91,99,100,104,105,106,111,120
23	medium blue	Manzanita/ bitterbrush	112
24	tan	Sage/manzanita mix	110
25	blue-green	Sparse brush	109,113,121
26	violet	Mountain mahogany	49,53,56,59,61

TABLE 2.- MECHANICAL OPERATIONS MODEL

Percent slope	Mechanical operations
0 - 9	Excellent for wheeled vehicle operations
10 - 19	Marginal operations for wheeled vehicles
20 - 29	Good catepillar operations. Poor for wheeled vehicles.
30 - 39	Marginal catepillar operations — fire line construction
40 +	No mechanical operations

TABLE 3.- BIG GAME HABITAT MODEL

Habitat ranking	Vegetation type
Excellent	Bitterbrush/sage, manzanita/bitterbrush
Good	Lush grass, hardwood/cottonwood, riparian, dense sage
Moderate	Cured grass, agriculture, medium density sage, manzanita/sage mix, sage/manzanita mix
Poor	Jeffrey pine less than 30% crown closure, pinyon/juniper less than 50% crown closure, aspen, sparse brush, mountain mahogany
Poor/none	All other cover types

TABLE 4.- HARVESTABILITY MODEL

Percent slope	Forest vegetation I	II	III	IV
0 - 9	Excellent	Excellent	Good	Good
10 - 19	Excellent	Good	Marginal	Marginal
20 - 29	Good	Good	Unharvestable	Unharvestable
30 - 39	Good	Marginal	Unharvestable	Unharvestable
40 +	Marginal	Unharvestable	Unharvestable	Unharvestable

I - Pine/fir greater than 50% crown closure
Jeffrey pine greater than 50% crown closure

II - Pinyon/juniper greater than 50% crown closure
Jeffrey pine 30%-50% crown closure

III - Pinyon/juniper 30%-50% crown closure
Jeffrey pine less than 30% crown closure

IV - Pinyon/juniper less than 30% crown closure

TABLE 5.- FIRE HAZARD MODEL

Percent slope	Vegetation I	II	III	IV	V
0 - 9	Low	Low	Moderate	Moderate	Moderate
10 - 19	Low	Moderate	High	High	Very high
20 - 29	Moderate	High	High	Very high	Extreme
30 - 39	Moderate	High	Very high	Extreme	Extreme
40 +	Moderate	Very high	Extreme	Extreme	Extreme

I - Agriculture, riparian, lush grass

II - Sparse brush, sparse sage, sparse grass, hardwood/cottonwood, aspen

III - Jeffrey pine less than 30% crown closure, pinyon/juniper less than 30% crown closure, cured grass, medium density sage, bitterbrush/sage, manzanita/sage, manzanita/bitterbrush, sage/manzanita, mountain mahogany

IV - Jeffrey pine 30%-50% crown closure, pinyon/juniper 30%-50% crown closure, dense sage

V - Jeffrey pine 30%-50% crown closure, pine/fire greater than 50% crown closure, pinyon/juniper greater than 50% crown closure

TABLE 6.- CLASSIFICATION OF VEGETATIVE COVER TYPES, CARSON CITY COUNTY, NEVADA

Vegetation type classified	Acres classified
Water	31
Barren	1,926
Jeffrey pine plus 50% crown closure	1,926
Jeffrey pine 30-50% crown closure	378
Jeffrey pine less than 30%	6,456
Pine/fir mix plus 50% crown closure	3,966
Pinyon/juniper plus 75% crown closure	2,074
Pinyon/juniper 50-75% crown closure	4,950
Pinyon/juniper 30-50% crown closure	14,376
Pinyon/juniper less than 30% crown closure	8,603
Lush grass	297
Cured grass	2,699
Hardwood/cottonwood	32
Riparian	1,828
Aspen	1,119
Agriculture	1,046
Dense sage	2,484
Moderate density sage	11,712
Bitterbrush/sage mix	7,374
Sparse sage/low sage	15,186
Manzanita/bitterbrush/sage	151
Sage/manzanita	694
Sparse brush	1,001
Mountain mahogany	25
Manzanita/sage	3,268
	97,216

TABLE 7.- CLASSIFICATION OF VEGETATIVE COVER TYPES, DOUGLAS COUNTY, NEVADA

Vegetation type classified	Acres classified
Water	334
Barren	3,893
Jeffrey pine plus 50% crown closure	7,282
Jeffrey pine 30-50% crown closure	2,290
Jeffrey pine less than 30%	14,703
Pine/fir mix plus 50% crown closure	14,033
Pinyon/juniper plus 75% crown closure	25,717
Pinyon/juniper 50-75% crown closure	45,359
Pinyon/juniper 30-50% crown closure	63,228
Pinyon/juniper less than 30% crown closure	40,250
Lush grass	847
Cured grass	26,502
Hardwood/cottonwood	639
Riparian	11,026
Aspen	1,767
Agriculture	21,941
Dense sage	14,055
Moderate density sage	42,968
Bitterbrush/sage mix	17,365
Sparse sage/low sage	103,766
Manzanita/bitterbrush/sage	424
Sage/manzanita	1,877
Sparse brush	4,698
Mountain mahogany	3,122
Manzanita/sage	7,549
	475,636

TABLE 8(a).- PINYON/JUNIPER FOREST TYPE CLASSES FOR BOTH COUNTIES COVERING THE PINE NUT RANGE

Vegetation type classified	Acres classified
Pinyon/juniper plus 75% crown closure	27,791
Pinyon/juniper 50-75% crown closure	50,309
Pinyon/juniper 30-50% crown closure	77,604
Pinyon/juniper less than 30%	48,853
	204,557

TABLE 8(b).- JEFFREY PINE FOREST TYPE CLASSES FOR BOTH COUNTIES COVERING THE SIERRA NEVADA RANGE

Vegetation type classified	Acres classified
Jeffrey pine plus 50% crown closure	9,208
Jeffrey pine 30-50% crown closure	2,668
Jeffrey pine less than 30%	21,159
	33,035
Jeffrey pine/fir mix plus 50%	17,999
	51,034

TABLE 9.- SUMMARY OF ACRES FOR MECHANICAL OPERATIONS FOR DOUGLAS COUNTY PER OWNERSHIP CLASS: DATA BASED ON PERCENT SLOPE PER OWNERSHIP CLASS

Vehicle operating code	Ownership class					
	BLM	BIA	County	USFS	State	Private
A	73,942	26,258	1,820	15,920	335	110,427
B	31,376	13,464	127	13,651	192	15,466
C	9,702	3,666	70	4,310	71	3,948
D	9,074	3,419	20	3,777	58	3,376
E	45,910	11,136	66	19,687	272	15,572

A = Excellent wheeled vehicle operations
B = Marginal for wheeled vehicle operations
C = Good bulldozer operations/poor for wheeled vehicles
D = Marginal bulldozer operations - fire line construction
E = No mechanical operations

TABLE 10.- SUMMARY OF ACRES PER OWNERSHIP CLASS FOR VEHICLE OPERATIONS IN CARSON CITY COUNTY, NEVADA; DATA BASED ON PERCENT SLOPE PER OWNERSHIP CLASS

Vehicle operating code	Ownership class					
	BLM	BIA	County	USFS	State	Private
A	15,643	1,800	312	1,336	1,881	19,369
B	10,140	879	221	1,164	332	3,978
C	3,319	340	188	674	298	1,290
D	2,405	211	224	724	264	1,224
E	8,101	445	1,498	4,551	1,193	4,843

A = Excellent wheeled vehicle operations
B = Marginal for wheeled vehicle operations
C = Good bulldozer operations/poor for wheeled vehicles
D = Marginal bulldozer operations - fire line construction
E = No mechanical operations

TABLE 11.- BIG GAME HABITAT STATISTICS FOR DOUGLAS COUNTY, NEVADA
Acres per ownership class

Habitat class	Ownership class					
	BLM	BIA	County	USFS	State	Private
Excellent	5,622	1,390	151	1,068	13	8,112
Good	13,845	2,583	89	1,992	3	5,913
Moderate	18,837	4,808	872	4,629	142	63,263
Marginal	53,157	24,104	113	19,746	267	19,833
Poor	78,326	24,971	873	29,807	492	51,138

TABLE 12.- BIG GAME HABITAT BY OWNERSHIP CLASS (IN ACRES) FOR CARSON CITY COUNTY, NEVADA

Habitat class	Ownership class					
	BLM	BIA	County	USFS	State	Private
Excellent	1,959	107	134	67	309	4,549
Good	2,030	85	123	143	309	1,922
Moderate	4,624	359	662	1,507	1,211	10,029
Marginal	18,666	1,958	1,234	3,028	802	4,239
Poor	12,257	1,156	283	3,676	1,527	9,905

TABLE 13.- FIRE HAZARD ACREAGES FOR DOUGLAS COUNTY

Fire hazard class	Ownership class					
	BLM	BIA	County	USFS	State	Private
Low	36,497	4,990	900	2,802	52	55,990
Moderate	56,915	24,868	979	17,214	354	61,255
High	28,094	8,930	77	9,364	218	21,090
Very high	17,125	8,877	66	10,455	125	8,254
Extreme	31,374	10,278	81	17,510	180	10,299

TABLE 14.- FIRE HAZARD ACREAGES FOR CARSON CITY COUNTY

Fire hazard class	Ownership class					
	BLM	BIA	County	USFS	State	Private
Low	3,251	163	120	182	366	8,761
Moderate	15,996	1,789	421	1,695	1,857	12,954
High	11,202	838	753	1,775	639	5,350
Very high	4,725	508	533	1,600	368	11,680
Extreme	4,435	375	615	3,197	926	1,958

TABLE 15.- FOREST HARVESTABILITY ACREAGES FOR DOUGLAS COUNTY

Forest harvestability class	Ownership class					
	BLM	BIA	County	USFS	State	Private
Excellent	5,706	6,974	138	10,566	206	6,463
Good	30,404	21,651	93	15,564	186	12,579
Marginal	13,623	7,313	29	8,347	128	5,478
Unharvestable	25,467	7,355	52	9,089	69	6,734

TABLE 16.- FOREST HARVESTABILITY ACREAGES FOR CARSON CITY COUNTY

Forest harvestability class	Ownership class					
	BLM	BIA	County	USFS	State	Private
Excellent	2,273	456	29	1,538	637	614
Good	10,692	1,366	192	1,462	641	1,578
Marginal	4,998	515	147	1,046	305	824
Poor	6,006	486	691	1,816	378	688

TABLE 17.- VERIFICATION TABULATION

Case	R^2 value, %	R value	N
Barren	1.6[a]	0.127	10
Jeffrey pine 50%+ crown closure	91.7	.958	14
Jeffrey pine 30-50% crown closure	83.7	.915	10
Jeffrey pine <30% crown closure	97.0	.985	18
Pine/fir 50%+ crown closure	92.1	.960	14
Pinyon/juniper 75%+ crown closure	95.2	.976	24
Pinyon/juniper 50-75% crown closure	96.5	.982	31
Pinyon/juniper 30-50% crown closure	91.4	.956	36
Pinyon/juniper <30% crown closure	95.1	.975	26
Lush grass	78.6	.887	4
Cured grass	81.8	.904	14
Hardwood/cottonwood	25.0[a]	.500	3
Riparian	73.9	.860	14
Aspen	26.1[a]	.511	10
Agriculture	73.8	.859	12
Dense big sage	96.7	.983	24
Moderate density big sage	73.5	.857	33
Bitterbrush/sage	90.8	.953	25
Sparse low sage	67.8	.823	50
Manzanita/sage	83.8	.915	16
Manzanita/bitterbrush/sage			2
Sage/manzanita	81.6	.903	7
Sparse brush	91.6	.957	9
Mountain mahogany	99.4	.997	5
Water			2

[a]Not significant at the 5% level.

TABLE 18.- TASK COMPLETION TIMES

Task	Time expended
Preprocessing Landsat image	2 weeks
Developing polynomial surface	1 week
Unsupervised clustering and classification	2 months[a]
Supervised clustering and classification field work	1 week[b]
Cluster analysis and mapping	5 months[c]
Cluster pooling and analysis	1 week
Classification assessment	1 week[d]
Final classification	~2 weeks[d]
Generation of slope image and correct errors	4 days

[a]Concurrent with field work for supervised classification and parts of the training task.

[b]As many as eight field workers were employed.

[c]Dependent upon staff availability.

[d]Three analysts.

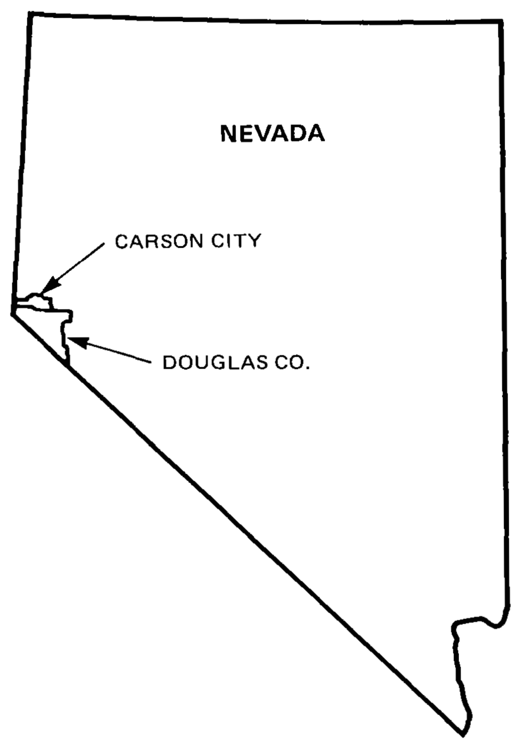

Figure 1.- Study area.

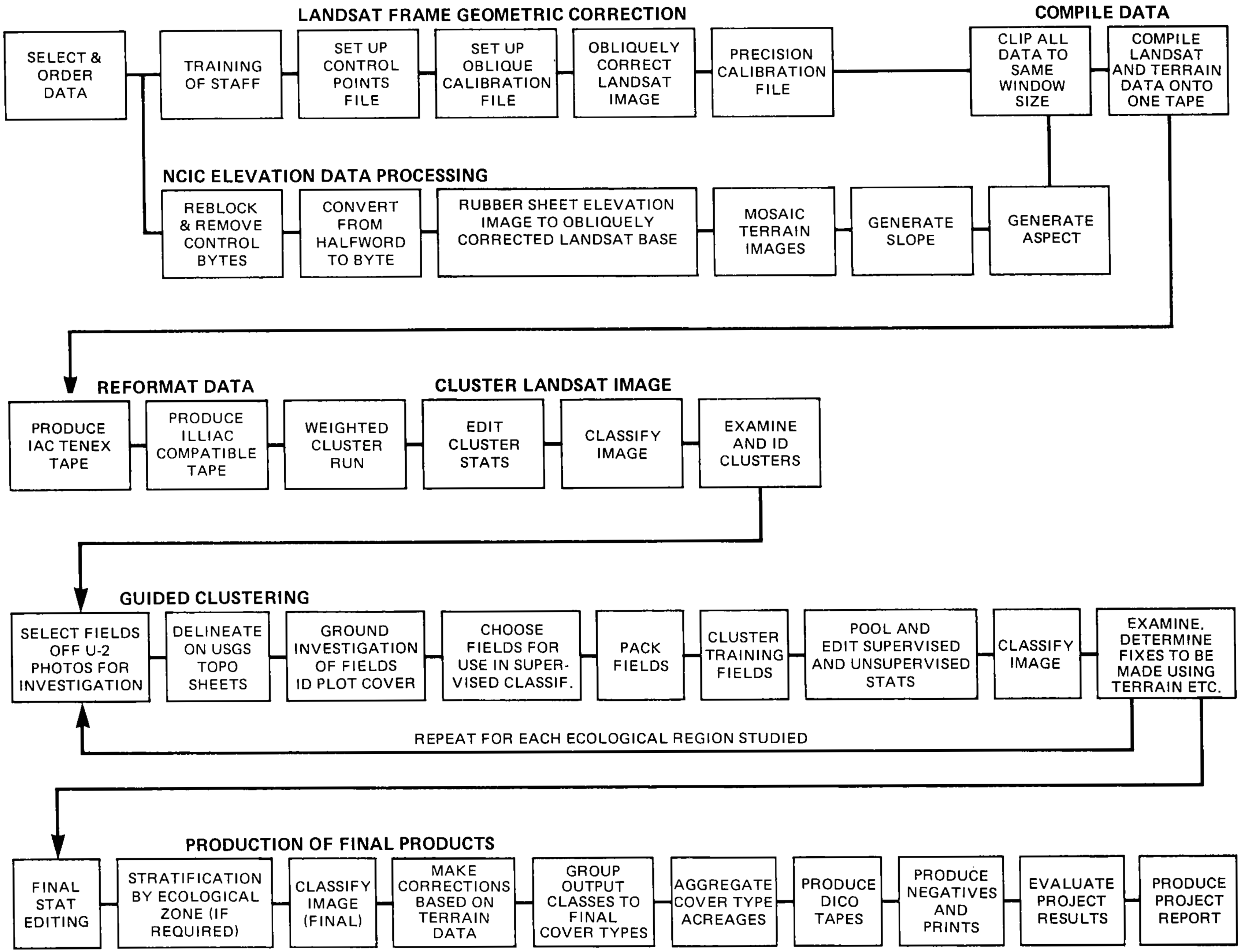

Figure 2.- Nevada Project flow chart.

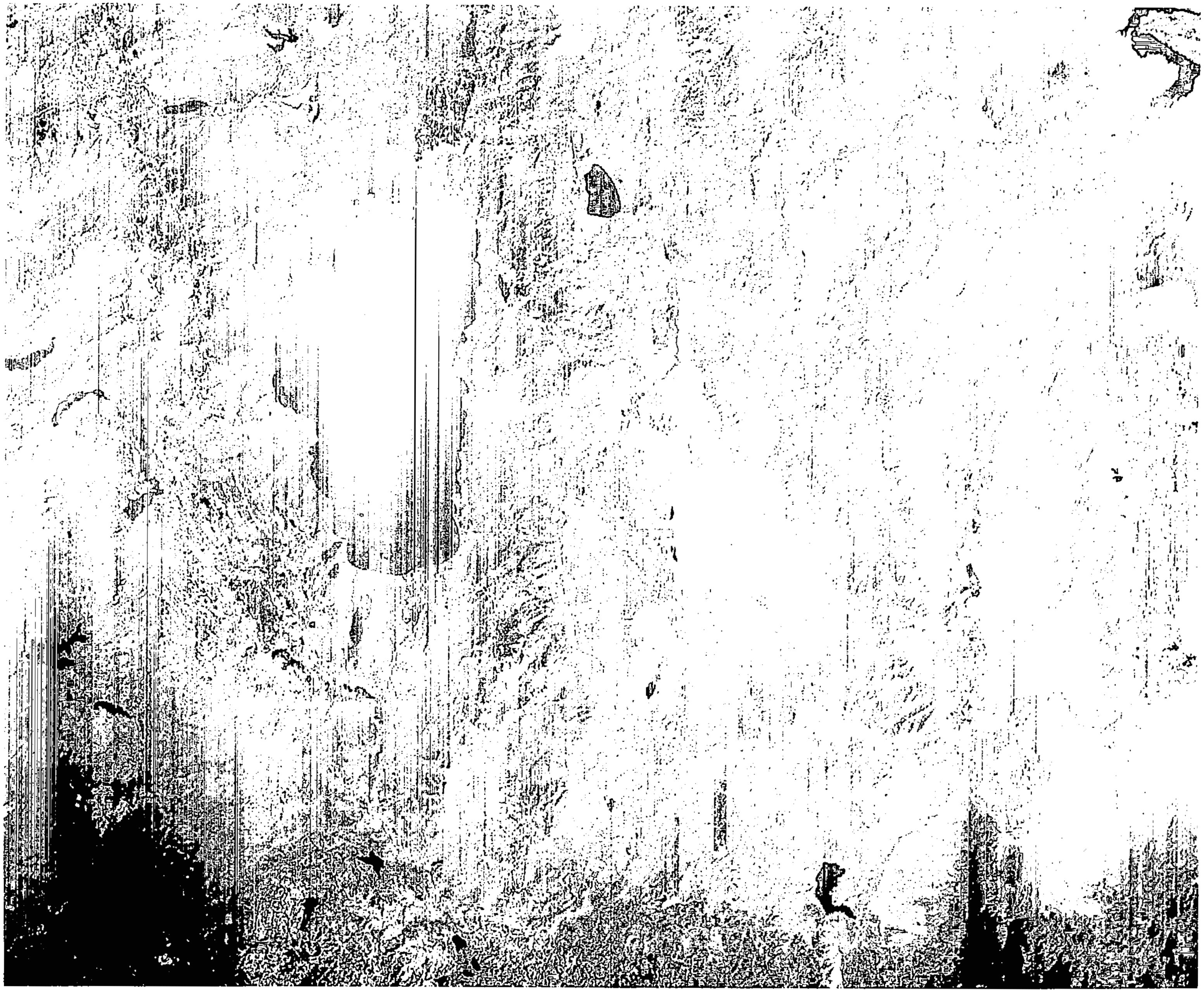

Figure 3.- False color composite of Nevada study area.

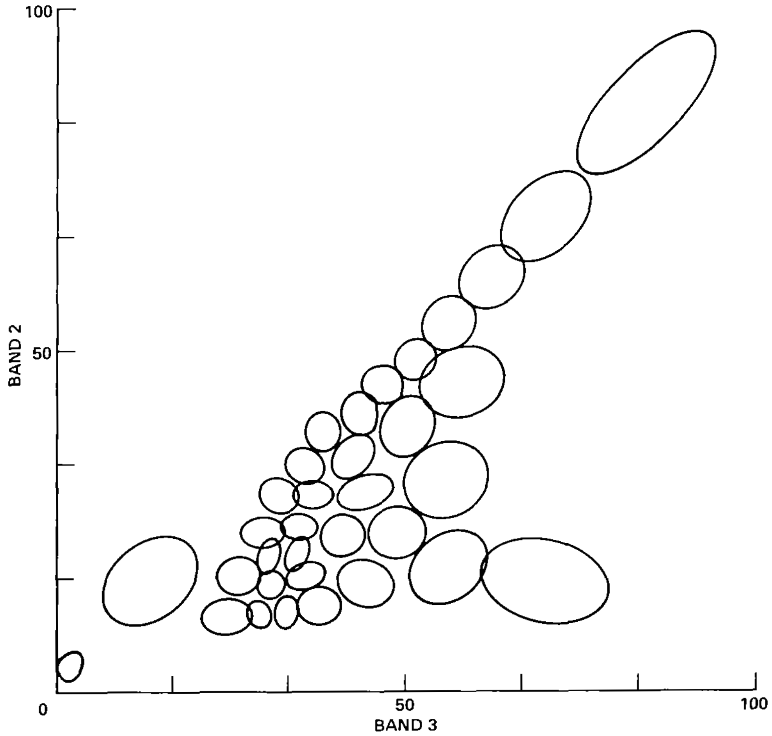

Figure 4.- Plot of 35 class unsupervised statistics.

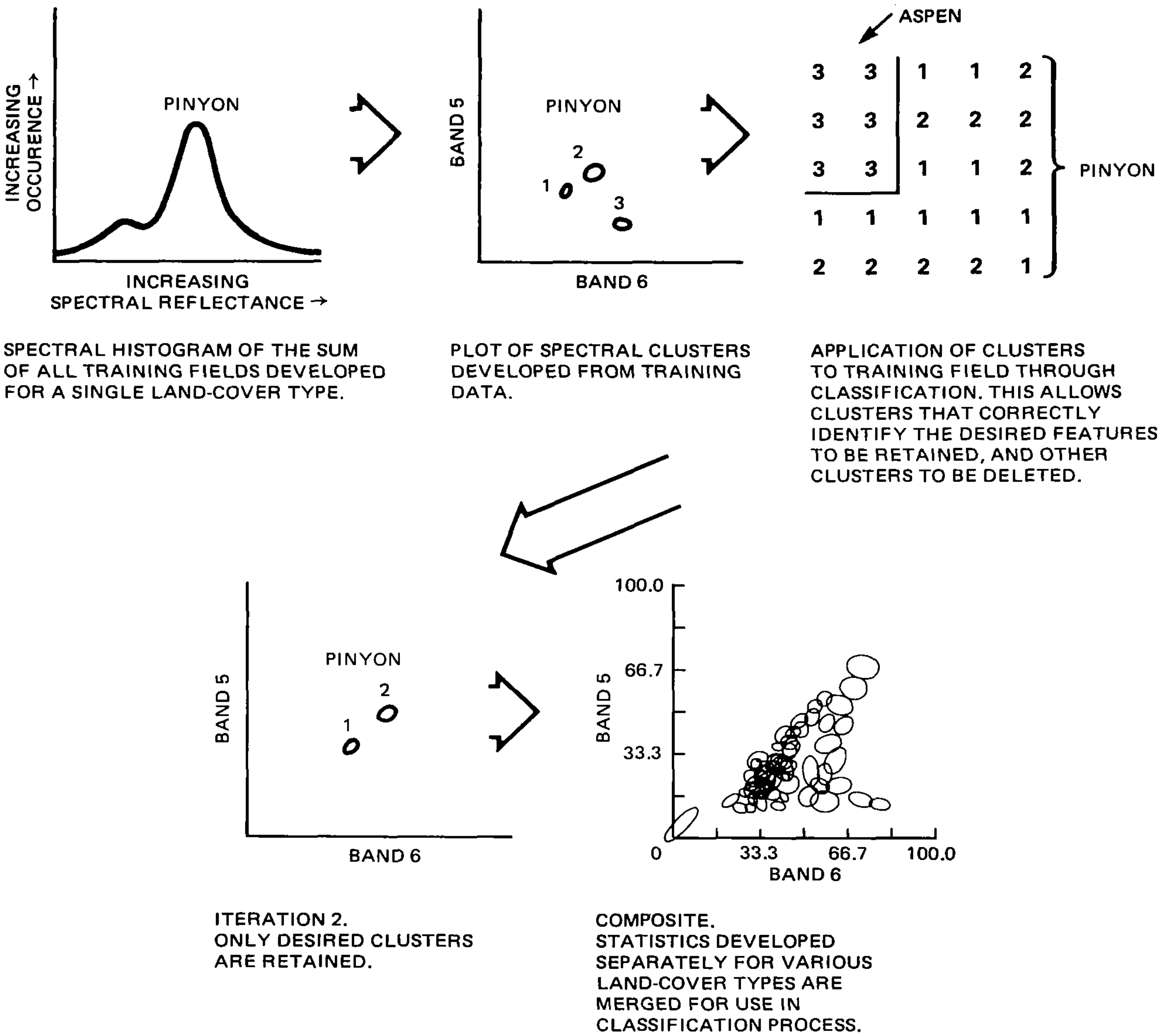

Figure 5.- Reiterative clustering process.

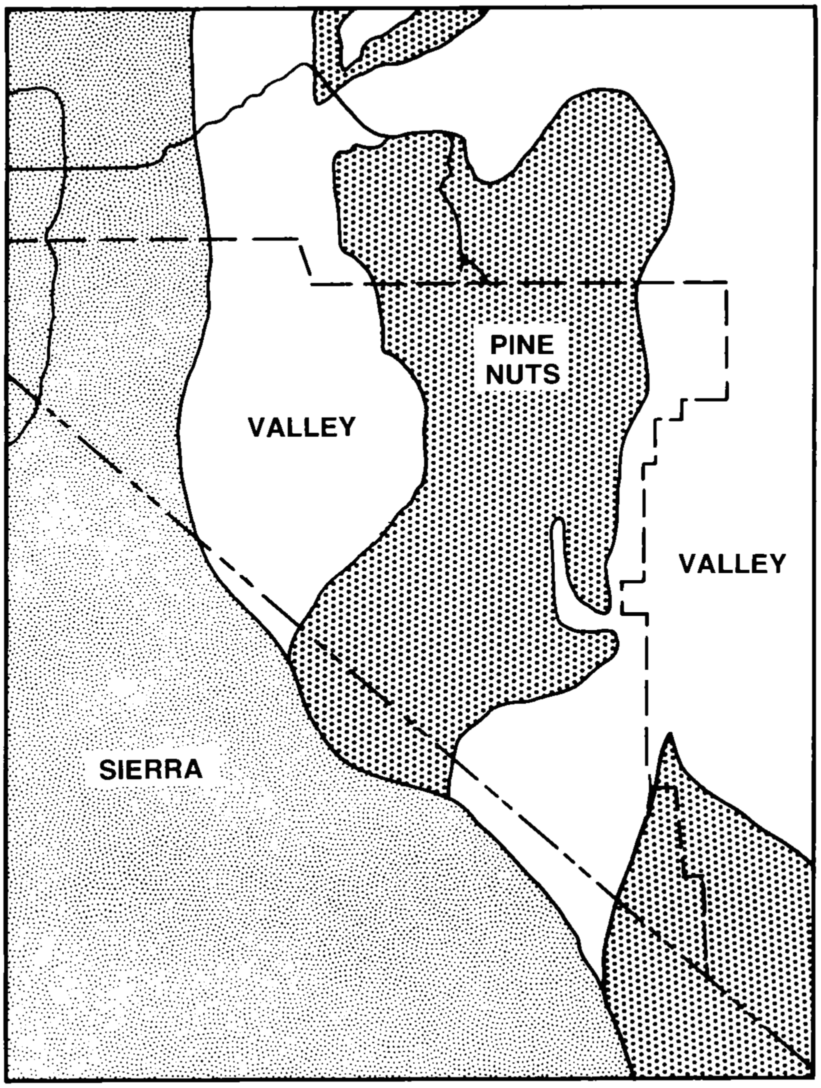

Figure 6.- Ecozone map of study area.

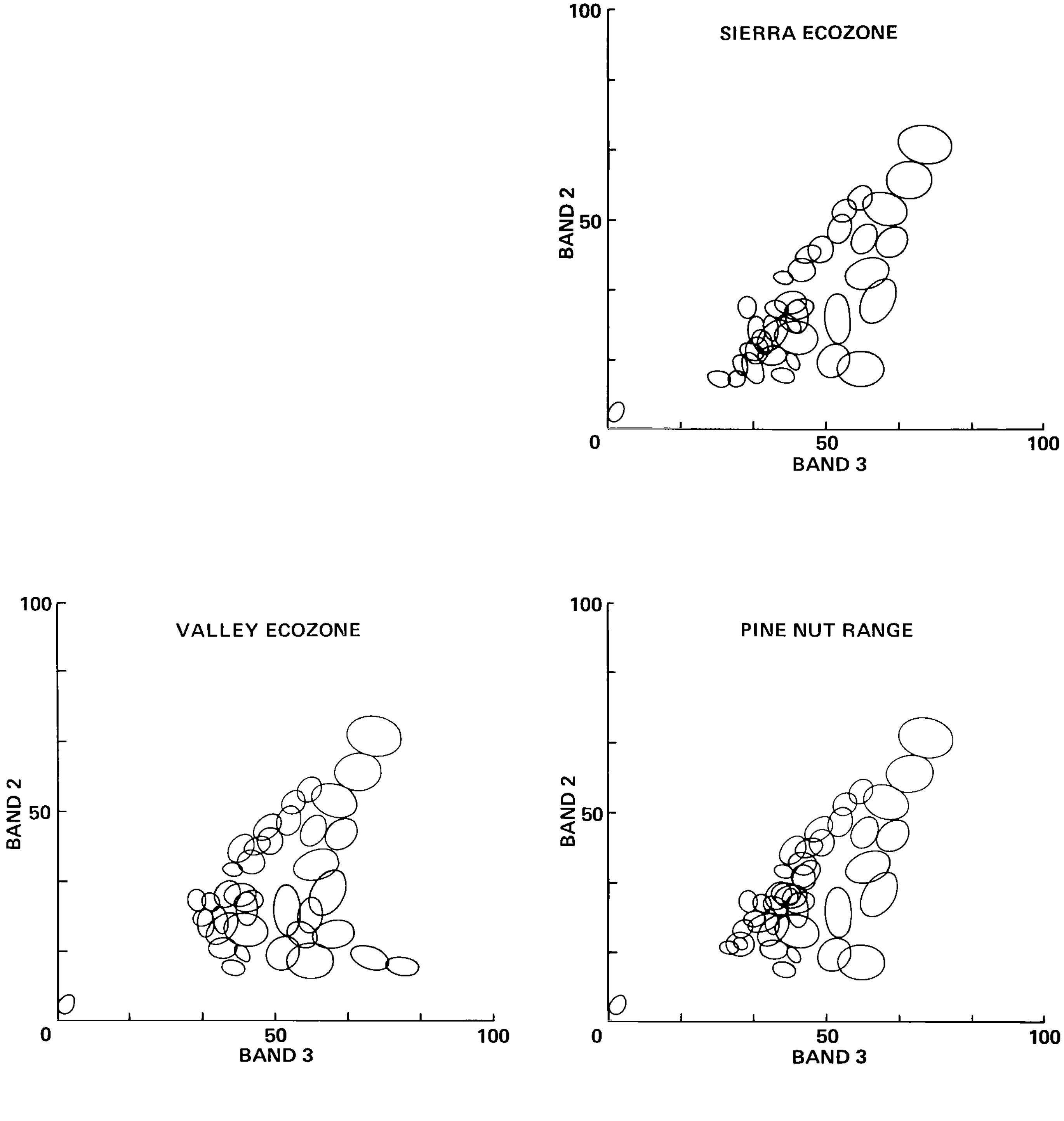

Figure 7.- Ecozone spectral cluster statistics plots.

Figure 8.- Nevada land cover map.

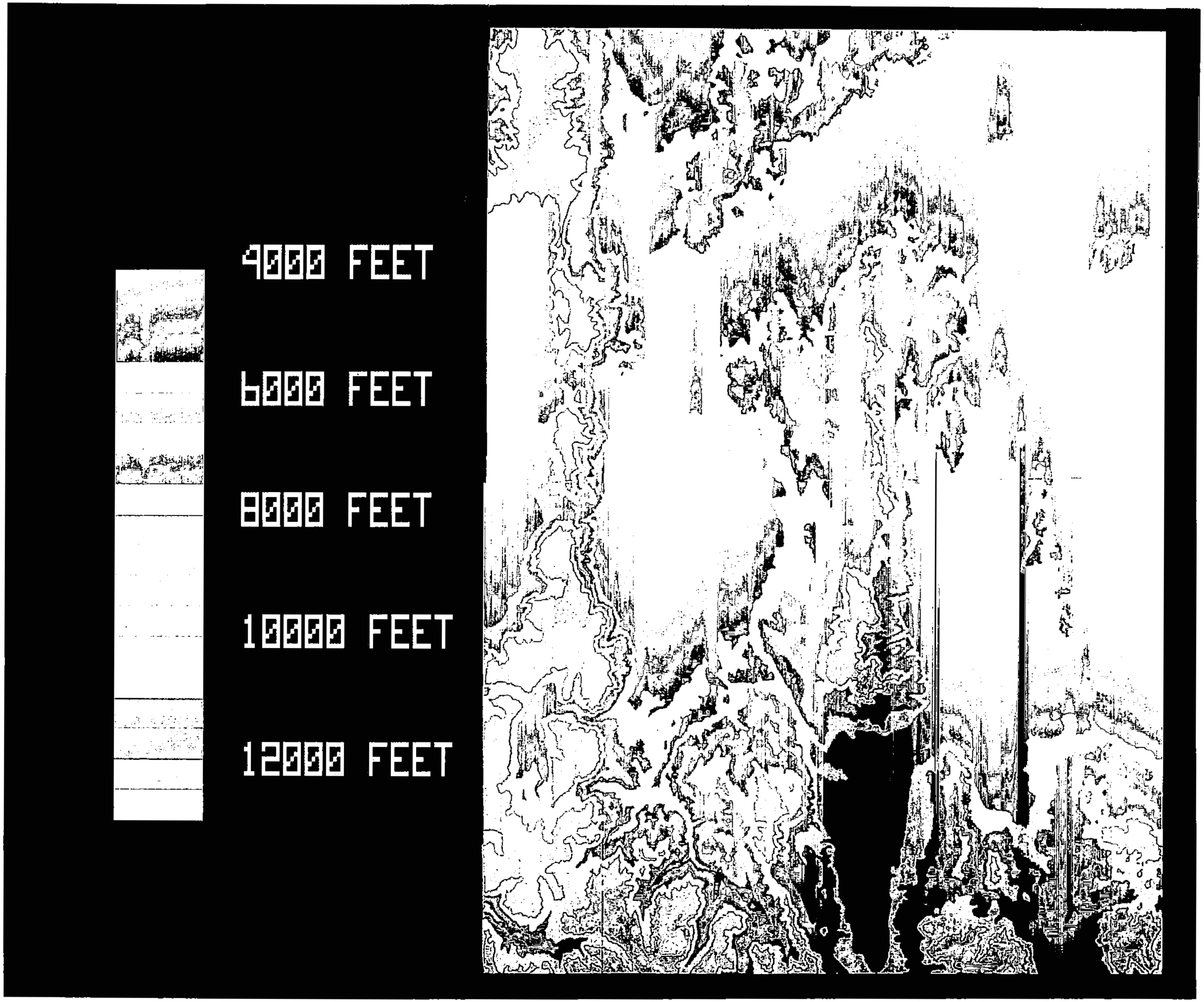

Figure 9.- Elevation map of Nevada study area.

Figure 10.- Ownership map of Douglas and Carson City Counties.

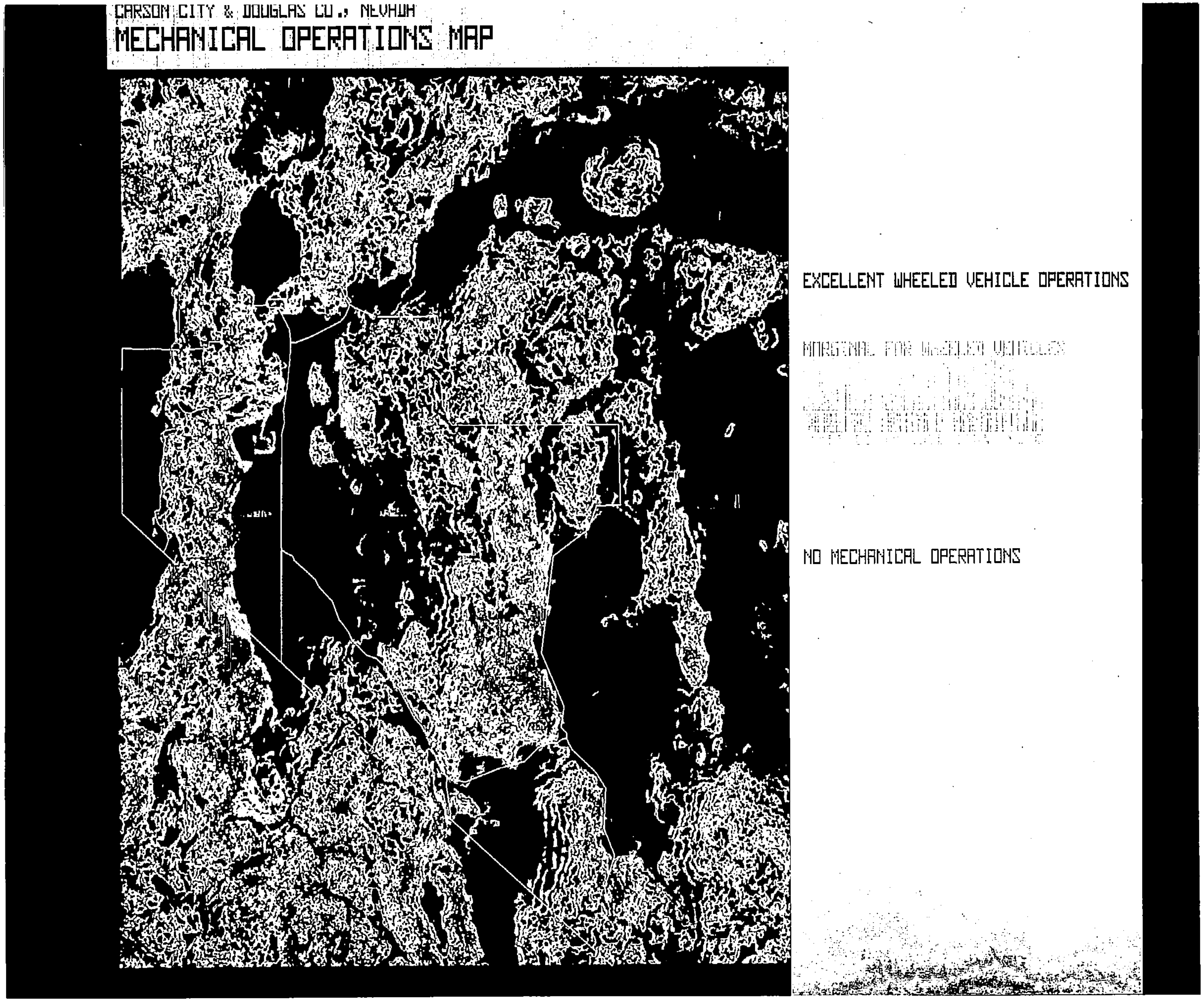

Figure 11.- Nevada mechanical operations map.

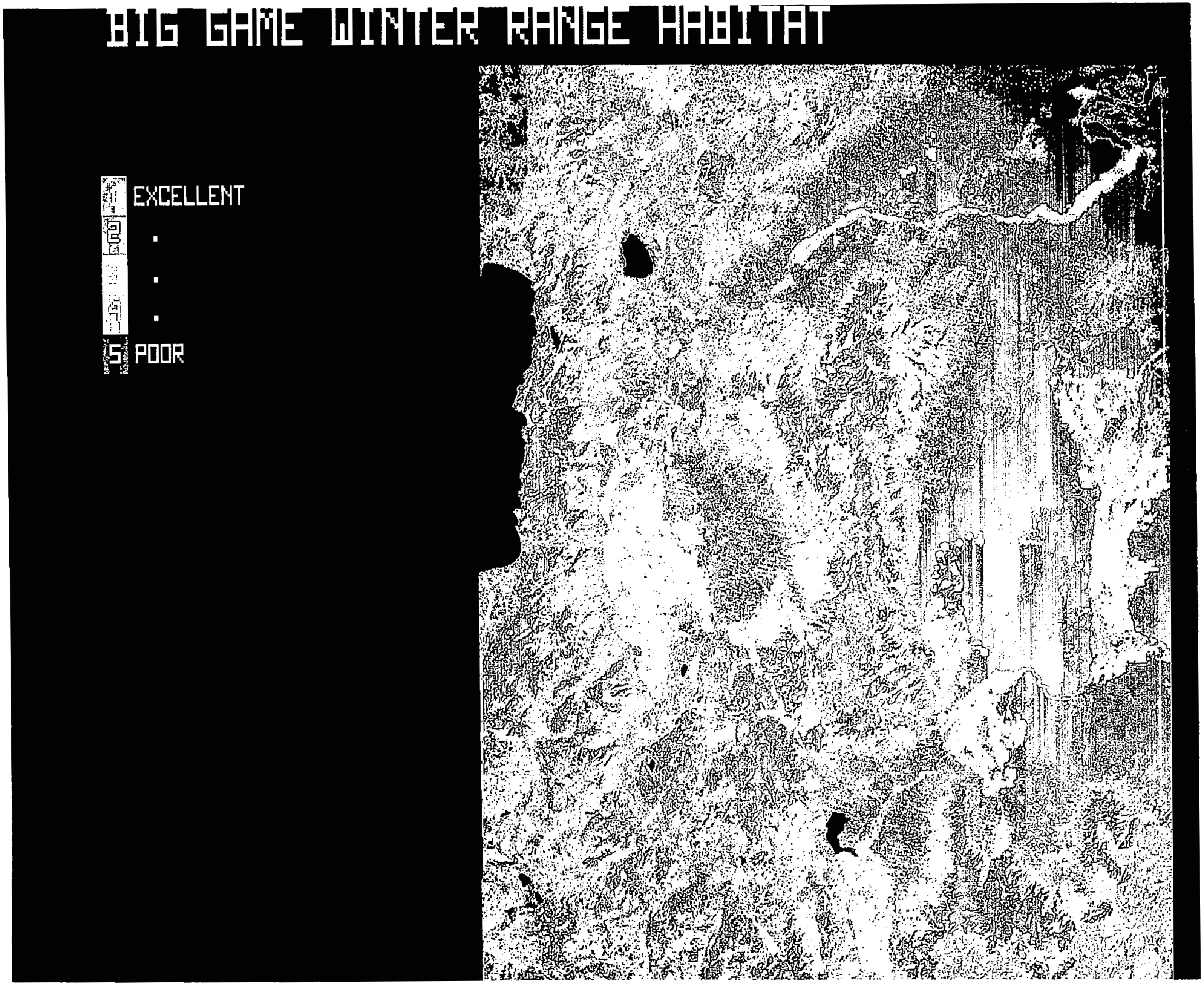

Figure 12.- Mule deer winter forage map of Nevada study area.

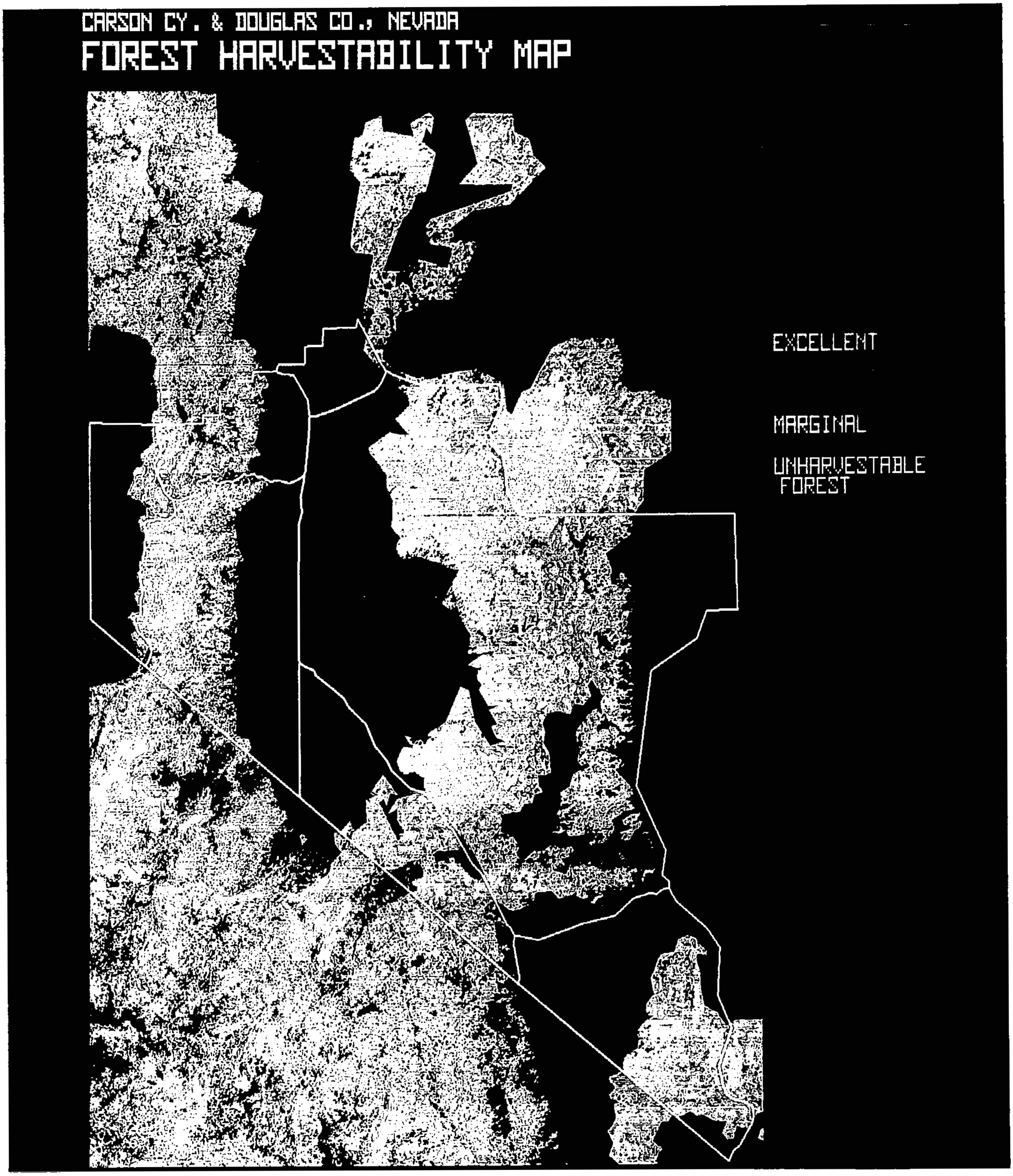

Figure 13.- Nevada study area harvestability map.

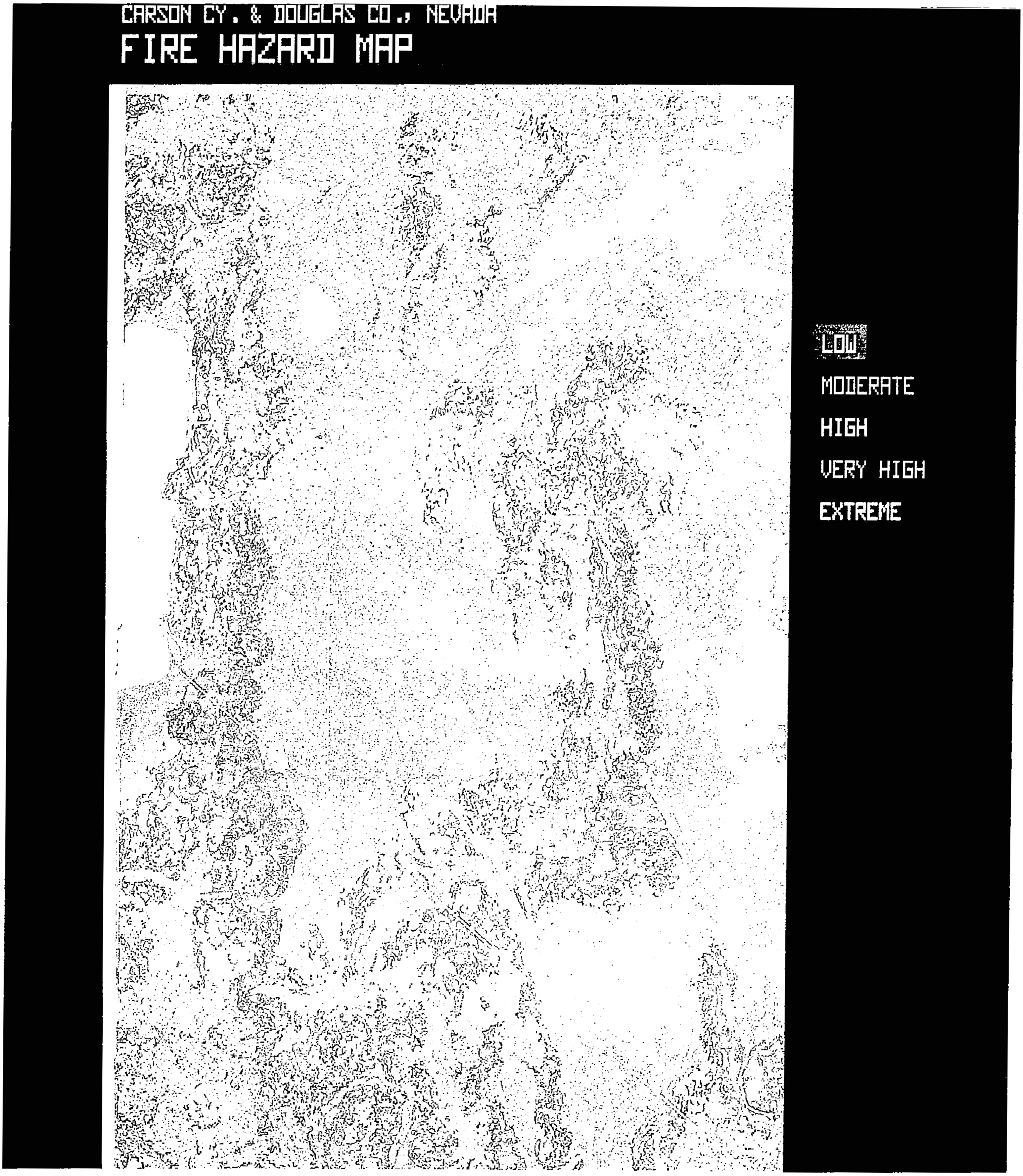

Figure 14.- Fire hazard map of Nevada study area.

1. Report No. NASA TP-2137	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle WILDLAND INVENTORY AND RESOURCE MODELING FOR DOUGLAS AND CARSON CITY COUNTIES, NEVADA, USING LANDSAT AND DIGITAL TERRAIN DATA		5. Report Date March 1983 6. Performing Organization Code
7. Author(s) James A. Brass, William C. Likens, and R. Ronan Thornhill*		8. Performing Organization Report No. A-8997
9. Performing Organization Name and Address NASA Ames Research Center Moffett Field, Calif. 94035 *Nevada Division of Forestry, Carson City, Nevada		10. Work Unit No. T-5918 11. Contract or Grant No.
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546		13. Type of Report and Period Covered Technical Paper 14. Sponsoring Agency Code 663-80-02

15. Supplementary Notes

Point of Contact: James A. Brass
Ames Research Center, MS 242-4, Moffett Field, CA 94035
(415) 965-5232 or FTS 448-5232

16. Abstract

This pilot forest inventory project was a joint effort of the National Aeronautics and Space Administration and the Nevada Division of Forestry, Division of State Lands, the Governor's Planning Office, and the University of Nevada-Reno. The overall goal of the project was to demonstrate the potential of using Landsat satellite imagery to map and inventory pinyon-juniper desert forest types in Douglas and Carson City Counties, Nevada. Specific map and statistical products produced include land cover, mechanical operations capability, big game winter range habitat, fire hazard, and forest harvestability. As a result of this project, the Nevada Division of Forestry has determined that Landsat can produce a reliable and low-cost resource data. Added benefits become apparent when the data are linked to a geographical information system (GIS) containing existing ownership, planning, elevation, slope, and aspect information.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Landsat Multispectral scanner Remote sensing Land cover classification Resource modeling	Unclassified - Unlimited Subject category - 43

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified	52	A03

*For sale by the National Technical Information Service, Springfield, Virginia 22161