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A REPORT OF A LANDSAT AND
COMPUTER MAPPING PROJECT

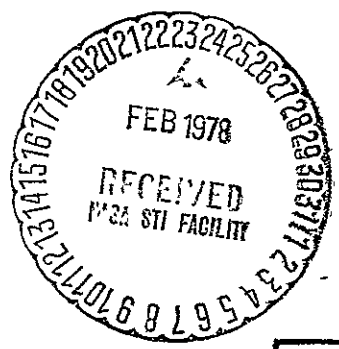
A Regional Land Use Survey

*based on remote sensing
and other data*

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Final Project Report

Prepared for:

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		12 Sponsoring Agency Name and Address Goddard Space Flight Center Greenbelt, Maryland 20771 Edmund Szajna, Technical Monitor Code 902		16 Abstract This final report describes the activities undertaken and results of a regional land use survey project in the Rocky Mountain states. The report is in three volumes: (1) an Executive Summary, (2) the Final Report, and (3) Appendices. The project mapped land use/cover classifications from LANDSAT computer compatible tape data and combined those results with other multisource data via computer mapping/compositing techniques to analyze various land-use planning/natural resource management problems. Data was analyzed on 1:24,000 scale maps at 1.1 acre resolution. New LANDSAT analysis software and linkages with other computer mapping software were developed. Significant results were also achieved in training, communication, and identification of needs for developing the LANDSAT/computer mapping technologies into operational tools for use by decision-makers. LANDSAT processing was conducted by Eugene Maxwell Colorado State University; most multisource computer mapping was handled by Richard Voge, Los Alamos Scientific Laboratory; project advisory committee was chaired by A. Keith Turner, Colorado School of Mines.	
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PREFACE

This report describes a multi-state project developed and coordinated by the Federation of Rocky Mountain States. The project developed and tested methods for combining earth resources satellite (LANDSAT) data with other multi-source data via computer mapping techniques for use in natural resources and land use planning in the Western States.

The project was carried out by mutually defined procedures in six states -- Montana, Wyoming, Colorado, New Mexico, Utah, and Arizona. Colorado State University and Los Alamos Scientific Laboratory provided technical assistance. Two interstate areas of 5,000 square miles each and two intrastate areas of 3,000 square each were delineated for all subsequent LANDSAT and high altitude remote sensing during the project. Four 7.5-minute quadrangles were selected within these large areas as test sites. LANDSAT computer-compatible tape classification mapping for 1.1 acre cells was conducted with multiple date imagery. Land use and cover categories were selected by the states, ranging from 19 categories in one state to 81 in another.

In order to place the LANDSAT application within the context of a regional data bank, various non-LANDSAT maps were collected on complementary topics. These were all converted into the 1.1 acre grid system and computer composited with the LANDSAT maps for deriving and displaying the complex patterns involved in determining feasibility for surface mining or urban development, etc. A key purpose was to demonstrate the appropriate mix of LANDSAT utilization, data banking and compositing relevant to regional planning.

The approach was designed for large areas of interspersed federal, state, and private lands, with dynamic interrelationships in mineral, water, agricultural and recreational land uses. This approach raised numerous administrative questions, such as standardization of the ground truth data analysis, standardization of land use categories/subcategories, and systematic central processing of LANDSAT tapes.

For this project, state governments designated state lead agencies to coordinate work among other state agencies. Through the lead agencies, state participation and understanding of LANDSAT use and regional data banking progressed toward more centralized operations in most participating states.

Although this was a relatively brief and modest project in this large and dynamic region, it developed several innovative procedures worthy of continuation: (1) a new LANDSAT Mapping System (LMS) for LANDSAT digital interpretations; (2) use of cellular mapping and compositing for combining the LANDSAT maps with other forms of data; (3) training new groups in each state; (4) defining the need for a ground truth manual; and (5) the need for fixed, repetitive ground truth sites for continual LANDSAT use.

This project marks the beginning of state, interstate, and federal collaboration in these techniques which should now be converted into more extensive operational systems to meet the characteristic problems of energy, agriculture, settlement, and water utilization in the West.

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1.0 INTRODUCTION

1.1 Scope

This is the Final Report of a multistate project to demonstrate the utility of satellite remote-sensed data in combination with other multi-source data as an aid to natural resources and land use planning decision-making.

This was a genuinely cooperative regional project involving the six Rocky Mountain states of Arizona, Colorado, Montana, New Mexico, Utah, and Wyoming. Colorado State University (CSU) and Los Alamos Scientific Laboratories (LASL) provided technical assistance, while the Federation¹ and its Earth Resources Technology Applications Committee of its Natural Resources Council coordinated all participants.

This effort combined LANDSAT digital data with other types of data from a variety of sources via a computer composite mapping process (see Figure 1.1). The process and results are designed to demonstrate the utility and potentials of such multisource analyses for use in solving land use and other geographic-related planning and decision-making problems.

1.2 Background

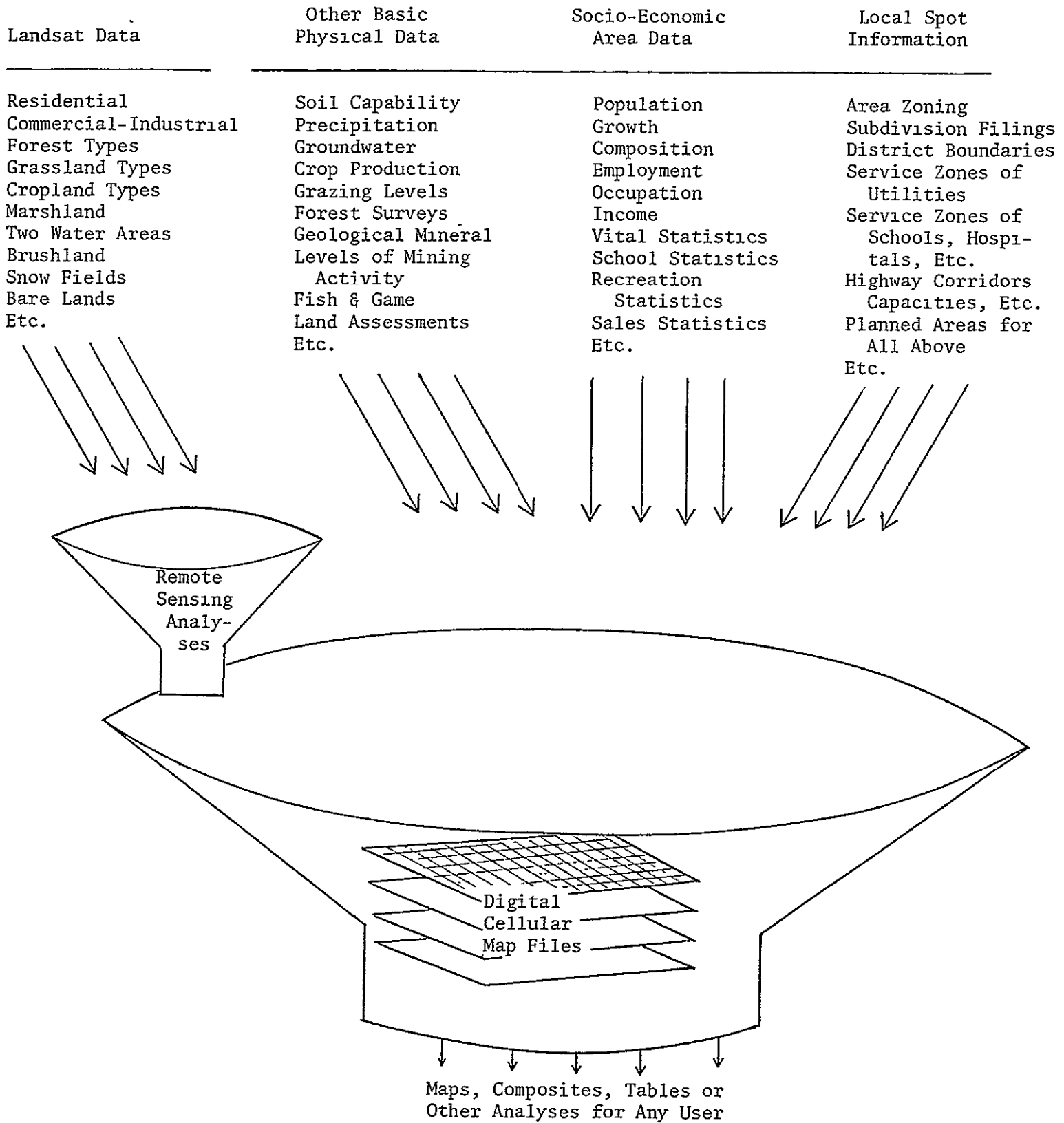
This project is closely related to and logically follows past Federation projects that developed and demonstrated the use of computers for multisource mapping and geographic analyses.² The U.S. Economic Development Administration (EDA) has sponsored continuing Federation efforts in this area.

¹The Federation of Rocky Mountain States; also, FRMS.

²See Section 7.0 -- References/Bibliography -- for a complete listing of FRMS reports on these subjects.

FIGURE 1.1

SCOPE OF A REGIONAL INFORMATION SYSTEM



The need for this type of automated data analysis (and storage) system is mounting, especially in the West. Many new and pressing demands are being made on the region's resources and way of life. Decisionmakers from all levels of government and the private sector are faced with increasingly complex problems concerning land use, resource management, environmental quality, and socioeconomic development.

Issues of energy development, urban planning, air quality, agriculture production, water allocation, and so on, are compounded because of interjurisdictional authority, mixed land ownership patterns seasonal fluctuations, and other common situations. Attention to these issues on the part of the states, the federal government, private business and regional organizations within the large Western area, has created an enormous amount of data and information that can be used to make decisions -- at both the policy and program levels. Therefore, a system that can analyze this variety of multisource data and show the implications of various decisions is highly desirable.

NASA's³ LANDSAT earth resources satellite is a new, powerful source of information that can contribute substantially to more informed decision-making. The LANDSAT is continually circling the earth, returning to the same point every 18 days. It is producing multispectral data that can provide a user with information at low cost for large areas. This information can be in the areas of geology, land cover, land use, water quality, crop conditions, etc.

This project demonstrated the repeatable LANDSAT survey procedures, together with composite mapping of all other types of data "invisible" to LANDSAT but needed for resource planning. It placed remote sensing and particularly LANDSAT digital data into its appropriate role in the overall process of producing complex surveys of agriculture, strip mining, urban development and water management, where numerous other forms of evidence in addition to LANDSAT data are needed on land ownership and leasing, industrial activity, subsurface resources, etc.

1.3 Objectives

The project was aimed at several long-term objectives of the Federation of Rocky Mountain States: (a) improved land and water use studies through systematic surveys, automated data banking and analysis; and (b) the transfer of technologies between levels of government, and especially to improve the state's capabilities to make better decision

Specific objectives were to:

- encourage interstate cooperation in the utilization of earth resources satellite technology for solving land use planning problems;

³National Aeronautics and Space Administration.

- work toward the development of compatible inter-agency, interstate information system procedures;
- test and adopt a common land use classification;
- evaluate the efficiency and applicability of using satellite data in combination with other data in a land use information system; and
- provide a mechanism for the exchange of information about remote sensing and geo-information systems.

1.4 Approach

To accomplish these objectives a series of demonstrations in each of the six participating states was initiated. A lead agency in each state worked with the Federation and the technical assistance organizations following these general tasks:

- Procurement and preparation of data for later LANDSAT data analysis, including: LANDSAT computer compatible tapes (CCT's); airplane coverage of the test sites (see Figure 3,1) and ground truth data.
- Identification and verification of land use and land cover information via statistical signature analysis of LANDSAT digital data, and field verification.
- Mapping, via computer, of the land use/cover data at a 1.1 acre resolution (cell size) and a scale of 1:24,000.
- Collection of multisource ancillary data for combination with LANDSAT data. Selection by each state of appropriate land use analysis problems and data values.
- Computer composite mapping of the LANDSAT land use/cover data with the other state-collected data to produce composite maps indicating solutions to complex land-use and energy-planning problems.
- Evaluation of the results, communications through meetings and reports and final report production and dissemination.

The Federation coordinated and managed the project and is responsible for the compilation of this project report, parts of which were written by all participants.

The Federation's Earth Resources Technology Applications Committee provided broad-based advisory services to project participants.

Each state lead agency handled ground truth, ancillary data collection and compositing aspects.

CSU conducted all LANDSAT data processing, using newly developed third-generation software programs: LANDSAT Mapping System (LMS).

LASL provided the bulk of multisource computer compositing. Utah and Montana utilized their own computer mapping programs. ;

In summary, this project is one of the most extensive geographic, interstate applications spanning a variety of test sites from a northern-border state to a southern-border state, from forest to desert, and from mining to urban development uses, with the participation of many state agencies.

1.5 Summary Recommendations

Regional Data Analysis Needs:

- Additional investments are required in designing and developing institutional mechanisms for increasing earth resources technology utilization.
- Regional data banking and analytic services should include a variety of multisource data and formats, be flexible for serving many users, and cover large areas rapidly.
- A regional earth resources technology applications center should be established in the West to provide for user awareness and education, information exchange and networking, technical assistance and capacity building, and mobilization of resources within the region.

For Centralized State Services:

- Additional information, training, and assistance should be given state agencies corresponding with their present capabilities and needs for multisource data analysis.
- Upgrading of LANDSAT products and use with other multisource data will encourage state efforts in central data use and management
- Standardized procedures for using LANDSAT, improved accuracy and low cost will also assist in developing state efforts.

For Operational Use of LANDSAT:

- Improved LANDSAT products such as computer-enhanced imagery and composites of LANDSAT with base maps or other data will provide users with more acceptable results.
- A standard training site procedures manual for use by nontechnical personnel would assist users in efficient, easy utilization of LANDSAT by streamlining ground truth and verification procedures.
- A series of standard, permanent training sites in each state and designation of a lead state monitoring agency would help to take LANDSAT use out of the project stage and into the operational stage by supplying immediate and detailed ground truth data.

The LANDSAT Mapping System (LMS):

- Optimum use of LANDSAT through automated digital analysis procedures requires users understand and supply adequate information for class selection, training data selection, and signature development.
- Documentation of the LMS system and its use are required for efficient, continued use of the system.

2.0 FINDINGS AND RECOMMENDATIONS

2.1 Regional Data Analysis Needs

2.1.1 Findings

In the sparsely settled and scenic states of the Mountain West, land use and natural resource issues are especially important. Increased energy development and potential boomtowns, combined with the region's water, agricultural and recreational needs, make these issues recurring topics in town councils, state legislatures and governors' offices throughout the Rocky Mountain States.

Businessmen, too, are often faced with land-use decisions, including where to locate industries and plants for optimum productivity and profitability -- with the least disruption to the environment and the most benefit to the people nearby.

Public concern about the use of some land may be clear now, but areas of future concern and land-use conflict require more than a crystal ball to deduce. Decision-makers need to consider all components of the present and future environment in order to make responsible plans.

Some of the primary land and resource management programs mandated by state and federal laws are:¹

- | | |
|----------------------------|-----------------------------------|
| • Land Use Planning | • Transportation Planning |
| • Wetlands Management | • Forestry Management |
| • Coastal Zone Management | • Water Resources Planning |
| • Floodplain Management | • Land Reclamation |
| • Water Quality Management | • Air Quality Management |
| • Agriculture | • Solid Waste Management |
| • Fish and Wildlife | • Environmental Impact Statements |

¹National Conference of State Legislatures, 1976. Final Report of the Task Force on State Use of Satellite Remote Sensing, Denver, CO

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These activities require a variety of data types, such as shown in the following categorization:²

CATEGORIES AND SUBCATEGORIES OF BASIC DATA

- | | |
|------------------------------|--------------------------------|
| 1. Cartographic Data | 4. Water Resources |
| a. Line Maps | a. Surface |
| b. Low Altitude Photography | b. Subsurface |
| c. High Altitude Photography | c. Man's Activities |
| d. Satellite Imagery | |
| e. Special Purpose Data | 5. Geologic and Land Resources |
| | a. Surface |
| 2. Meteorological | b. Subsurface |
| a. Climate | c. Man's Activities |
| b. Air Quality | |
| c. Man's Activities | 6. Socio-Economic Resources |
| | a. Social |
| 3. Biological Resources | b. Economic |
| a. Animal | c. Commerce |
| b. Plant | d. Governmental |
| c. Micro-organisms | e. Archaeological |

Many other studies³ have demonstrated this need for a variety of wide-reaching types and scales of data from a variety of sources.

NASA's LANDSAT earth resources satellite is a new, powerful source of information that can contribute substantially to more informed decision-making. The LANDSAT is continually circling the earth, returning to the same point every 18 days. It is producing multispectral data that can provide a user with information at low cost for large areas. This information can be in the areas of geology, land cover, land use, water quality, crop conditions, etc.

Other relatively new geographic computer analysis technologies have been emerging as a substantial aid in utilizing data from satellites and the more standard air photos, maps, and statistical

²Myers, R., 1976. "Data Needs in Missouri" - a presentation given at the conference on Future Directions for Earth Observation Data Management Systems, Washington University, St. Louis, MO, April 1976.

³Council of State Governments, 1976. Natural Resources Data Needs Recommendations, Lexington, KY.
Council of State Governments, 1975. An Evaluation of Natural Resources Data Products by State Data Users, Lexington, KY.
Federation of Rocky Mountain States, 1973. Statewide Geographic Information Systems to Meet State Specific Needs, Denver, CO.
Federation of Rocky Mountain States, 1972. Data Applications in State Land Use Planning, Denver, CO.

reports.⁴

Many of these techniques are developed by the federal government and its private contractors and are not originally designed for operational use by state and local decision-makers.

The demonstrated multisource data compositing approach of this project is designed for complex resource management and planning problems such as shown in Figure 2.1.1. It is observed among states and counties in this region that multilevel decisions on complex problems may become bogged down in the "information problem," and that the weaker the information, the more difficult the ultimate decision. This is particularly noticeable where several governmental jurisdictions are involved. The system approach designed by this project would improve interagency data-sharing and make possible mutual analyses such as agreement on the components of formulation of EIS procedures, systematic application of the data bank to state evaluation of local projects under various state laws, multiagency project evaluation under A-95 review procedures, and so on.

Optimal use of CCT's calls for supplemental data. The project found that while LANDSAT CCT input constituted the prime input to a regional data bank, it is really only complementary to all other data and dependent upon other sources for complete answers to users. While it can detect "reflectance characteristics" of many types land cover, it cannot account for "activity categories" which are essential to many analytic operations. In short, as the basic ground-cover description improves, so does the need for multitopic analysis in most kinds of functional planning. For these reasons, LANDSAT's best utilization would seem to lie in multisource regional data banks.

In terms of "land use" identification, this leads to dual or multiple classifications containing both the "visible" (from remote sensing) and the "invisible," such as all categories urban zoning, economic activities, social data, legal boundaries, etc.

Still another reason for "data mixing" in a regional data bank is the heterogeneous nature of original data coming from various agencies. The clientele of a regional data bank will include numerous bodies, providing peculiar forms of input and seeking numerous forms of output.

⁴The Federation has been involved in many efforts over the past seven years to improve states' capabilities to make decisions, using these computer mapping and satellite remote sensing technologies; for example:

Information for Land Use Decisionmaking in Wyoming: A Computer Mapping Methodology (1974).

A Computer Mapping System for Regional Resources, Basic Industry and Public Facilities -- Analysis and Projection. (1972).

Jefferson County Open Space Study -- A Summary. (1973).

FIGURE 2.1.1

POTENTIAL APPLICATIONS FOR MULTISOURCE DATA COMPOSITING SYSTEM

	DATA SOURCES			NEEDS FOR COMPOSITE ANALYSIS
	LANDSAT	Airborne	Ground Surveys	
A. <u>Mapping of prime agricultural lands, soils, potential irrigation, agricultural production levels, other conflicting land uses, conflicting water uses, conflicting zoning, etc.</u>	Film product (1:250,000) Classified maps (1:48,000)	High altitude color IR	Soils Crop production Land value Water allocation	Soil capability class map Precipitation and irrigation map competing zoning, subdivisions Industrial infrastructure Etc.
B. <u>Mining and energy production, potential for various types, stripping, shaft, pit, bench; power plant siting, pipeline and electric transmission lines, associated water planning.</u>	Film product (1:250,000) Classified maps (1:24,000)	Large scale black & white photography of potential routes, etc.	Mineral map series Soils Ground water, etc.	Top soils Agricultural potentials Mineral geology Overburden seam ratios Area pattern surface land uses Ecology maps Etc.
C. <u>Watershed engineering and management, snow basin forest conservation, reservoirs, downstream diversion for irrigation, mining, municipal and industrial hydrogeographic models of steam basins.</u>	Film product (1:250,000) Classified maps (1:24,000)	Black & white medium altitude coverage	Hydrology Ground water Various facility engineering maps	Snow basin participation Forest conditions Stream flow networks Potential engineering Etc.
D. <u>Regional and urban studies, land use trends, urban corridors, industrial locations, potential growth areas, etc.</u>	Film product (1:250,000) Classified maps (1:24,000)	Black & white for detailed urban areas	Land use surveys New subdivision & zoning proposals. New urban facilities plans.	Past land use patterns Present patterns (change) Imminent growth following water-sewer areas Political jurisdictions Land use plans, constraints Etc.
E. <u>Major recreation resources and development constraints, each season optimal human occupancy etc.</u>	Film product (1:250,000) Classified maps (1:48,000)		Seasonal human occupancy sampling.	Wildlife pattern maps Ecology map series Seasonal sports Land ownership Zoning constraints
F. <u>Critical land and water competition areas defined by states and localities (example Colorado Law 1041) for detailed review of new developments, mining subdivision, water diversions, etc.</u>	Film product (1:250,000) Classified maps (1:48,000 for critical areas)	Black & white photography	Subsurface mineral/ground water maps. Industrial resources.	Conservable resources (series) Potential industrial land and water uses Existing and potential urban or industrial uses
G. <u>Wide regional modeling of broad land uses and socio-economic distributions, future patterns expressing various planning scenarios, state development policies, federal coal, shale, leasing and water development, etc.</u>	Film product (1:250,000)		Population and employment, maps Industrial classification maps Major resource and infrastructure existing Hypothetical development and population distribution	Population density of various land uses Employment densities Potential employment growth, resources and infrastructure Environmental constraints Public facilities future pattern Zoning and density standards Etc.
H. <u>Up to date environmental impact statements, preparation by private and public developers, immediate data surveys and compilation of available secondary data showing plans and models of above activities, etc.</u>	Need to utilize above LANDSAT products	Need to utilize above airborne products	Need to utilize above ground surveys	Need to utilize above composite maps

In these circumstances, the project arrived at the cellular map, based upon the LANDSAT picture elements of 1.1 acres. This defined the fine grid to which most other forms of data could be adapted, still permitting the nesting into larger cell sizes if needed for handling coarse regional data (economic, social, climate, etc.). There were other advantages in adopting the grid system.

2.1.2 Recommendations

Institutional Mechanisms. A principal question is, then, how to further enhance state and local governments' ability to utilize these new technologies on a day-to-day basis. This question of public technology, stimulating implementation of techniques (especially new, federally produced) by state and local governments, in many cases is a problem of developing adequate intergovernmental relationships and institutions resulting in transfer of a given technology. Roessner suggests that:

"Public technology policy issues, then, rest at the nexus of two broad streams of public concern: the perceived need to stimulate the use of research and new technology by regional, state, and local governments, and the need to assist these same governments as they assume greater responsibilities for the solution of increasingly complex public problems. The problem for federal policymakers is how to develop and implement programs that will at once increase the availability and use of new technologies by state and local government and ensure that doing so actually helps solve the complex problems they face."⁵

In the years ahead, the primary concerns of state government, in both the executive and legislative branches, are going to center on policy management -- that is, enhancing their capacity for goal setting, evaluation and assessment, interinstitutional relations, and interjurisdictional relations. A tremendous amount of knowledge and experience and good social theory are available to guide that process. Nevertheless, ways and means have to be found to get the leadership and the front-end resources together to engage in the massive process of institutional design and development if the great investments in research and technology made by the federal government are going to be used effectively to meet national needs.

What is lacking is the capacity to use the existing research and technology -- which in almost every case involves (1) creating new institutional capabilities (and especially those that will enhance the ability of state and local governments and their elected leadership to participate more fully in the federal R&D agenda-setting and utilization process); and, (2) strengthening policy management capacity, including science and technology manpower

⁵Roessner, J.D., 1976. Federal Policy and the Transfer of Technology to State and Local Government.

capabilities at the state and local level.

There is a need to invest money and talent in the social architecture of research and technology in the design and development of better institutional mechanisms to use this existing research and technology. Then these same mechanisms will help establish and sustain the communication between the different elements of the research and technology community -- particularly research providers and the R&T resource users -- and this will, in turn, likely result in better research and operational useage of the technology.

Data Banking. This project addressed the needs of "operational" data banking and analytic services for "regional" programs of federal agencies, states, and multicounty bodies.

- An essential requirement is a broad range of data sources -- physical, economic, and social -- for regional development studies, wildlife studies, water quality and quantity planning, identifying critical areas of land conflict, and multifactor studies in transportation, energy development, etc.
- Another requirement is ability to handle a broad range of formats -- LANDSAT digital data; airborne sensing; freeform maps such as soils, crops, timber, or wildlife; human population characteristics; land ownership patterns; local climatic and similar data types.
- Ingestion of any input form or scale and convertibility to any other scale.
- Category transformation into different sets of symbols, different ordinal ranking, or various summarized categories, etc.
- Compositing ability to overlay numerous topic maps under given relationships, such as arithmetic, with different topic weights, or logical relationships, etc.
- Or conversely, ability to analyze map relationships statistically, by subjecting digitized (preferably in cellular array format) maps to analysis, or multiple regression, etc., as elected by the analyst.

While the original plan was to meet average resolution requirements with a grid of 2.5 acre cells, aggregative to 10 or 40 acres, the LANDSAT processing subcontractor, Colorado State University, offered a fine grid of individual picture elements or 1.1 acre cells.

Advantages: This had the advantage of matching the standard 1:24,000 USGS base map (in the LANDSAT cellular printout of 8x10 cells per inch), a convenient grid for other non-LANDSAT data compositing. Given the aggregative possibilities of the 1.1 acre cells to 10 acre cells (3x3x1.1), this would be ideal for a regional data bank.

Disadvantages: There were drawbacks in imposing such fine detail on LANDSAT training site work and verification. It was not necessary to use such a fine cell pattern for most subjects in regional planning. A significant factor is the LUDA program of USGS, which will be supplying 10-acre and 40-acre polygonal resolution elements (for Level II and Level I categories, respectively) as a major input to any regional data bank.

In retrospect, any state centralized data bank should plan an "optimum" grid scale for extensive regional mapping, reserving a finer, nested grid for intensive local mapping -- probably 40 acres and 1.1 acres respectively.

To achieve truly operational status, cover large regions, and represent various agencies, a system would have to balance various parameters such as grid scale(s), land-use classification(s), and the multidecade survey calendar. It would have to do this with a view to the most common resource management problems at hand.

Such balancing could not be attempted in this relatively brief project. As matters turned out, the LANDSAT Computer Compatible Tapes picture elements were ambitiously adopted as the basis for a 1.1 acre grid system and also used for encoding all other types of data and experimenting with composite maps. At the conclusions of the project, some states reported that this cell resolution was too detailed and resulted in location registration problems for training sites and verification. This, together with the future available LUDA polygonal resolution of 10 to 40 acres, leaves a clear implication for aggregating LANDSAT pixels in the interpretation process and working toward LANDSAT output maps having 10 or more acres per cell.

Another problem in balancing the parameters concerns the detailed breakdown of categories. A great variety of land-use classification was tried by the state teams, ranging from the original 19 categories selected by the interstate workshop of April 19, 1975, up to 81 categories for one of the states. The various state lists were not compatible except at gross levels. This experience showed that it would be necessary for two or three adjoining states to begin a common Level I and Level II system from the outset, while still pursuing different categories at Level III.

Regional Assistance. An increased ability of the public sector -- principally state and local governments -- to use satellite remote sensing and related computer mapping technologies on a continuing basis to make decisions is required.

This goal could be accomplished through aggregation of the user community (market) and transfer of the technology to this market by:

- improving user (existing and potential) awareness of the technologies and their applications;
- building user capabilities to utilize the technologies;
- mobilizing existing resources in the region to provide maximum opportunities for technology transfer.

Central to achieving these objectives set forth is the establishment of a regional Earth Resources Technology Applications Assistance Center (ERTAAC) and subsequent development of operational programs. Such regional centers were recommended by a recent National Conference of State Legislatures report:⁶

A center would be widely used by various groups active in the West (see Figure 2.1.2). These groups would, in many cases, also provide resources for a networking effect. The center would be the hub -- the catalyst -- of a regional network of users, researchers, and suppliers.

The focus of a Center's activities initially should be the applications of proven LANDSAT capabilities and related multisource computer mapping technologies.

Functions of the center should include:

1. User awareness and education --

- formal and informal training (technical and applications);
- information about the availability, costs, etc. of data and services;
- availability of education resources such as speakers, audio/visuals, etc.;
- a central library for technicians and users.

2. Information exchange and networking --

- regular newsletter about innovations, applications, projects, activities, etc.;
- a publications system providing reports, summaries, bibliographies, etc.;
- data exchange services with other information centers/systems;

⁶ NCSL 1976, op. cit.

- an annual meeting for users and technicians providing a forum for information exchange and contact (through exhibits) with commercial and other suppliers; and
- information referral services with libraries, organizations in the region, etc.

3. Technical assistance and capacity building --

- conducting user needs evaluations,
- performing services and demonstrations,
- personnel exchanges,
- providing user access to data and hardware,
- assistance in establishing user in-house capabilities,
- standardization of products and procedures to enhance operational uses, and
- establishment of standard ground truth test sites in individual states.

4. Mobilization of resources within the region --

- keep center staff at a minimum and use existing expertise,
- provide assistance in travel costs, etc.,
- establish training/assistance teams throughout the region,
- coordinate regional activities as much as possible,
- provide referral and information exchange services.

2.2 Toward Centralized State Services

2.2.1 Findings

While this project involved a mix of functional state agencies and "technical" organizations, most state reports indicate the need and desirability for increased efforts of centralizing state data management. Although the project did not attempt a general review of the internal organization in member states, it found that information service organization was in flux and tending to centralize. A recent study by the Federation of Rocky Mountain States examined the issues and the evolution of land use planning operations in the member states.⁷

Following were the several state agencies in each state which appeared to have the closest concern for the kind of data system here being demonstrated:

⁷Lamont, W. and M. B. Jones. Land Use Planning in the Rocky Mountain Region: Background and Status. Federation of Rocky Mountain States Regional Background Paper, Denver, CO 1976.

FIGURE 2.1.2

EXAMPLE REGIONAL ASSISTANCE USERS
AND PARTICIPANTS IN THE WEST

FEDERAL GOVERNMENT

Department of Commerce

- Environmental Research Labs
- Weather Service

Department of Housing & Urban Development
Department of Interior

- Bureau of Reclamation
- Geological Survey
- Bureau of Land Management
- Park Service
- Fish & Wildlife Service

Department of Agriculture

- Forest Service
- Soil Conservation Service

Department of Defense

- Corps of Engineers

Department of Transportation
Department of Health, Education
and Welfare

- Public Health Service

STATE GOVERNMENT

- Governors
- Legislatures
- Planning Agencies
- Resources Agencies
- Development Agencies
- Human Resources Agencies

LOCAL GOVERNMENT

- Counties
- Regions
- Service Districts
- Cities

PUBLIC SECTOR

- Interest Groups
- Citizen Organizations
- Public-at-Large

PRIVATE SECTOR

- Utilities
- Planners - Engineers
- Resource Firms
- Research

REGIONAL GROUPS

- Policy Development
- Coordination
- Research
- Planning

UNIVERSITIES

- State
- Private

ARIZONA	Arizona Resource Information System in the Department of Revenue Division of Planning, Office of Economic Planning & Development
COLORADO	Colorado Division of Planning, Department of Local Affairs Colorado Land Use Commission
MONTANA	Division of Planning, Montana Department of Community Affairs Department of Natural Resources
NEW MEXICO	State Planning Office Department of Minerals and Natural Resources
UTAH	Office of City Planning Coordinator Department of Community Affairs
WYOMING	Wyoming Land Use Commission Planning Division, Wyoming Department of Economic Planning & Development

A multisource data bank of value to various state and local agencies requires central technical functions. In this project the organizational situation differed widely among states, but generally it was found that either natural resource or planning agencies (whichever became the Lead Agency) began to assume more centralized responsibilities for the technology required. The project contributed to this evolution. Sometimes state data banking services had already been legislatively mandated to serve local jurisdictions and turned out to be useful also for other state and federal agencies. At the same time, the accessibility of federal and state aerial photo coverage and LANDSAT services tended to bring about this state centralization.

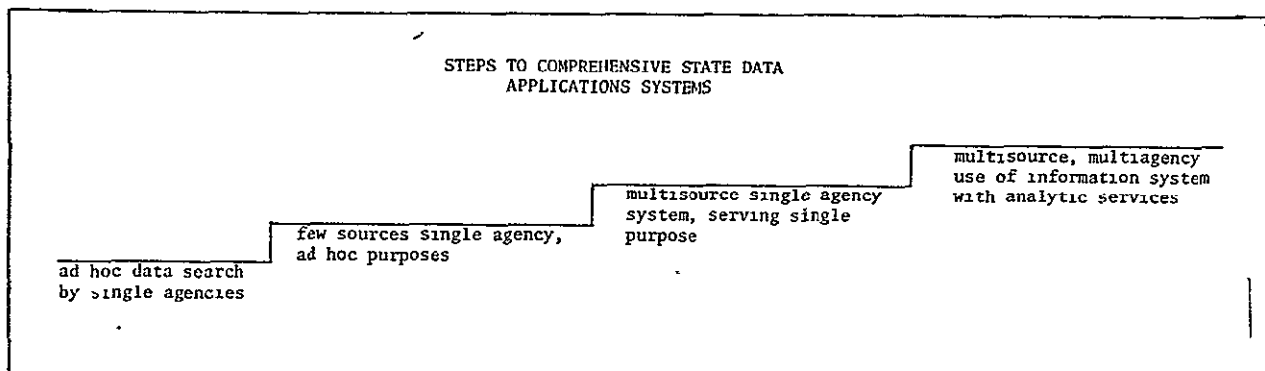
Many states in the West are now actively moving toward operational usage of computer mapping and LANDSAT data. There is, however, a definite evolutionary process, ultimately arriving at the broadest, most flexible usage of these technologies in making policy and program decisions; no western state has yet reached this climax.

More particularly, state situations could be described as evolving up a "ladder" of data operations (see Figure 2.2.1):

- Stages I and II. - where there exists only "ad hoc" assembly of data by each agency for its own purpose, generally resulting in duplicative and expensive efforts by various operational agencies, and eventually executive or legislative directives toward centralization.

- Stage III - where a general purpose "map library" function develops in an agency having widespread responsibility for state planning or for some extensive repetitive survey of natural resources, etc., procurement of remote sensing, possibly also cartographic standardization, gathering and indexing of various agency data products, etc.
- Stage IV - where analytic and modeling services are added to the foregoing map library, making possible more complex map analyses, regional change studies, and provision of information services to other agencies, to the governors and legislative committees, etc.

FIGURE 2.2.1



2.2.2 Recommendations

Information, dissemination, demonstrations, and technical assistance to states and localities -- either unilaterally or via a regional approach-- are required to move them up this evolutionary ladder, to build their technical capacity and to increase their interest in utilizing the technology.

Continued upgrading of LANDSAT products and use in combination with multisource data will encourage state efforts at standardization, coordination, and centralization of data management.

Additional training of state personnel, applications demonstrations, standard procedures, improved accuracy and lowering of costs will also assist in developing state efforts.

2.3 Toward Operational Use of LANDSAT

2.3.1 Findings

As might be expected for a project of this type, the results were a mixture of good and bad. The most disappointing aspect of the project stems from our inability to achieve the maximum capability from the LANDSAT imagery. This inability to maximize the results was caused by lack of communications, inexperience on the part of all project participants, by the lack of time and funds to correct deficiencies which were noted during the first processing of the data. Even with the most experienced personnel, an iterative mode of operation is required to achieve the best results.

On the positive side, the discrimination capability of multi-date LANDSAT imagery was very encouraging. Separation of forest species, residential types, vegetation density/condition classes, and many other Level III types appears to be possible.

Although there are technical questions which remain to be answered, the largest question is one of how to achieve operational status. LANDSAT and other remote sensing systems can provide useful information for land use planners and natural resource managers. We have yet to accomplish a mode of operation which is timely, cost effective and consistently reliable.

All indications from this project and other projects of a similar nature show that LANDSAT has the capability of mapping land use wherever such use affects the land cover characteristics in a consistent manner. When the land use does not affect land cover characteristics, LANDSAT is, of course, of no value. From the comments received from the state participants associated with this project, this appears to be a serious limitation from their point of view. In many instances, state and local organizations are more concerned with ownership and activity characteristics of land use than with those characteristics which affect land cover. In other words, they would like to know, not that an area is covered with grass and trees, but whether it is used as a golf course, cemetery, park, pasture, or some other activity.

Clearly, LANDSAT promoters are faced with a need to communicate more effectively the potential benefits of LANDSAT data in order to obtain the support from state and local agencies which will be needed before an operational status will be achieved. This will be considered again under recommendations.

All in all, the results from this project show that many land cover characteristics can be classified using LANDSAT data. The use of multirate classification enhances this capability under many circumstances. Although we need to learn more about the temporal characteristics of vegetation type and land use (including activity types of land use) to maximize the potential from multirate processing, this project has shown that the capability is there.

It is important for all participants in this project to realize that the maximum capability from multidate LANDSAT imagery was not achieved. In the one instance when the opportunity arose to retrace steps, obtain a better selection of classes and better training data to represent them, very satisfactory results were achieved. This was accomplished for the Buffalo, Wyoming, quadrangle after the preparation of the Wyoming State final report. In this one instance, there also was the opportunity to compare the multidate results with single-date classification, using the best single date possible for classifying the land uses in the Buffalo quadrangle. The multidate classification was clearly superior. A quantitative evaluation of the superiority in terms of accuracy of classification has not been made, but it is apparent from a side-by-side comparison that the multidate map is more consistent with known land uses in the quadrangle. The single-date classification results themselves, however, appear to be quite satisfactory.

2.3.2 Recommendations

As previously stated, many of the efforts toward operational use of LANDSAT lie in developing new institutional mechanisms for multisource data management, oriented to "real" user problems.

Products. Much work remains to be done before routine use of LANDSAT data will be accomplished in a timely and cost effective manner, with output products being enthusiastically received by the land use planner and natural resource manager.

Perhaps as important as any change which could be made in the use of LANDSAT would be an improvement in the output products to make them more palatable to the users. This could be accomplished in many ways, but perhaps one of the most important would be to provide the user with an output product generated not only from LANDSAT information. If those organizations generating LANDSAT products would combine them with digitized information relative to land ownership, zoning, and activity types of information, the final product provided to the users might be much more acceptable.

Training Site Procedures. It is recommended that a training site manual be written in a standardized form for use by nontechnical personnel, concerning the following subjects:

- Selection of land use and cover categories in consideration of the end purposes of a study and availability of other more accurate information on functions and activities on the land to be used in a compositing system.
- Particularly, selection of LANDSAT categories for their spectral characteristics.

- Hierarchical classifications of land uses, cover, and functions, permitting appropriate aggregation in the LMS and in the composite mapping programs.
- Rules concerning homogeneity of land cover conditions, mixture of vegetation, etc., based on lessons learned in this and other LANDSAT exercises.
- New rules concerning multirate ground/vegetation conditions.
- Rules concerning the location and size of training fields, concerning amount of data needed, size of sites, number of sites, site-to-site variability for a given class, slope/aspect considerations, etc.
- Rules on documentation of training data: field mapping and documenting procedures, particularly seasonal tracing of changes; standard annotation form for description of all pertinent field characteristics; and optimum use of other sources of data, aerial photography, etc.

Standard Training Sites. In order to approach a fully operating system, for optimum use of LANDSAT and an all-source data bank over wide regions, the root problem of ground truth must be solved. Many weaknesses were experienced in organization of this work on a first-time basis with inexperienced personnel, which will reoccur with each new LANDSAT application. Therefore, a key recommendation for follow-on work is to establish a "standard test site system" with numerous permanent ground truth survey sites under repeated observation for changing land uses. This would go far toward practical LANDSAT use in this large region of public and private lands. A system of standard training sites will provide first grade seasonal or annual coverage of the changeable land uses, cover types, water and moisture status, etc. Sites would be distributed in strategic locations within each LANDSAT scene. Any new user of LANDSAT need only call upon the new bank of standard training site data for the ground truth for practically any LANDSAT or remote sensing survey.

More particularly, the reasons and advantages of such a program are:

- The optimal ground resolution of LANDSAT is relatively coarse but very cost effective for wider regional applications.
- Similarly, it is made increasingly effective by repetitive coverage.

- LANDSAT's relative freedom from geometric distortion is a large advantage in repetitive regional coverage.
- LANDSAT's special ability to discern vegetation conditions, biomass, water conditions, etc. is ideal for seasonal and/or annual repeat coverage.
- The cellular output format of LANDSAT CCT's makes possible a basic grid suitable also for supplemental mapping of various land use "functions," slope and aspect, etc. to optimize land use cover classification for a data bank.
- The new LANDSAT systems, C and Follow-on, provide more and different reflectance bands and will require a great deal of new ground truth to match them.
- Any inadequacies in LANDSAT discrimination may be augmented by compositing with other information on crop conditions and production levels, forest types and conditions, urban land uses, mining activity zones, construction zones, and recognizable geodetic reference points.

Concerning the locations of standard sites, experience in this project suggests that standard sites be located in each LANDSAT scene -- enough sites to represent each important category. For example, if a state needed 16 LANDSAT frames for complete coverage, and if there were 20 land use and cover categories of interest, the required number of sites would be something less than 16×20 , because some larger sites could be selected which have subareas that cleanly represent the categories.

In repetitive system, there would be certain economies. For example, the first round of ground truth would have to survey every category of interest. It would establish (1) the permanent characteristics of slopes, aspects, soils, major forests, riverine vegetation, etc., and (2) the changeable characteristics of agriculture, water status, surface disturbance from mining, construction, etc. However, future repetitive surveys could focus only on the changeable land uses and vegetation, at a large savings in work.

Such a system would permit the use of best technical methods -- usually also the most economic, if used repetitively. Various agencies would become adapted to the system, contribute their survey methods and data, and call upon the central system to support any LANDSAT or other remote sensing project they wish to initiate.

Essential technical dimensions of the system might include:

- A sufficient number of designated sites in each LANDSAT scene.
- Areas of 160 acres to several square miles each.
- Grouping of the test sites for economy of field work while preserving the homogeneity of individual categories of subareas.
- Most characteristics of the categories located in the land use/cover areas.
- Location in characteristic land forms, slopes, aspects, soil zones.
- Possible categories --

- 3 - 6 rangeland types
- 5 - 10 crop types
- 3 - 6 forest types
- 3 - 6 local water "states"
- 2 - 3 types of land surface disturbance
- slope, aspect, general elevation
- soil classes, moisture conditions
- surficial geology
- crop and forest condition indicators, disease, biomass, leaf moisture, erosion state, etc.

Starting such a system would require the appointment in each state of a "permanent survey agency" with a standard procedure manual, common training, close working relationships with the remote sensing processing facilities.

The system would also require one or several remote sensing processing facilities, under appropriate interstate and state-federal arrangements. In the beginning, a single center of strategic planning and training would be needed to ensure uniformity of approach.

2.4 The LANDSAT Mapping System

The LANDSAT Mapping System (LMS) was developed for this project by Colorado State University.⁸ The major and minor operations built into LMS are illustrated in the CSU portion of this report and will not be repeated here. Among its objectives were: (1) to simplify human interactions, (2) make possible efficient multirate LANDSAT applications, (3) handle a variety of locations of training data, (4) efficiently develop class signatures, (5) perform selective masking of training fields and (6) focus statistical analysis on the remaining training data.

⁸The LMS System was evolved from Colorado State University's earlier Pattern Recognition Program (RECOG) by Dr. Lee Miller and Dr. Eugene Maxwell.

2.4.1 Findings

Data Handling. The data-handling capabilities of LMS are not entirely satisfactory. It is time consuming to obtain given portions of data in the desired format for the different steps of LMS and still leaves too many opportunities for human errors. Even though this system has achieved an order of magnitude improvement over the old RECOG or LARSYS type system, it still falls short of the capability of interactive systems. CSU now has an interactive computer capability and as time and funds permit, an improvement in the data handling capabilities will be sought.

Geometric Corrections. The geometric corrections achieved by LMS appeared to be adequate for quadrangle size areas. If it were desired to correct and display an entire scene as a single image, it is doubtful that these corrections would be adequate. In general, however, the geometric correction capability of LMS is quite flexible and effective.

Radiometric Corrections. The only radiometric correction which LMS had during this project was in the form of low pass filtering. This achieved some correction for radiometric banding, but it was not adequate to correct serious problems of this type. Future modifications of LMS should provide for banding correction and for removal of atmospheric effects. A recent modification of LMS, not available during the lifetime of this project, provides for the replacement of missing pixels or entire missing scan lines.

Signature Development. LMS has excellent flexibility for computing training-data statistics and in modifying and correcting that data to achieve the best signature. The speed and efficiency of carrying out these operations, however, leave something to be desired. Again, a more truly interactive mode of operation with LMS might correct this deficiency.

Classification Algorithm. The classification algorithm of LMS is as effective and accurate as any other software system currently being used. It employs a maximum likelihood algorithm which could be easily modified to use a priori probabilities and other weighting factors to achieve the best accuracy possible. Being a software system, it is not as fast and cost effective as hardware systems, but this is probably its only serious deficiency.

Display. The display capability of LMS, being limited to microfilm or line printer types of output, is deficient primarily in terms of product appeal. Technically, the LMS products are as accurate and useful as products supplied by any system, but we cannot ignore the appeal of photographic color displays, which LMS cannot produce. Incorporation of some sort of a color display capability with the system is highly desirable.

Costs. Because of the developmental aspects of using LMS during this project and the inexperienced project personnel, the costs discussed do not reflect an operational mode. Costs and

comparisons of LANDSAT versus use of other data types are discussed in each of the reports in the appendices. CSU reported computer processing costs for classification at \$300 per quadrangle, or about \$5 to \$6 per square mile. Complete analysis costs, including man-time, would be much higher, but total costs are unknown (and presumably lower) for an operational mode.

2.4.2 Recommendations

Class Selection. To achieve the most effective results from LANDSAT data, it is important that careful consideration be given to the requirements imposed by the assumption of a normal distribution of radiance values. This assumption requires that the radiance detected by the satellite sensors should come from the same mixture of materials on the ground for each pixel within a given class. This, and considerations of the reflectance characteristics of materials, should be used as a guide in the selection of classes at the outset of any project. Problems associated with improper selection of classes are undoubtedly a major factor in the current popularity of unsupervised, clustering modes of operation. The unsupervised, clustering mode of operation automatically takes into account the factors noted above.

Total dependence on unsupervised clustering, however, will increase the problem of convincing users that LANDSAT can provide useful information for their applications. If there is difficulty in convincing state and local agencies that land cover of known categories are of value, what chance will there be to convince them that some unknown and changing set of land cover characteristics can be fit into their scheme of operations? Furthermore, the distinct advantages of multirate classification could well be lost by an unsupervised, clustering type of analysis.

The preparation of a class selection and training data manual might help to eliminate some of the problems which stem from improper class selection.

Training Data Selection. Similar to the problems of class selection, the selection of training data by inexperienced and untrained personnel can detract greatly from the results achievable with LANDSAT data. The preparation of a manual, clearly defining the requirements for training data (to optimize final mapping results) is highly desirable.

Signature Development. Considerably more research needs to be done relative to signature development and the optimization of both the supervised and unsupervised algorithms. Although interactive modes of operation, which depend on testing the classification results, are generally quite effective, we cannot depend on such methods if we are to achieve repeat results for essentially

the same classes at different times in different locations. Much research is under way at the present time relative to signature extension and signature problems in general; so there is reason to believe that many of these problems will be solved in the near future.

Software Documentation. Documentation of the LMS software is an absolute requirement before it can be used effectively by other organizations. Adequate users' and operators' manuals are required to train new personnel as they begin use of the system. CSU will make this system available to anyone desiring to incorporate it into their computer operations. This cannot be effectively accomplished, however, without adequate documentation.

3.0 STUDY AREAS

3.1 General Study Areas

Figure 3.1 outlines the large study areas selected to represent characteristic natural resources and economic activity zones in the Rocky Mountain region.

The Montana-Wyoming area contains some of the vast Powder River coal deposits. Energy developments will significantly affect the prevailing grazing and farming. This area, part of the Great Plains physiographic region, is mostly rolling grass and brush prairies with scattered, wooded uplands.

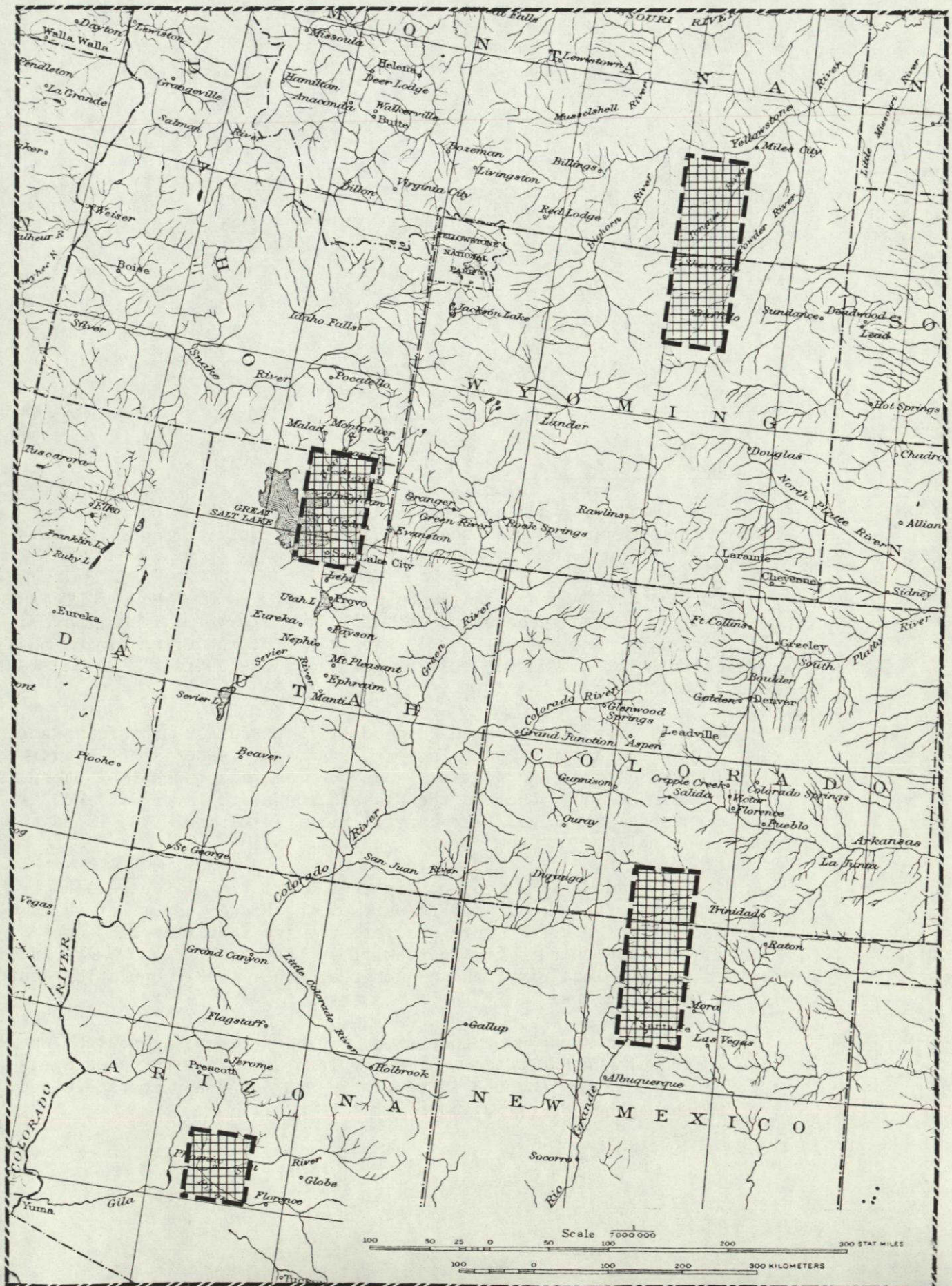
The Utah area was selected because it is a rapidly urbanizing corridor along the Wasatch mountain range. A major issue is the transition of agricultural and grazing lands to urban and industrial uses. There is commercial timber in the Wasatch range and large wetlands along the Great Salt Lake. The capitol city, Salt Lake City, is in the study area.

The Colorado-New Mexico area is characteristic of southern Rocky Mountain physiography. It covers part of the Rio Grande river valley. Grazing, irrigated agriculture and forestry are important land uses. Second home developments are increasing in the study area. Santa Fe, New Mexico's capitol city, and a number of other small population centers lie in the study area.

The Arizona study area covers the Phoenix metropolitan area, where widely spreading urbanization is moving into areas of irrigated agriculture and desert. Located in the Basin and Range physiographic region, the area has a hot desert climate.

FIGURE 3.1
STUDY AREA LOCATIONS

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Within these large study areas, each state selected four smaller test sites. These served as foci of the detailed data collection and analysis.

3.2 Specific Test Sites

Within the large characteristic study areas, each state selected four U.S. Geological Survey 7½-minute quadrangles (scale 1:24,000) for detailed training site and computer analysis work (Figures 3.2 through 3.7).

Selection of these test sites was accomplished early in the project so that best cloud-free multitemporal LANDSAT and high altitude aerial data could be sought. Numerous training sites were then selected in these quadrangles. Additional information about these sites may be found in the individual state reports, Appendices C through H.

Each state selected one of their test sites (shaded in the following figures) for conducting the multisource computer compositing described in Section 6.0.

3.2.1 Arizona Sites

The Arizona test sites are all located within the Phoenix metropolitan area. This area is undergoing rapid urbanization of agricultural and open-space lands. The test sites offer a mix of land forms: steep, rocky mountains, rolling hills, flats, and watercourses. The hot desert climate and resultant ecosystems offer unique constraints for agriculture and urban development. Citrus crops are the most significant agricultural activity.

The Tempe site is highly urbanized with scattered agricultural lands. Most of the site is flat. There is a group of steep mountains in the center of the site, and the Salt River -- the major watercourse in the region -- bisects the area.

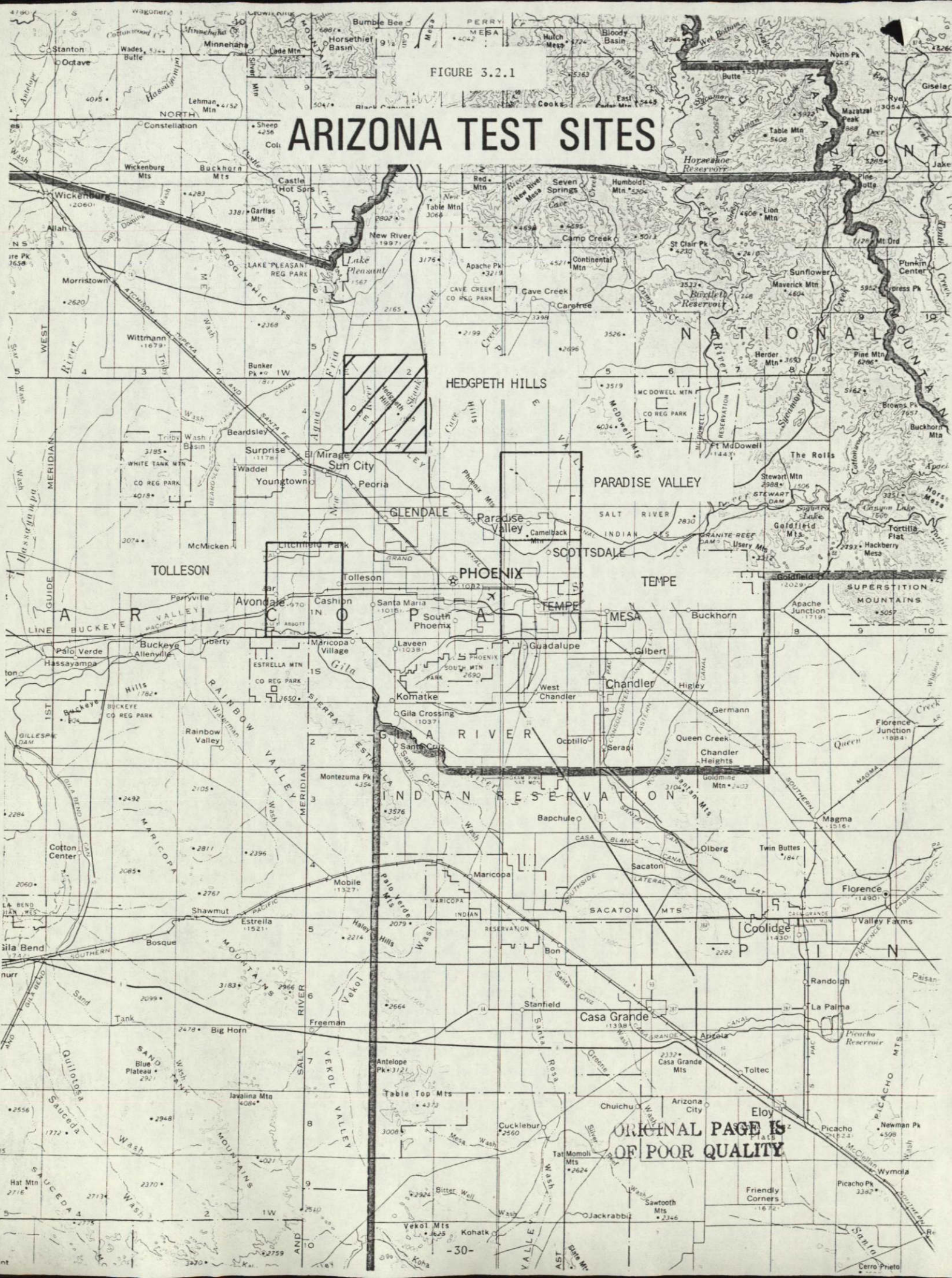
Paradise Valley is also an urban area and includes part of the cities of Phoenix and Scottsdale. The several scattered mountains are surrounded by residential land uses.

The Tolleson site is less urbanized, being mostly scattered small communities and extensive agriculture. It consists of almost completely flat, mountainless terrain, with one major watercourse in the southern-most sections of the site.

The comprehensive test site, Hedgpeth Hills, is mostly rural in nature with subdivisions encroaching on agricultural lands. Several streams flow through the area and steep mountains and ridges persist in the northern sections.

FIGURE 3.2.1

ARIZONA TEST SITES



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3.2.2 Colorado Test Sites

All sites are situated in the San Luis Valley of Southern Colorado. The sites are representative of land uses and vegetation reflecting the entire study area.

Zapata Ranch characterizes the tightly stacked vegetation zones on the west slope rise of the Sangre de Cristo Mountains. It also provides instances of rangeland and mass wasting processes associated with the sand accumulations in that sector of the valley.

Alamosa West contains commercial and semi-urban land uses, some agriculture, and a sample of the greasewood-saltmarsh complex which is scattered throughout the valley on the less well-drained portions.

Manassa quadrangle exhibits examples of riparian and basalt butte communities, and includes the best cross-section agricultural and small-town land uses.

The Fox Creek quadrangle, selected as the comprehensive test site, is situated on the western edge of the San Luis Valley. It is located partly in the San Juan Mountains. Here the mountains rise in a very moderate upslope from east to west, capped by a resistant basalt layer. Cutting through this flat plateau top is the Conejos River and several minor drainages. As is the case with the Zapata Ranch quadrangle, agricultural lands are few, scattered along the Conejos River. The predominant vegetation type, adapted to the lower elevations, is open, dry range characterized by bunch grasses and small shrubs. Mixed with this range type are stands of pinyon-juniper, Ponderosa pine, and some sagebrush. In the higher valleys, Douglas fir/White fir communities occupy steep northern exposures. Aspen groves and meadow lands are found on higher elevation sites in the drainages. The high tabletop land of this upslope is dominated by mixtures of spruce, fir, and aspen. These areas were heavily logged in the early 1900's which accounts for a variety of vegetation patterns, and it is the problem of revegetation which provides the compositing exercise of revegetation index mapping.

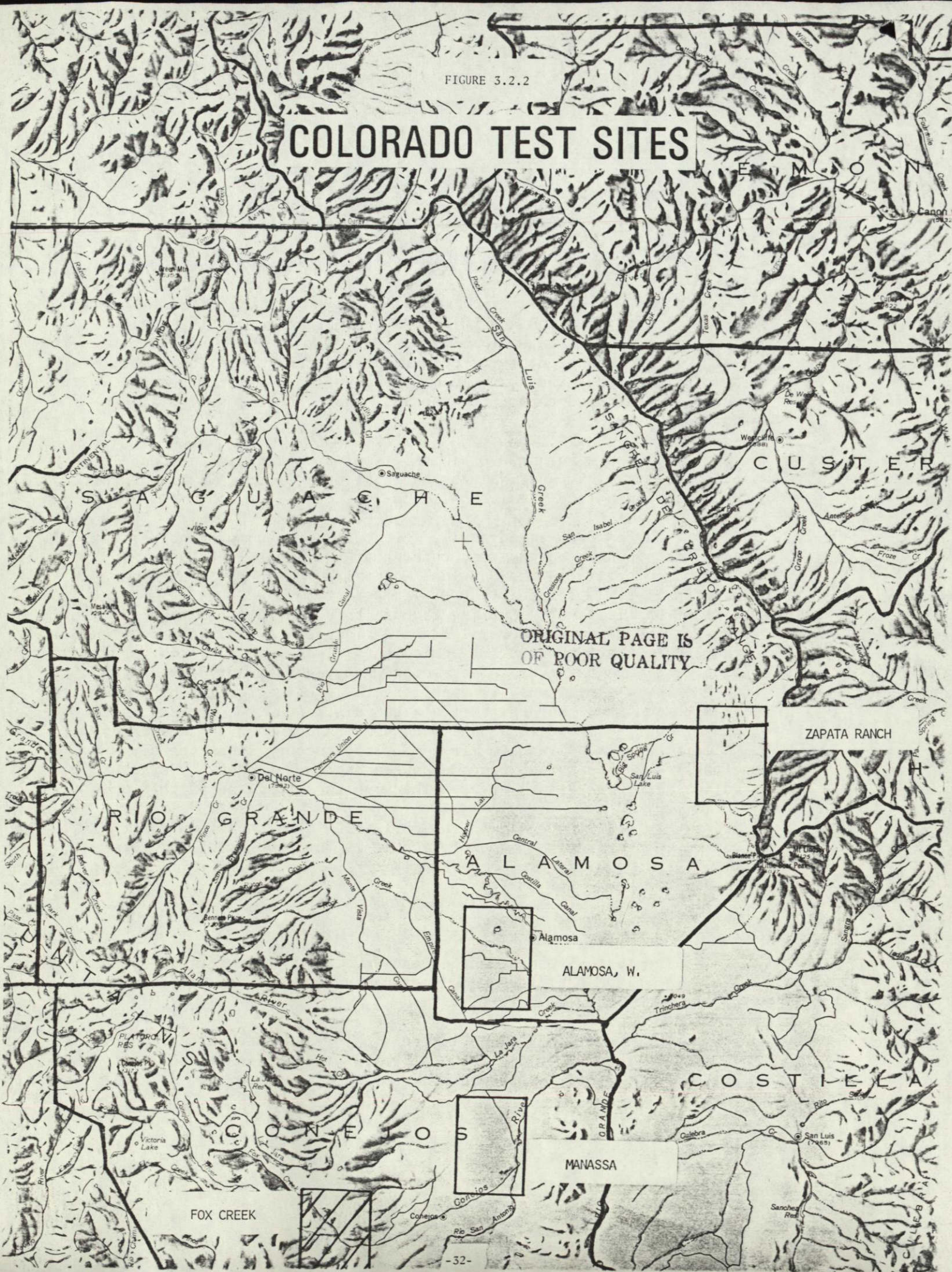
3.2.3 Montana Test Sites

The test sites in Montana are underlaid by Powder River coal. Surface mining and large-scale energy developments are underway with more planned for the future.

The Beaver Creek School site's major land uses are dryland farming on the valley floors. Timber is produced in the shallow soils of the deeply incised drainages and is an important economic

FIGURE 3.2.2

COLORADO TEST SITES



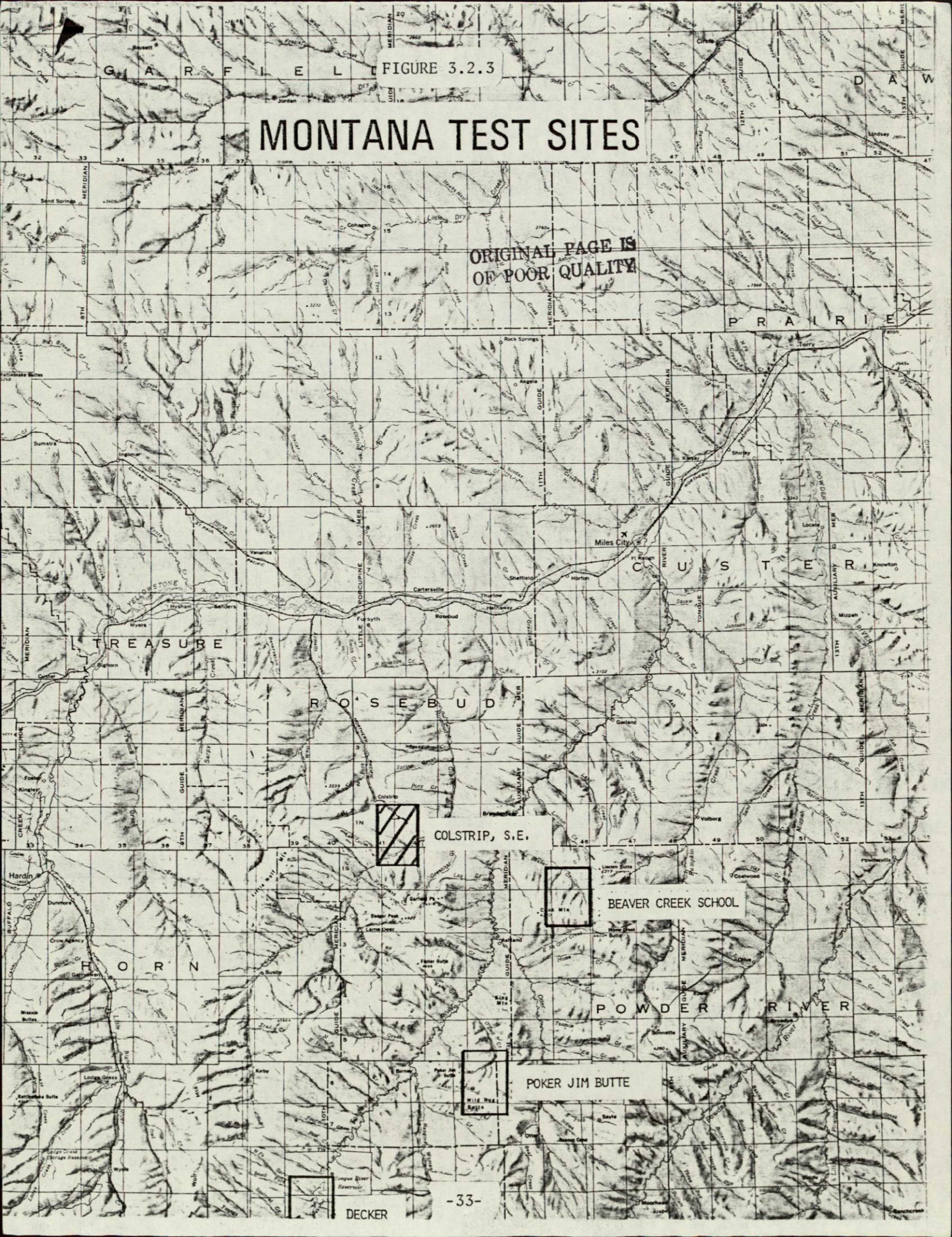


FIGURE 3.2.3

MONTANA TEST SITES

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COLSTRIP, S.E.



BEAVER CREEK SCHOOL



POKER JIM BUTTE

crop to the area, as is hay production on low terraces and floodplains. Grazing land dominates the moderately steep rolling uplands.

On Poker Jim Butte, timber production and grazing of native rangeland are the principal land uses. Small amounts of hay are being grown in the floodplains. The timber is confined to the steeper slopes but is quite productive and important economically. Recreational use will drastically increase with energy development.

On the Decker site, rangeland dominates the quadrangle with very limited amounts of dry cropland. Some irrigated hay is grown along the lower fens, terraces and floodplains of the Tongue River. Intensive energy development is currently underway with the Decker mine expanding its production and applying for new mining permits on the east side of the Tongue River. The Tongue River Reservoir is important for water resource management, irrigation, recreation, and potential energy conversion uses.

The major land uses of Colstrip Southeast, the comprehensive test site, are rangeland with limited dry crop land and timber production. Intensive surface mining of coal is being undertaken and several levels of development of the power plant at Colstrip are under construction. A variety of stages of reclamation of the surface-mined areas is present. Interest in the quadrangle stems from energy development and conversion and its potential impacts on land use, recreational opportunities and the quality of the surrounding environment.

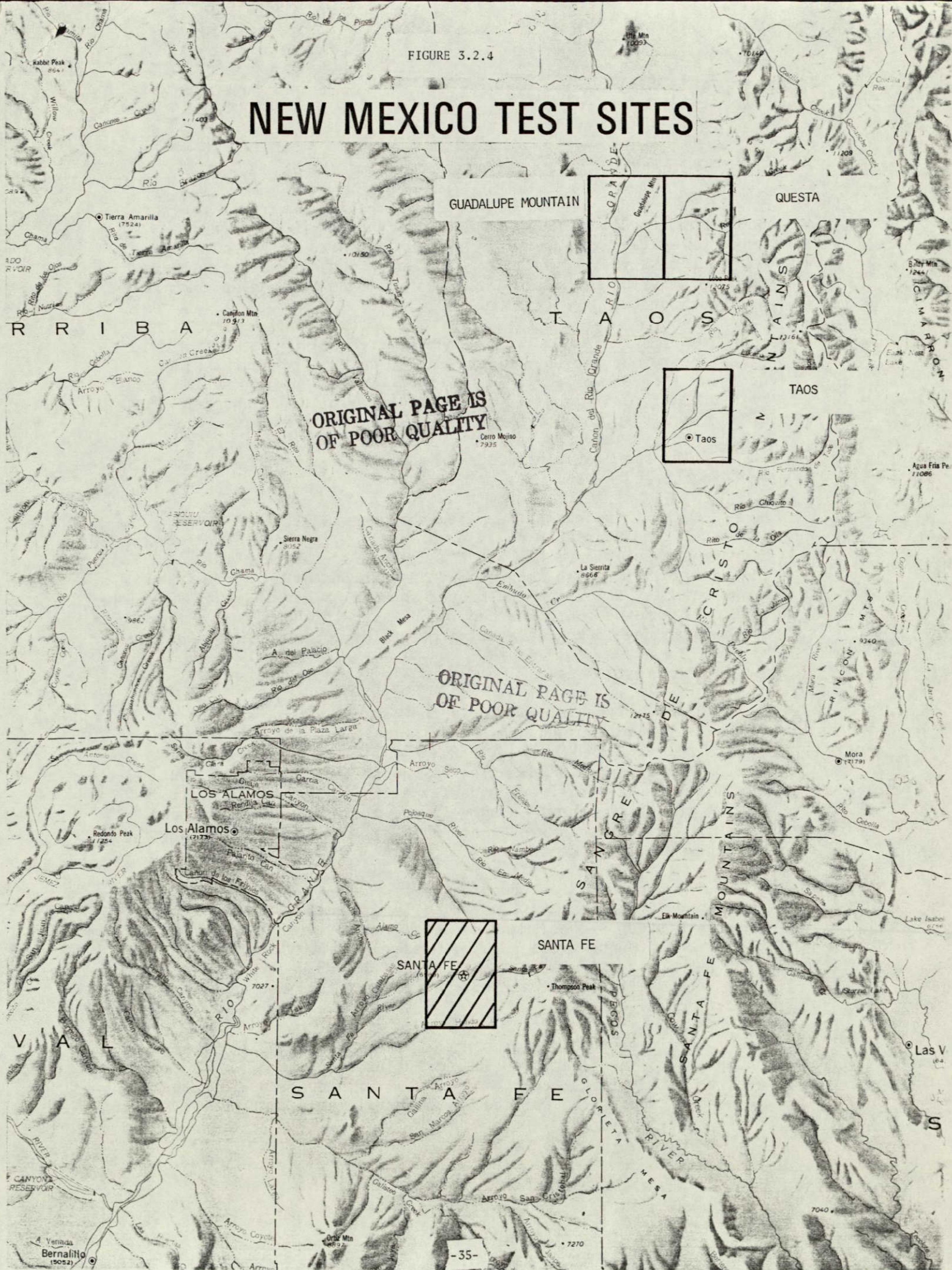
3.2.4 New Mexico Test Sites

Characteristically, the mountains in the test sites are forested and valleys are brush covered with a smattering of pinyon and juniper. A scattered population inhabits this rural area and only in the Santa Fe quadrangle, which contains the city of Santa Fe, is there a large concentration of people. Valley agriculture and grazing dominate the region with mining and forestry being important locally. Land ownership or management responsibility is under the control of the U.S. Forest Service, Bureau of Land Management, several northern Indian pueblos, and private individuals. In selecting the quadrangles, an effort was made to focus on one of several characteristics within the region.

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FIGURE 3.2.4

NEW MEXICO TEST SITES



Taos land uses include agriculture and commercial forestry. Questa and Guadalupe Mountain are adjacent to one another and represent extensive sage grazing lands, a large molybdenum open-pit mine with related mill and settling ponds, as well as diverse commercial timber stands. The Bureau of Land Management administers much of the sage grazing land.

The Santa Fe quadrangle, the comprehensive test site, is an urban area at the base of the Sangre de Cristo Mountains and contains the city of Santa Fe. Strong population and development pressures are being applied to an area of limited resources. The city lies within, and to the south of, the Santa Fe River flood plain, a gently sloping valley. Topographic relief is great; within 10 miles the elevation drops from 8,500 feet in the east to 6,500 feet in the southwest.

Water is primarily supplied through wells but an increasing emphasis is being placed on reservoirs along the Santa Fe River. Many of the soils have high shrink and swell characteristics and low permeability which impairs the development of an area without help from city utilities and proper foundation development. Development over arroyos increases the flood hazard problem, and efforts to combat such development are being built into city zoning guidelines.

3.2.5 Utah Test Sites

The Utah test sites are in the Wasatch Front, an area of dynamic urbanization and dense population.

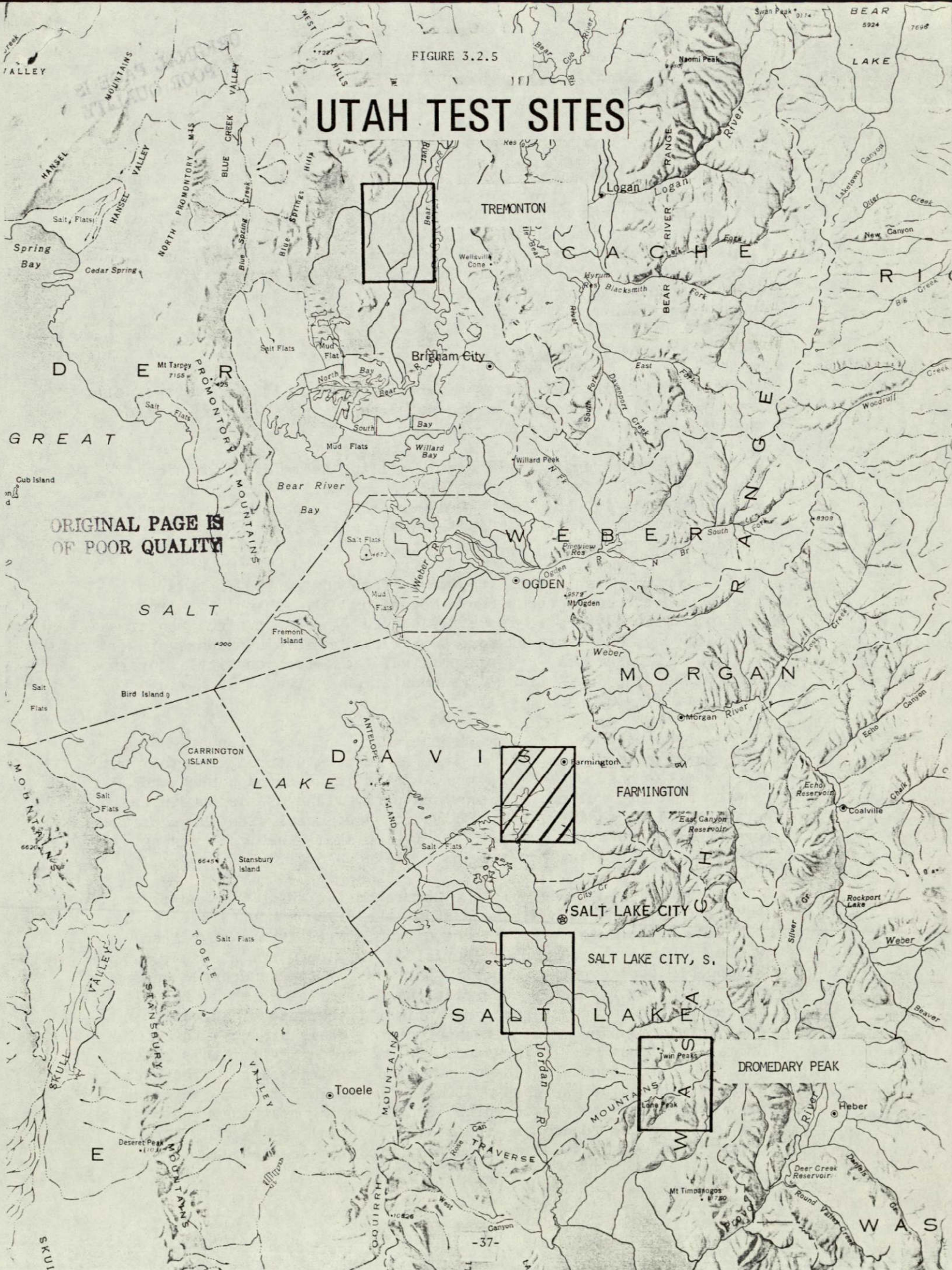
The Tremonton quadrangle represents something of the antithesis of The Wasatch Front urbanizing trend. Farms there are larger, the agricultural economy is prevalent, and the distance from urban clusters is great enough to reduce the threat of rapid change.

The Dromedary Peak quadrangle is the only representative of mountain environments. It is typically mountainous northeastern Utah, with steep slopes, many aspects, and covered by a mixture of conifers, deciduous trees, brush, meadow, and bare rock. The Salt Lake City South site is an ideal example of rapid urbanization and small field agricultural activity as well as land-use change near the city core.

Farmington, as the comprehensive test quadrangle, represents the epitome of dynamic variety. It includes an arm of Great Salt Lake, which itself is undergoing constant fluctuations in water level and economic/political battles for industrial, recreational, wildlife,

FIGURE 3.2.5

UTAH TEST SITES



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and hydrologic demands. The transition from irrigated agriculture to urban/industrial/transportation corridor uses is of great concern to planners in the area for three reasons: (1) loss of farmland; (2) scattered and uncontrolled development; and (3) encroachment into sensitive foothill areas threatened by flooding, faulting, and slumping. Foothill development further compounds the hazards of instability, threatening land and structures and seriously reducing big game winter habitat.

3.2.6 Wyoming Test Sites

The Wyoming test sites offer a variety of land uses, including energy (coal) development, urban development, water storage, forestry and grazing.

Acme quadrangle is in gently rolling terrain, underlaid by thick coal deposits. It is the site of an active strip coal mine, one of the few in the Wyoming Project area. Riparian vegetation and agricultural land uses, as well as grazing areas, are present on the quadrangle.

Hunter Mesa is close to the Buffalo quadrangle, but is in the lower reaches of the Bighorn Mountains. It is wholly within Bighorn National Forest, is mostly wooded (lodgepole pine, ponderosa pine, aspen), and contains some significant mountain meadows or "parks." Pressure for new recreational facilities on sites contained on that quadrangle is likely, as population increases in Buffalo to the east.

Lake de Smet, West, is to the north and west of nearby Buffalo. This quadrangle covers much of Lake de Smet, a natural reservoir not far from the base of the Bighorns. It is in dissected table land, with low to moderate relief. The most extensive land use is low-intensity grazing, although irrigated cultivation does occur along some of the creeks that cross the quadrangle. It is likely that coal mining will soon take place along the margins of Lake de Smet.

Buffalo quadrangle is the comprehensive test site and is in gently rolling terrain at the base of the Bighorn Mountains. It is the site of Buffalo, Wyoming, one of two cities in the test area whose population exceeds 500 (Buffalo's 1970 population was 3,394). Strippable coal deposits underlie portions of the quadrangle and coal mining is presently occurring some six miles north of Buffalo. As regional development proceeds (primarily because of increase in coal extraction and related technologies), it is expected that Buffalo will be heavily impacted. It was primarily for this reason that the Buffalo quadrangle was selected for inclusion in the study. While expansion of the town of Buffalo seems inevitable, there are many constraints to growth which lead to vexing planning problems. Land uses in the quadrangle include residential, commercial agriculture, and grazing, as well as some riparian vegetation.

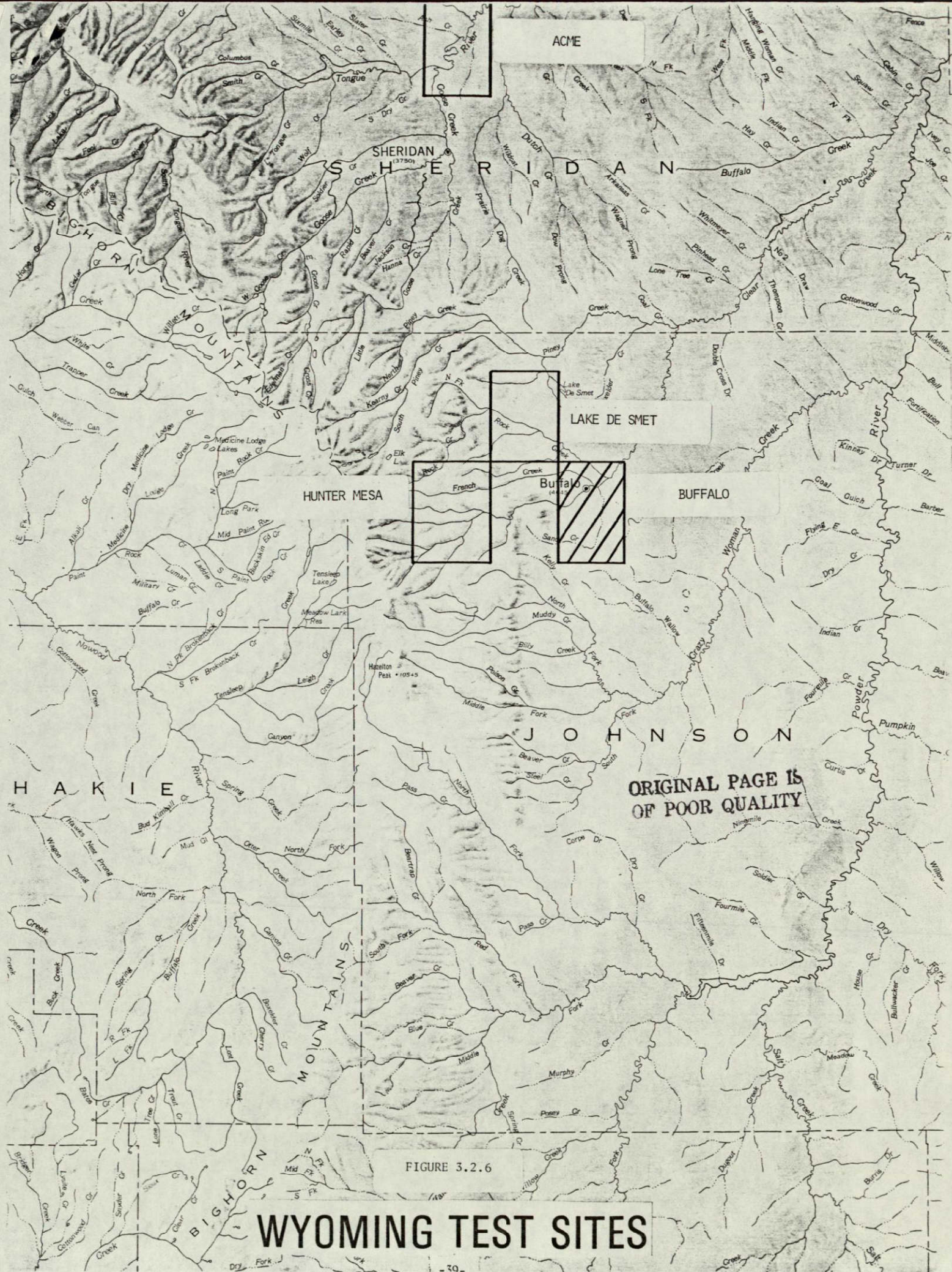


FIGURE 3.2.6

WYOMING TEST SITES

TABLE OF ORGANIZATION

FIGURE 4.1

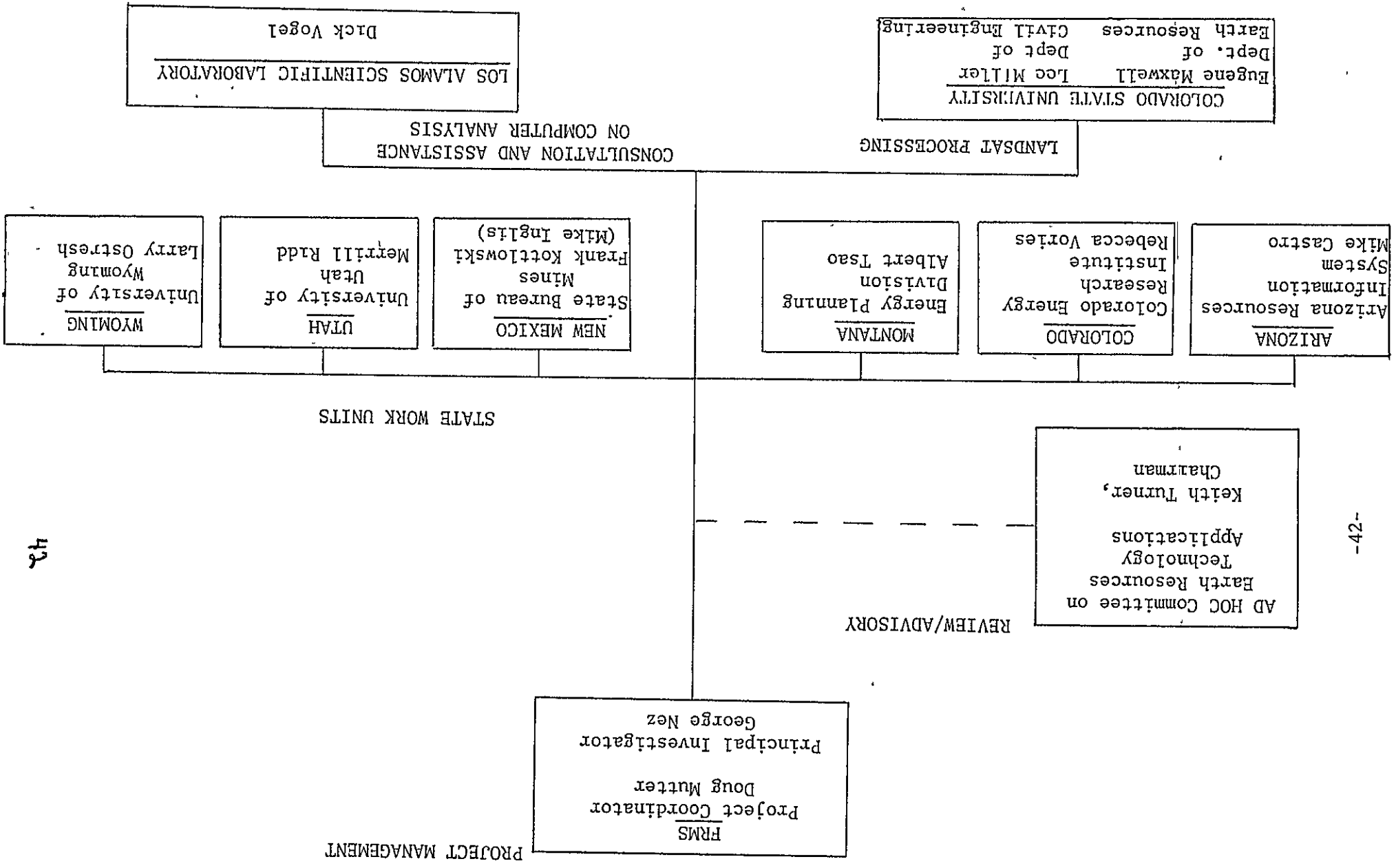


FIGURE 4.2

AD HOC EARTH RESOURCES

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On key questions of policy and technique, the Federation Committee on Earth Resources Technology Applications (representing scientific and administrative bodies in the region) periodically met and reviewed the project.

4.2 Geographic Approach

Two representative interstate resource areas of approximately 5,000 square miles each were selected, particularly to cross state boundaries and link four of the states to encourage use of common remote sensing procedures, land/cover categories and analytic procedures. The Montana and Wyoming test region included active surface mining coal lands, irrigated and dry farming and limited watercourses subject to intensive water engineering. The Colorado and New Mexico test region followed the main drainage of the Rio Grande River. The two intrastate test regions of Utah and Arizona were defined as dynamic metropolitan areas where conflicts would continue to occur between existing and potential land and water uses.

Within each state's large test regions, four quadrangles were selected as having characteristic types of land use and vegetation. These quadrangles were used for training site work and for LANDSAT land use/cover mapping. Ultimately one of the four quadrangles became the target area (comprehensive test site) for full land use analysis. Correspondingly, final LANDSAT verification work was conducted in these quadrangles (see also Chapter 3 of this report).

4.3 Procedural Approach

Four general phases were followed as outlined in the following summary of the project procedure:

1. Data procurement and preparation for later analyses.
 - Large study areas were reviewed and four 7½-minute quadrangles selected in each state.
 - Initial land use and cover classes were selected, beginning with 19 classes of Level I adapted from the USGS Anderson-Hardy table.¹ These were later modified to those shown in Figure 4.3.
 - Initial rules and procedures were defined for selecting sites and describing and documenting site data.
 - High altitude color infrared photography was procured from NASA to aid in the training-site work.
 - Multidate LANDSAT imagery was selected for three or four seasons (1974) for each test area.
 - Compositing exercises were formulated for the comprehensive test quadrangle in each state according to a characteristic resource management problem existing in the area.

¹Anderson, J.R., et. al., A Land Use Classification System for Use with Remote Sensor Data, U.S. Geological Survey Circular 671, 1972.

- Corresponding types of multisource data (maps) were selected and converted into 1.1 acre grid cells, with various weights assigned for relative importance. LANDSAT cellular maps were edited for selection of certain features to be used in the composites.

FIGURE 4.3

LAND USE/COVER CLASSIFICATION	
<u>Level I</u>	<u>Level II</u>
Urban Land	Residential Commercial/Industrial
Forest Land	Deciduous Forest Coniferous Forest
Rangeland	Shrubland Desert Shrubland Irrigated Grassland Nonirrigated Grassland
Agricultural Land	Orchards & Vineyards Irrigated Cropland
Water	Water Wetlands
Barrenland	Barelands Other Bare Rock
Unclassified	Unclassified

2. LANDSAT data analysis.

- A new LANDSAT Mapping System (LMS) for CCT processing was developed by Colorado State University.
- Initial grey scale LANDSAT printouts at 1.1 acre (pixel or picture element size) were produced for state quadrangles, showing unsupervised variations in reflectance.
- Classified land use/cover maps were produced for several quadrangles in each state, using their given third and fourth level land-use categories.
- Field verification work was conducted by the states, using common forms and procedures as adapted in regional workshops.

3. Multi-source computer map compositing.

- Computer work was performed by Los Alamos Scientific Labs for four of the states, using a special interactive grid mapping program, Generalized Map Analysis Planning System (GMAPS), developed from the Composite Mapping System (CMS-II) by Dr. Keith Turner, Chairman of the FRMS Advisory Committee.
- Two states -- Utah and Montana -- performed their own composite mapping with original programs (Resource Analysis Program (RAP), and Environmental Resource Geo-Information System (ERGIS).

4. Evaluation and reporting.

- Three formal advisory meetings were held to discuss and evaluate project progress and findings.
- Several other review sessions and state workshops were held.
- Individual reports were developed by each of the six states, CSU, and LASL (see appendices).
- This final report will be given wide distribution to technicians and policymakers alike.

4.4 The Multisource Approach

One of the project objectives, of course, was to utilize LANDSAT data in conjunction with data from other sources to demonstrate procedures and applications. Several factors warrant discussion of this approach.

The decision to use the finest grid size of 1.1 acre cells followed the initiative of Colorado State University in programming a new LANDSAT Mapping System for the purpose of efficient output of pixel² level maps (see the CSU report, Appendix A). This cell size was finer than necessary for most of the

²LANDSAT picture element, also about 1.1 acres.

other relevant data to be used in compositing, yet permitted the preservation in the data bank of full details for other purposes. The 1.1 acre cellular format provides the most discrete resolution for LANDSAT mapping, and offers a convenient line printer output scale of 1:24,000 which corresponds with the 7½-minute quadrangle map series of USGS and, therefore, enables use of overlays. A very significant commitment was that of using multidate (seasonal) imagery to demonstrate the efficiency of the new LMS software and provide as complete a series of land cover signatures as possible. This began with a search for good LANDSAT coverage during three or four seasons of one year, and the resulting adoption of an optimum sequence during 1974 (three seasons in some states and four in others).

Several workshops were held in which training-site analysis procedures were formulated. Subsequently, forms and instructions for documentation were developed by CSU and the Federation and published in the periodical project journal, The Remote Sensor.

The following types of training-site problems were anticipated:

1. Avoiding or fully describing variability within classes.
2. Documenting any significant slope, aspect and ground moisture variations.
3. Variable tree crown density and variable soil backgrounds.
4. Minimum required site sizes and number of sites.
5. Location and documentation of slope and aspect.
6. Possible changes of land use since the 1974 LANDSAT image dates and how to research the original state.
7. Locational referencing problems.

The compositing objectives required the selection of other non-LANDSAT topic maps -- social, economic and physical. These formulations were developed through several project workshops and additional meetings of interested agencies in each state, under the guidance of the state lead agencies. Compositing exercises were developed to analyze relevant resource planning problems in each test site area. (This is further discussed in Section 6.0.)

In this procedure, the land-use/cover information from LANDSAT served variously as positive or negative overlays or as land-use constraints in relation to the geological or urban characteristics, etc. shown by the other maps. Studies have been made in each state and in each federal agency concerning land-use classification systems for various purposes. Every state has several agencies concerned with this. Consolidation studies have been made by the Regional Planning Council of the Federation of Rocky Mountain States.³ But the user diversity persists, and the more appropriate agreement would be in a process for interchanging area land-use studies and observing essential nesting

³FRMS Land Use Classification Project. 1971.

FRMS Toward a Common System of First Order Land Use Classification. 1971

FRMS Toward a Common System of Land Use Classification. 1972.

FRMS Data Applications in State Land Use Planning. 1972.

definitions (levels of classification) plus establishing common geographic boundaries for polygon-grid and grid-to-grid nesting. In each functional area -- agriculture, natural resources, etc. -- there will inevitably occur different classifications of particular activities or conditions of resources. Therefore, a "general purpose" system must be approached from "elementary indicators" which can be mixed into more complex activities and functions.

Remote sensing can generally see only elementary indicators of certain kinds. It is equally important to use low-altitude photography, geological data, water data, industrial and urban data and other kinds of elementary indicators. These indicators, when converted into digital cells, are able to produce any sort of combinations for functional or activity maps at low cost; for example, "Forest Grazing Area," "Open Pit and Strip Mining," "Parks and Recreation Areas," or any index maps of specific environmental impact. This project attempts both the efficient reading of remote-sensed data, and the efficient manipulation of the other conventional elementary data.

To bring the states along rapidly within the project calendar, the most general compositing relationship was used -- namely, arithmetic compositing in which each topic map was factored by some relative weight and all were summed into the composite map. In some states, these composites were further recomposited with relative weights (see New Mexico and Colorado reports). This approach implied a known relationship of the factors. The variety of compositing programs (GMAPS, RAP and ERGIS) was salutary and offered the basis for efficiency comparisons, some of which are noted in the state reports. A uniform data entry system was established.

4.5 Related Activities

A basic consideration throughout the project was to involve and communicate to as many people as possible in the region who may be potential users of the type of process demonstrated.

As a result, a Project Briefing Paper was given wide distribution in the West, including copies sent to sixteen governors' science advisors. The project "newsletter," The Remote Sensor, was produced on eight occasions and distributed to the Advisory Committee and project participants, as well as many other interested persons. General information was disseminated through five articles to several thousand public and private sector leaders in the region via the Federation Forum, a regional newsletter. The December 1976 Newsletter of the Rocky Mountain Science Council also reported on the project.

A total of seven regional meetings were held related to project efforts involving some 125 persons. Another seven workshops were held in individual states involving some 76 state and federal agency representatives. Presentations were given by various project participants at several other regional meetings and workshops and report dissemination and discussions will continue.

5.0 LANDSAT DATA UTILIZATION

A principal objective of the project was to utilize digital LANDSAT data for land use oriented problem-solving by combining those data with other multisource data via computer mapping/compositing techniques. The analysis of digital data as opposed to optical products offers greater resolution (1.1 acres) and more efficient combination with other data. Colorado State University conducted all LANDSAT data processing, and this section summarizes their report (see Appendix A). Los Alamos Scientific Laboratory, with CSU, conducted the integration process, making the LANDSAT analysis results compatible with existing computer mapping techniques (see Section 6.0).

5.1 LANDSAT Data

Over 200 pages of computer listings of LANDSAT coverage over FRMS target areas were cataloged according to date, quality, and cloud cover. Calendars were then made of all possible coverages. There were up to eight different "image positions" which yielded data of interest in a given state. Each of the orbital groupings of these image positions had a calendar for each of the three years in question (1972 - 1974). On these calendars, CSU plotted all the high quality, less cloudy images, coding each to maintain 0, <10, <20, and <30 percent cloud distinction, as well as 0, 2, 5, or 8 quality ratings for each band.

A decision was made to limit a given seasonal set of images to one calendar year, in order to maximize the consistency of land-use patterns for one season to the next. The calendar year 1974 offered the best choice of seasonal options in almost all cases. 1974 was also the closest full year choice to the timing of field selection of training areas in the summer and fall of 1975.

On this basis, primary coverage selections were made for each of the six areas. Neither of the two common strips in Wyoming-Montana and New Mexico-Colorado could be covered by a single image on any date. It should be noted that the coverages for Montana and Wyoming, as well as

Colorado and New Mexico, were interdependent; all of one state's test sites, plus one of the other's, were typically on one image, while the rest of the other state's sites were contained within an additional image. Since training data from one site were extended to use in classifying other sites in the same state, the dates of these two images had to be either the same or within 18 days¹ of each other. Thus cloudy coverage had to be minimized over not four but eight sites for a given season, and cloud problems were encountered where they might have been avoided if the states' areas were more geographically distinct.

All primary alternatives were studied, using film cassette browse files at CSU and USGS in Denver. While the quality of the film files and/or viewing equipment was frequently so marginal as to prevent total insurance against unfortunate cloud locations, the search provided an invaluable definition of potential imagery and satisfied the objective that final choices were optimal. We do recommend that an upgrading of browse file display equipment be achieved and that a print capability be available at cost to the users of the regional browse files.

For each of the following LANDSAT scenes (See Figure 5.1), computer compatible tapes and 1:500,000 scale positive prints of MSS bands 5 and 7 were obtained.

Since the new program (see Section 5.3) for processing the multi-spectral tapes provided up to 18 channels of simultaneous data per grid cell, it was possible to use three or four calendar dates of imagery and, therefore, achieve a much greater discrimination of the land uses and cover types. Thus, seasonal LANDSAT coverage for spring, mid-summer, harvest season, and post-harvest season were used by four of the states, (Arizona, Utah, Wyoming, and Montana), and spring-summer-harvest seasons were used by the other two (Colorado and New Mexico). This posed a prodigious problem of statistical fine tuning and required ground truth of corresponding detail. Yet such detail was accomplished in only two or perhaps three of the states (Colorado, Arizona, and Utah). Numerous difficulties and sources of error have been discussed by the CSU report and the state reports. Following are some key points:

- First, there was needed extensive and seasonal ground truth for subtle differences of reflectance influenced by slope, aspect, moisture, vegetation overstory and understory, urban roofs, vegetation and mixtures in urban land uses, etc.

¹For spring coverage in Colorado and New Mexico, we were forced to separate dates in order to minimize clouds. Unfortunately, the two images did not completely overlap, and the Questa, New Mexico quadrangle had its northeast corner missing.

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FIGURE 5.1

SUMMARY OF LANDSAT IMAGERY OBTAINED

<u>State</u>	<u>Date</u>	<u>Location*</u>	<u>Quality</u> (4-Band)	<u>Cloud %</u>	<u>Test Sites Affected</u>
ARIZONA	2/17/74	39,37	8888	0	
ARIZONA	5/15/74	39,37	8888	0	
ARIZONA	8/31/74	39,37	8888	10	{ Paradise Valley, Tempe (Fowler) Granite Reef Dam
ARIZONA	11/21/74	39,37	5888	0	
COLO/NM	5/30/74	36,34	8888	0	
COLORADO	7/05/74	36,34	8888	10	Fox Creek, Zapata Ranch
COLO/NM	11/26/74	36,34	5885	0	
NEW MEXICO	5/12/74	36,35	8888	10	
NEW MEXICO	7/05/74	36,35	8888	10	Santa Fe, Questa
NEW MEXICO	11/26/74	36,35	8888	0	
UTAH	6/22/74	41,31	8888	0	
UTAH	8/15/74	41,31	8888	0	
UTAH	10/08/74	41,31	8888	10	
UTAH	6/22/74	41,32	8888	0	
UTAH	8/15/74	41,32	8888	0	
UTAH	10/08/74	41,32	8888	30	
WYO/MONT	6/01/74	38,29	8888	10	
WYO/MONT	7/25/74	38,29	8888	10	{ Decker, Hunter Mesa, North-Ridge
WYO/MONT	9/17/74	38,29	8888	0	
WYO/MONT	10/10/74	38,29	5858	10	Decker
MONTANA	6/01/74	38,28	8888	20	
MONTANA	7/25/74	38,28	8888	0	
MONTANA	9/17/74	38,28	8888	0	
MONTANA	10/10/74	38,38	8888	0	

*Path, row in BEST COVERAGE reference grid of U S.

- The program itself was new and complex, having been developed during the period when six different sets of ground training site data were coming in replete with gaps.
- There arose a problem of ascertaining "retroactive" ground truth in the training sites, because the best LANDSAT seasonal coverage was available for 1974, but field work had to begin in 1975 and in some cases go on into 1976. Only Arizona had near-adequate field detail for 1974 because they already had orthophotos for that year.

5.2 Training Site Data

The selection of training data from which signatures for each of the land-use categories are obtained is the most important part of any computer analysis of remote sensing data. The final classification maps will, of course, reflect the characteristics of the training data used in signature development. If the training data used for establishing a signature for a ponderosa pine ecosystem are representative of a particular stand of ponderosa pine, with a specific canopy cover density and a specific understory characteristic, then the final classification maps will show very good results for this specific ponderosa pine type, but may not produce good results for other variations of ponderosa pine. On the other hand, if the training sites for ponderosa pine were to be carelessly selected, in that they actually included other vegetation types, then a considerable confusion between these cover types could be expected.

These problems of training site selection were magnified beyond their normal importance for this project, since multidate, as well as multispectral imagery, were used for classification. In other words, when imagery from several dates are combined to form signatures for a class, there is a tendency for the training data to represent only those specific fields or locations and not be representative of a general cover type.

In retrospect, it is apparent that the selection of training data was the weakest point of this project because of the critical requirements of multidate data, and because the training site selection task was neither standardized nor carefully coordinated with CSU analysis efforts. The personnel in each of the six states had very different backgrounds and interests, ranging from people with very little experience in remote sensing to individuals with a great deal of understanding and competence. Under these conditions, the instructions given to the states and communications with the states were really not adequate to ensure the best results.

It is apparent that the instructions provided the states was an important factor in obtaining usable training data. It is also apparent that these instructions, frequent and extensive as they were in most cases, were less than adequate and could not take the place of first-hand experience with this kind of problem. More thorough instructions are needed, perhaps in the form of a training site selection manual, for future projects. Even with such instructions, the use of experienced personnel will always be needed to ensure the best results.

Computerized analysis of multispectral scanner data is dependent upon significant differences in the spectral reflectance characteristics of the categories to be classified. Basically, this means that computer analysis of LANDSAT MSS data is to all intents and purposes limited to the detection of land-cover differences. A cemetery, a city park, an irrigated pasture, and a golf course may all be essentially identical, relative to the existence of land covered by lush grassland and trees. The activities associated with these land uses are significantly different and are important to the land-use manager. A photointerpreter will probably have little difficulty, with large scale imagery, in telling the difference between the park, the cemetery, the golf course and the irrigated pasture. Computer analysis of MSS data, on the other hand, will very likely confuse these areas because of the similarity of cover types.

At the initial meeting for this project (held April 8 and 9, 1975, in Denver), the problems with the USGS classification system² were discussed, and a new selection of Level II land-use categories was prepared, which was subsequently refined to that shown in Figure 4.3.

The objective was to test the absolute limits of the LANDSAT Mapping System. The representatives of each of the states were informed that crop lands, for instance, could be subdivided into specific crop types for consideration on this project. Therefore, each of the states provided training data on as many subcategories as they wished.

Suffice it to say, at this point some of the states provided many subdivisions (81 in Arizona) of the original 19 categories, which ultimately pushed the capability of the system beyond its current limits. Other states kept primarily to the list developed on April 9 and did not make any attempt to establish subcategories. Naturally, this resulted in considerable difference in the ultimate results obtained for each of the states.

The following Figure 5.2 summarizes the states' training site exercises. Every state had specific problems, some more serious than others. The need for standard procedures and clear communications was very apparent. There was also a need for a clear hierarchical system of classification for each states' land-use categories to allow for consistent class division or combination.

²Anderson 1972, op. cit.

FIGURE 5.2

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State	Number of Land Use Classes	Number of Training Sites	Training Fields in Test Sites	Ancillary Data Descriptions	Experienced Personnel	Result
ARIZONA	81	245	More	Field Trips Orthophotos	Yes	Good
COLORADO	45	161	Yes	Field Trips Existing Data	Yes	Good
NEW MEXICO	35	48	Yes	Field Trips Existing Data	Yes	Fair
MONTANA				Field Trips Existing Data	No	Fair
UTAH	50	175	Yes	Air Photos Field Trips Existing Data	Yes	Good
WYOMING	19	76	Yes	Field Trips Existing Data	No	Fair

*See the CSU Report, Appendix A for a detailed evaluation and individual State Reports, Appendices C-H, for procedures of each state.

5.3 LANDSAT Mapping System

Initially, this project called for the use of CSU's pattern recognition system, RECOG. RECOG, however, had been developed primarily as an educational tool for use in the undergraduate and graduate remote sensing courses which are taught at CSU. This system did not provide for the coordinate transformations required to produce rectangular and scaled maps, as was desired for this project. Nor did this system provide for any preprocessing of the data or for the specialized selection and refinement of data which was believed necessary. As a training tool, it had been designed to provide for many opportunities of human interactions with the system. In other words, it was necessary for the operator of the program to interact with the data flow and make manual decisions and selections at many points. Although ideal for instructional purposes and desirable for certain kinds of basic research, it was seen primarily as an opportunity for many human errors to occur during the processing of the large volume of data required on this project.

Other capabilities not provided by RECOG, which were needed for this project, included means to register files of data so that multirate files could be prepared for the desired multirate processing. Furthermore, means of displaying training data and preclassification analysis results were needed to permit the efficient analysis of the large quantities of training data received from the states.

In summary, capabilities to be provided by the LANDSAT Mapping System (LMS) are listed below:

1. Fewer points of human interaction in the data processing flow.
2. Improvements in the efficiency of all of the computer programs to be used.
3. A coordinate transformation and scaling capability.
4. A data preprocessing capability to include generation of new variables and spatial filtering.
5. A capability to form a single registered multirate file for combined multivariate analyses.
6. Improved training data analysis to include the ability to extract irregular fields; maintenance of the training data on tapes; provision for semiautomatic cleaning or refinement of the data; calculation of numerous training data statistics; and the capability to display the training data in map form to verify location and spatial distribution of data performance.
7. Provision for more versatility in classification methods and display of classification results.

The following descriptions will show that most of these desired capabilities were met under this project.

The LANDSAT Mapping System is composed of four steps. Each performs a specific task in the production of the final results. The tasks involve (1) preprocessing of LANDSAT data, (2) analysis of class acceptability, (3) development of class signatures, and (4) final classification and display.

The descriptions in this section are based on the original design of LMS. Some of this capability has not been achieved as yet, as will be discussed. A more detailed description of LMS may be found in Appendix A, the CSU Report.

5.3.1 Step I

The first module of the LANDSAT Mapping System is called Step I. It prepares LANDSAT data received from the EROS Data Center for easier and more efficient processing and modifies the data format to be compatible with CSU's programs. This step performs several data preprocessing functions, including rotation and rectification of the spatial coordinate, correction for geometric errors and spatial filtering. The step also provides for data displays in the form of computer generated graymaps. It consists of four separate programs linked together by a system of JCL (Job Control Language) cards. The operational sequence is given in Figure 5.3.1.

5.3.2 Step II

The module of LMS called Step II was designed to make it possible for the user to interweave images from various dates and/or ancillary data to form a multitime-multivariate file of a particular map area. This step is composed of two programs -- one which combines the channels and one which trims the data file to a user defined map region. (See Figure 5.3.2.)

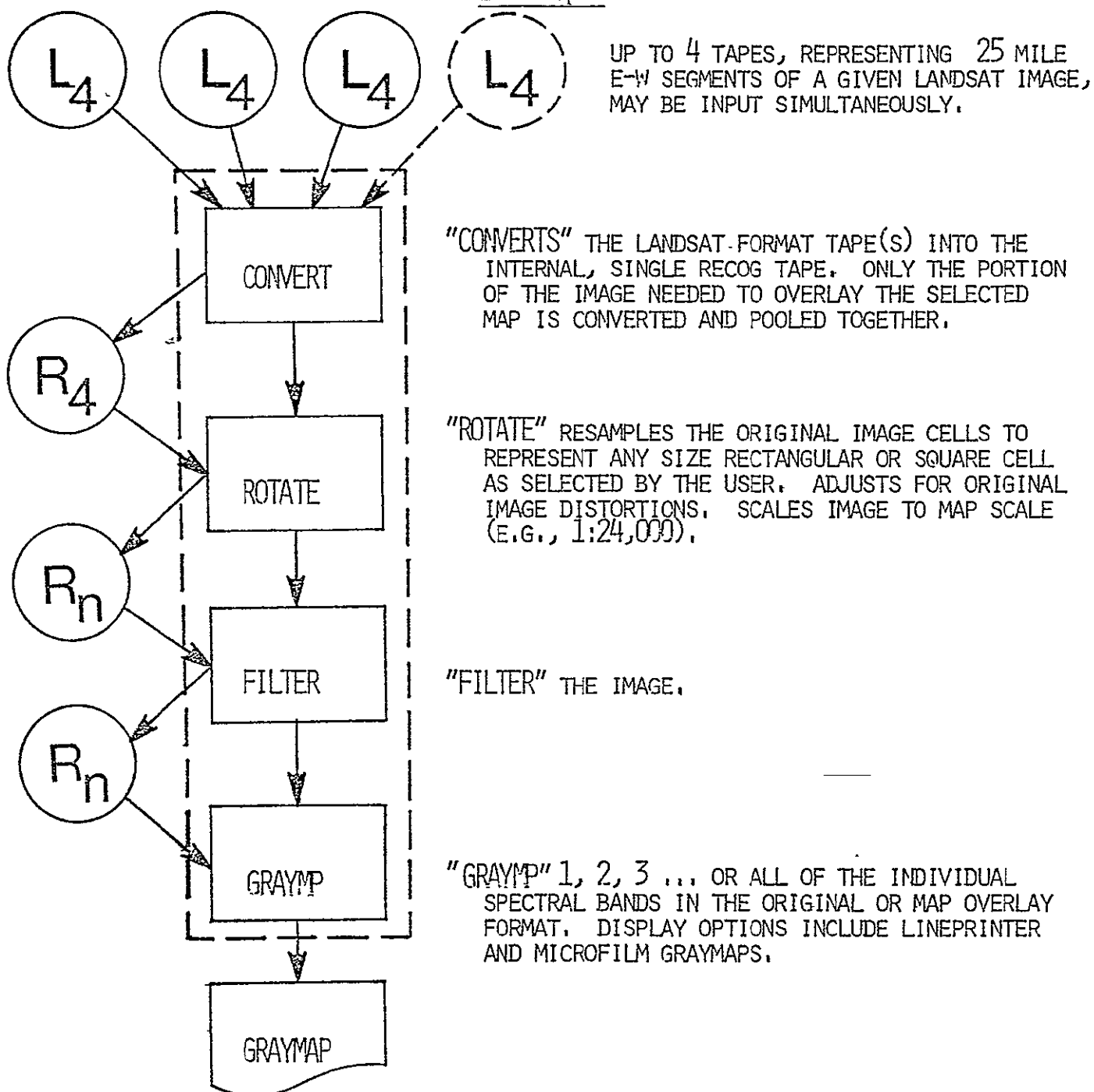
5.3.3 Step III

The third step in LMS is designed to analyze training data and compute statistical "signatures" of the classes to be mapped. The signatures are composed of a covariance matrix and a mean vector which statistically describe the spectral characteristics of the training fields for each class. This step is the most important of the four that comprise LMS. The analysis strength and flexibility of this step gives LMS a distinct advantage over other scene analysis systems. It is well known that computer classification of multispectral data is only as good as the signatures used for the classes. The programs of Step III give the analyst the opportunity to optimize signature definition and thereby maximize the accuracy and significance of classification results.

The module is composed of nine programs, each performing a specific task directed toward the generation of the above signatures (see Figure 5.3.3.) EXTRACT and TRANSF2 are preliminary

FIGURE 5.3.1

LMS Step I



L_4

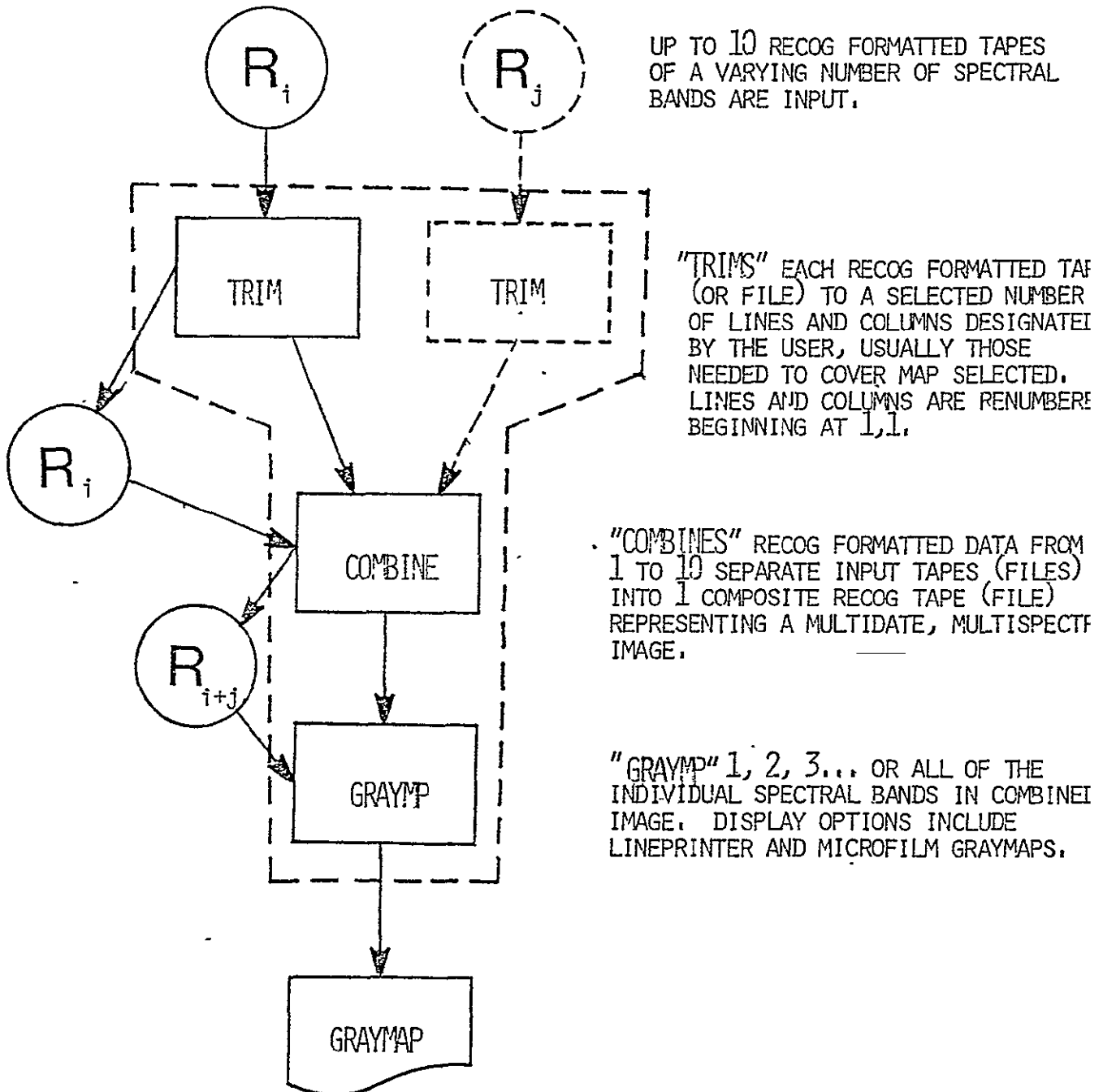
"LANDSAT" COMPUTER COMPATIBLE TAPE (CCT) AS SUPPLIED BY EROS DATA CENTER.

R_4

"RECOG" FORMATTED TAPE (OR DISK) FILE - AS STANDARD TAPE FORMAT USED THROUGHOUT THE IMAGE PROCESSING ACTIVITY. ($N = 1$ TO 4)

FIGURE 5.3.2

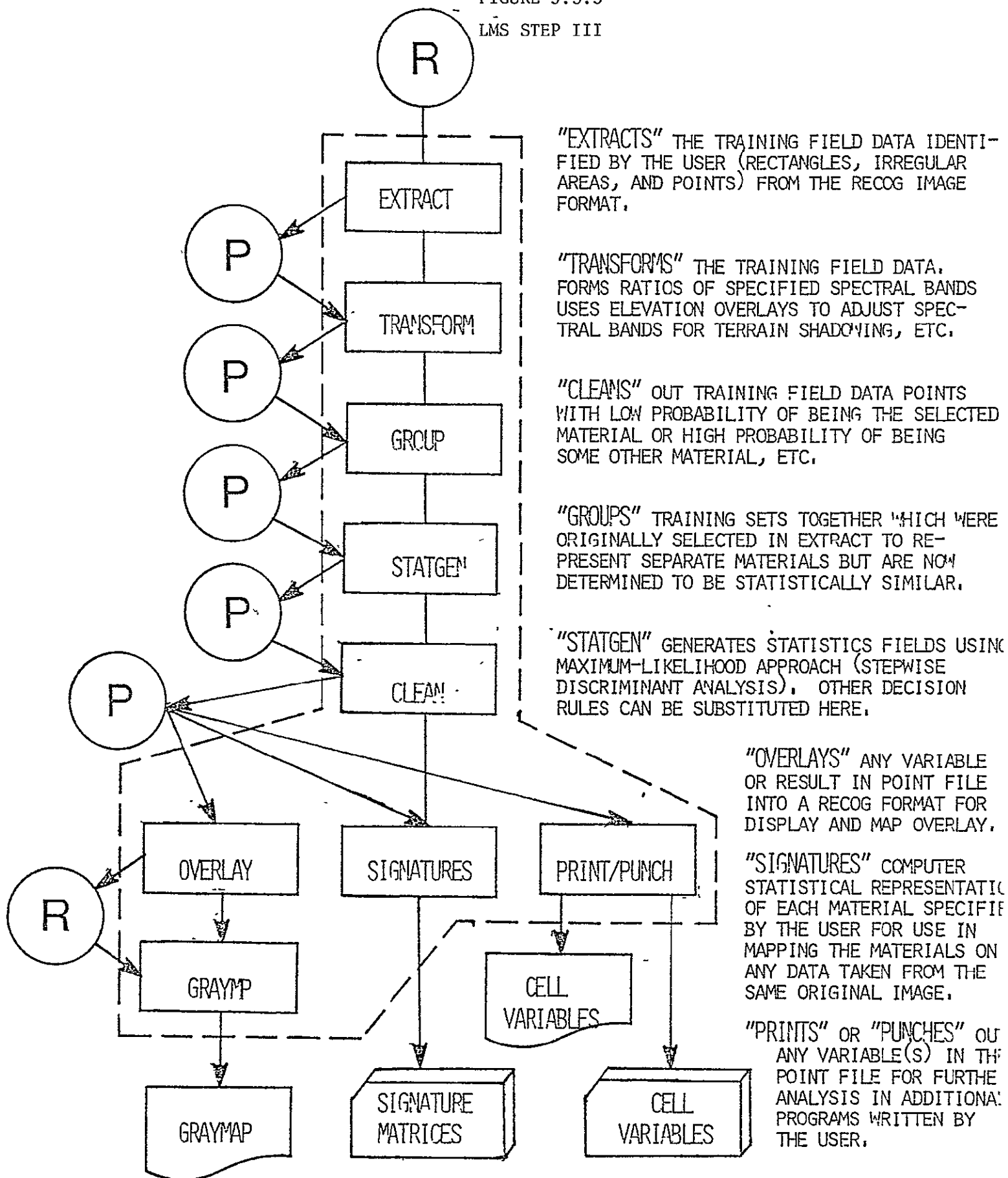
LMS Step II



($i + j$ are any integers)

FIGURE 5.3.3

LMS STEP III



(P)

"POINT" BY POINT TAPE (OR DISK) FILE. - AN INTERNAL TAPE, DISK, AND/OR CARD FILE FORMAT WHICH CONTAINS ONLY THE EXTRACTED TRAINING FIELD DATA AND MAINTAINS ITS CORRECT MAP OVERLAY POSITION.

programs which respectively isolate the training data from their source file and expand the data to include any extra transformations of original variables. The resulting output is then ready to be analyzed with the other programs. STATGEN calculates various statistics on the data and is the central assessment tool. CLEAN and GROUP are manipulative programs which delete or recombine training data at the operator's command. OVERLAY and PRIPUN are pixel-by-pixel output devices, the first in map form and the second either print or punched cards. SIGNIT generates the class signatures when the training data has reached a satisfactory level of performance.

5.3.4 Step IV

The final step in the LMS system performs the classification of each pixel of an image area and then displays that area via some visual medium. At this time the only visual media that have been developed for this step are microfilm or a printed symbol map. This step uses the signatures produced by SIGNIT in Step III, and the target data file produced by Step II to generate the desired output classification map.

5.3.5 Present Status of LMS Development

The LANDSAT Mapping System is a valuable system because of its many capabilities and options; but, because of the problem discussed below, the system is in many ways difficult to use and in some cases more expensive than necessary. A complete documentation of the system is not available due to time and money constraints and is very badly needed.

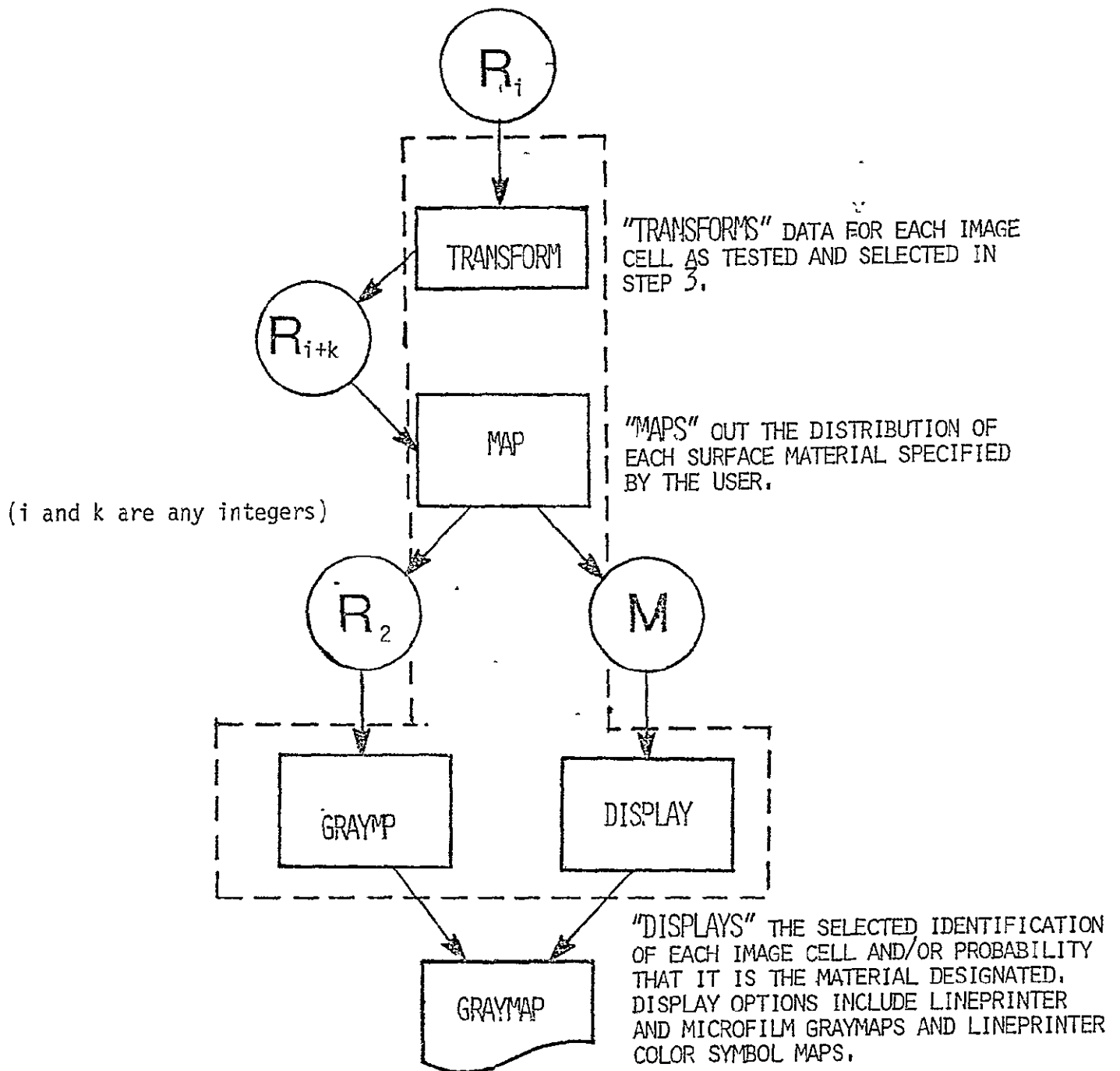
During the development of LMS, the programs were written by a small staff under very tight time constraints. Therefore, only minimal documentation was written. Also, because of the lack of time, parts of the system are not efficient. A particular case in point is program OVERLAY in Step III, which in most cases is too expensive to run, but remains a valuable tool in determining the character of individual results during Step III processing. The package has not been entirely completed (90 percent complete) and contains some problems which currently impede its use.

5.3.6 Future LMS Development

The LMS package, because of its many options and capabilities in performing classification of various areas, is a valuable tool in the field of remote sensing. But as it currently exists, it would be difficult for anyone to use the software because of the lack of optimization and documentation.

FIGURE 5.3.4

LMS Step IV



R

"RECOG" FORMATED TAPE FILE WITH n CHANNELS.

M

"MAP" FILE WHICH CONTAINS CLASSIFICATION OUTPUT FOR EACH PIXEL IN A SPECIFIED MAP REGION.

The decision points encountered in the operation of LMS need clarification in terms of the implications of alternatives presented. In order to export LMS, subsequent to the above improvements, the preparation of manuals for training data collection, software operation, installation, and program maintenance must be achieved. These have been outlined in Appendix A, the CSU Report.

5.4 Processing the Data

5.4.1 Preprocessing LANDSAT Data

In this section we will describe the problems encountered and the results obtained while using Steps I and II of LMS for the preprocessing of LANDSAT data. Unfortunately, Steps I and II of LMS were not fully developed when we initiated data preprocessing for several of the states. Therefore, we had a continually changing system with little or no documentation during this preprocessing stage. This compounded and greatly magnified the normal problems always encountered when using digital data. First, we will discuss the kinds of problems that any user of LMS will likely encounter, and then we will briefly describe the problems and results associated with the preprocessing of data for each state.

There were many problems which resulted from use of software which was under development and undocumented. They were very frustrating and caused many delays and some cost inefficiencies. These problems should not be encountered by future users of LMS and so will not be discussed here to any extent. The greatest importance of these problems lies in the impact they had on the design of Steps I and II of LMS. A very regimented step-by-step procedure was required if this system were to be used by relatively inexperienced personnel. Initially, a series of equations were written for determining the location of data for target areas on the digital tapes. The use of these equations resulted in many errors and many repeat operations of Step I. Step I was modified, therefore, so that the user need only identify one corner of the area to be extracted. The software was then designed to compute the other parameters required to extract the correct data for the target area. This greatly reduced extraction errors but did not completely eliminate them.

Mistakes in extracting data from the digital tapes continues to occur, primarily because of a lack of exact correspondence between the region shown on the 1:500,000 scale printed images and the region encompassed by the data on the digital tapes. In other words, there were instances where the image prints did not correspond exactly with the data on the computer compatible tapes. These vertical location errors were at times as great as 50 lines. Horizontal location errors were generally of small magnitude and did not present a serious problem. These difficulties could be circumvented, of course, by extracting data for regions which extend significantly beyond the target area. This can be costly since more data is processed than necessary; but in the final analysis, it will probably save money since it will eliminate the need for repeat computer runs when target areas are missed.

Radiometric errors, caused by differences in the sensitivity and calibration of detectors on LANDSAT, produce marked, horizontal striations on the images. This problem is particularly serious for MSS band 7. The rotation and filtering of the data reduce the seriousness of these radiometric errors, but for some of the worst images, the problem was still quite significant and can be seen on the final classification results. The LANDSAT tapes do provide some calibration information which could be used to further reduce radiometric problems. At present, LMS does not provide an algorithm for making use of this calibration data, so no additional correction was possible under this project. Provision for such correction will be a high priority item for continued development of LMS.

Parity errors and the associated missing data affected the images for several states. It was not a serious problem except for one Wyoming quadrangle which will be discussed later. When only one line of data is missing, the two-dimensional filtering of the data provides some fill-in capability. This is far from adequate for the filtering intensities used on this project, however, and a surface fitting algorithm should be developed to replace missing data.

Unfortunately, it is very difficult -- if not impossible -- to identify radiometric errors and parity errors on the image prints used to select image dates. For this reason, the quality of the data is unknown until preprocessing begins.

Another data problem which was not detectable on the image prints was the presence of thin cirrus clouds or small cumulus clouds in some of the images. Some very thin clouds in Wyoming were not detected until their effect was noted during the analysis of training field data. It would be desirable in the future to develop software to adjust radiance values under thin cirrus clouds, based on the radiance of near-by areas and to fill in data for locations underneath very small cumulus clouds.

The same filter weights (filtering intensity) were used for all image dates for all states. This was undoubtedly not optimum filtering. In those areas, such as urban scenes, which contained many small but important features having high spectral contrasts, it would have been preferable to filter with less intensity. For certain wildland scenes and some large water body areas, however, it would probably have been desirable to filter with greater intensity. The intensity used was probably adequate for most situations with the possible exception of the urban, suburban areas.

No problems were encountered in using the filter algorithm, but it is likely that improved results could have been obtained in some quadrangles if the algorithm had been more flexible (provided different weights for different scene conditions).

The between-date registration of scenes and the overall registration of the scenes to the 7.5-minute quadrangle maps presented very few problems in agricultural and urban, suburban areas, but proved to be quite difficult in most wildland regions. The serious problems encountered generally resulted from either changing scene characteristics from date to date, or the lack of image contrast for certain quadrangles.

For example, the Dromedary Peak quadrangle was by far the most difficult Utah quadrangle to register, but it was not because of lack of scene contrast. The problem lay in the changing characteristics of the scene in this very rugged terrain. Specifically, the apparent location of ridge lines changed from date to date because of the shifting of shadow lines as the sun zenith angle changed.

On the other hand, in Wyoming and Montana some of the quadrangles contained no major topographic or geographic feature for use in establishing registration. These relatively flat areas contained no ridge lines, no lakes, nor any other feature to ensure accurate registration. Under these conditions, there was probably a certain amount of residual errors in the final registration results. In most instances, however, a careful examination of the imagery located several vegetation or topographic features which were consistent over the dates in use. It is likely, therefore, that the between-dates registration was, in most instances, within one pixel. Final registration to the topographic map, however, could have contained errors of two or three pixels for several quadrangles.

5.4.2 Analysis of Training Data

Step III is that portion of LMS which provides analytical tools for the evaluation and optimization of training data. This could be called the signature development step of LMS. Without question, this is the most important and critical step of any image analysis system, since the final accuracy and quality of the image analysis are dependent upon the accuracy and validity of the signatures. The computer analysis of the image data can do nothing more than compare the spectral characteristics of each pixel with the spectral signatures which have been established in Step III. If the spectral signatures are wrong, the classification results will also be wrong.

Since the training data generated by each date differed appreciably in character, quality, and documentation, treatment of those data varied accordingly.

Summary of Step III procedures:

1. Extraction of Training Data. The first procedure in Step III calls for the extraction of training data from the master files created in Step II. This is accomplished with program EXTRACT whose output is in the form of a POINT file where each individual pixel within the training fields can be identified and analyzed.

2. Generation of New Variables. After extracting the original data from the master files, there is the option of generating new variables through transformations performed on selected bands from the original data. This is accomplished with program TRANSFORM. For this project, new ratio variables were generated by ratioing MSS bands 7 and 5 and bands 5 and 4.
3. Initial Class Grouping. The user now has the option of reordering the training data pertaining to specific classes to facilitate the analysis of a subset of these classes. This is accomplished with program GROUP. This grouping of classes is needed because program STATGEN analyzes a user specified quantity of data, always beginning at the start of a point file. If only part of the classes is to be analyzed at any given time, therefore, it is necessary that these classes be at the front of the POINT file. The reasons for analyzing a subset of classes are discussed later in this section.
4. Analysis of Training Data. Program STATGEN generates all of the statistics used in analyzing the training data. These statistics include the mean vectors and covariance matrices of classes, a measure of the value of each of the variables in terms of F ratios, an F matrix for measuring the separability of each class from every other class, a within-groups correlation matrix to identify the correlation between variables, and a list of a posteriori probabilities used in the next procedure to eliminate individual pixels which are degrading the reflectance characteristics of specific classes.

(At this point, many options are available to the user. If all the statistical measures of class separability are satisfied, he can return to Procedure 3 above and access and analyze the next subset of classes. If the class performances are substandard, he may choose one or both of the next two following procedures:)

5. Cleaning Training Data. Program CLEAN is used as noted above to delete anomalous pixels in selected classes. In many instances, it may be desirable to operate procedures 4 and 5 in an iterative fashion, until the performance of each of the classes is acceptable. In other words, as pixels are deleted, the mean vectors and covariance matrices (this is the signature for each class) are modified and the classification results are usually improved.
6. Combining or Deletion of Classes. At this point, program GROUP can be used to combine classes which are not separable to establish a lower-level class or at least a class that is a combination of previous individual classes. This program can also be used to delete any class from subsequent analysis.

7. Final STATGEN Run. The final step in the detailed analysis of the training data normally will call for a combination of all classes used in each of the subsets of classes for a combined computation of classification statistics. This is to ensure a minimum of confusion between class subsets.
8. Calculation of Signatures. After all of the analysis and manipulations performed have been concluded to the satisfaction of the user, program SIGNIT is used to create final signatures for each class for use in Step IV.

5.4.3 Processing of LANDSAT Data

Upon the completion of the development of signatures for each land use category, processing of the LANDSAT data for each quadrangle to be classified began. This was accomplished in Step IV of LMS, using programs MAP and DISPLAY. The inputs to program MAP are (1) the mean vectors and covariance matrices which define the signatures for each of the classes; (2) the matrix of multispectral and multitemporal data for the area to be classified. Since a normal distribution of spectral values is assumed, program MAP calculates the probability density function for each pixel using the equation:

$$f(\underline{X} \mid C_i) = \frac{1}{(2\pi)^{N/2} \mid \underline{\Sigma} \mid^{1/2}} \left[\exp - 1/2 (\underline{X} - \underline{\mu}_i)^T \underline{\Sigma}_i^{-1} (\underline{X} - \underline{\mu}_i) \right] \quad (5.1)$$

where \underline{X} is the matrix of data in the spectral, temporal and spatial domains;

N is the sample size;

$\underline{\mu}_i$ is the mean vector for class C_i ; and

$\underline{\Sigma}_i$ is the covariance matrix for class C_i .

This equation is calculated for each class having a finite probability of occurrence within the quadrangle being mapped. For each pixel a decision for one class versus another is based on the simple comparison of density values given by

$$\frac{f(X_j \mid C_1)}{f(X_j \mid C_2)} \geq 1 \quad (\text{decide } C_1) \quad (5.2)$$

There is always the probability, of course, that a given pixel may not belong to any of the categories or classes being considered. A probability density threshold T is used, therefore, to establish a lower threshold, below which a decision will be made to leave the pixel

unclassified. This decision algorithm may be expressed by:

$$\begin{aligned} \text{If } f(X_j | C_i) < T & \quad (\text{decide none}) \quad (5.3) \\ \text{for all } i \end{aligned}$$

The threshold values T are selected on the basis that the probability density values for normally distributed populations of variables will have a Chi Square distribution. Therefore, the values for T are selected from a Chi Square distribution table. (See Figures 5.4.1 and 5.4.2 for examples of the 0% and 10% threshold land use classification maps.)

Under normal conditions, the processing of LANDSAT data (after a proper selection of classes and an adequate development of signatures) becomes routine. Such was not the case for this project. As already noted in previous sections, the selection of classes and the selection of data for the development of signatures left much to be desired in all of the states. In addition to the problems generated by these shortcomings, two new difficulties arose to compound the problems.

First, the covariance matrices would not invert, as is required by equation (5.1). Second, there were money problems since the large number of classes and variables raised the cost of classification beyond budget limitations. These problems are briefly discussed below, along with the procedures used in processing the data.

Frequently large matrices will not invert because of one or the other of two common problems. First, if a row or column of a matrix is repeated, the matrix will not invert because of the complete correlation between the identical columns or rows. Secondly, a large matrix will often be noninvertible when there is a large difference in magnitude of data values within the matrix. Essentially, this second problem arises from a lack of sufficient accuracy in computed values, resulting from limitations in computer word size.

Both the problems noted above appeared to exist for the signature covariance matrices developed under this project. It was discovered, for instance, that none of the matrices would invert when ratio variables, generated by taking the ratio of original LANDSAT variables, were employed. This appeared to be due to the correlation between the generated new variables and the original variables from which they were formed. On other projects we had successfully used ratio variables, but these projects used imagery from only one date, thereby reducing the total number of variables and the size of the matrix. Furthermore, the previous projects only involved classes of natural vegetation types. A comparison of the correlation between ratio and original variables for natural vegetation classes and such classes as residential and agricultural crops has shown a higher correlation for the latter classes.

FIGURE 5.4.1

Partial Map: LANDSAT LAND USE CLASSIFICATION -- 0% Threshold

LAND USE MAP

7.5 MINUTE QUADRANGLE

GUADALUPE MT., NEW MEXICO

SCALE 1:24,000

LANDSAT IMAGE DATES: May 15, 1974, November 26, 1974
July 7, 1974

CLASSIFICATION SUMMARY

(Classification Threshold 0%)

CLASS DESCRIPTION	SYMBOL	ACRES	PERCENT
PINYON-JUNIPER - open	A	3309	9
95P/SJ lush underbush			
PINYON-JUNIPER - open	B	4739	12
90P/10J soil underbush			
PINYON-JUNIPER - open	C	2140	6
70P/30J soil underbush			
PINYON-JUNIPER - closed	D	2210	6
cover-very little soil			
PINYON-SAGE - 50 sage/50	E	48	<1
pinion			
MIXED CONIFER - open 10P/	F	2090	5
50J/20P/20D			
MIXED CONIFER - closed	M	821	2
25J/50P/25D			
COTTONWOOD	T	10	<1
WESTERN WHEATGRASS	"	6	<1
MEADOW	"	471	1
GOOD CONDITION SAGE	"	9446	25
FAIR CONDITION SAGE	"	652	2
POOR CONDITION SAGE	"	11896	31
WINTERPAC	"	220	<1
PHAIREDOT TOWN/SALTBUSS	"	226	<1
TAILING POND	[]	91	<1
CLASSIFIED		38375	100
UNCLASSIFIED		0	0
TOTAL AREA		38375	100

NOTES:

1. THESE LAND USE CLASSIFICATIONS WERE MADE BY COMPUTER PROCESSING OF LANDSAT IMAGERY. MULTIVARIATE FILES WERE PROCESSED AS A SINGLE MULTIVARIATE IMAGE.
2. THE DATA WERE FILTERED USING A TWO DIMENSIONAL WEIGHTED AVERAGING TECHNIQUE. THIS MAY PRODUCE ERRORS OR UNCLASSIFIED BORDERS BETWEEN CLASSES HAVING LARGE RADIONOMETRIC DIFFERENCES.
3. EACH SYMBOL REPRESENTS AN AREA OF 1,523 ACRES. SMALLER SIZE REGIONS WILL BE IGNORED OR CLASSIFIED WITH THE SURROUNDING AREA.
4. THE CLASSIFICATION THRESHOLD ESTABLISHES A LOWER BOUNDARY FOR THE DISCRIMINANT FUNCTION. IF THE DISCRIMINANT VALUES FOR ALL CLASSES FALL BELOW THIS THRESHOLD, THE PIXEL IS LEFT UNCLASSIFIED. IN THE CLASSIFICATION, A GUARANTEE OBTAINED FROM A DATA SAMPLE THAT A GIVEN DISTRIBUTION, THE THRESHOLD PROBABILITY WOULD BE A TRUE PROBABILITY THRESHOLD.

THIS MAP PREPARED BY: COLORADO STATE UNIVERSITY,
FORT COLLINS, COLORADO 80523. UNDER CONTRACT TO:
FEDERATION OF ROCKY MOUNTAIN STATES, Project
Number: NGS 5-22338. For Additional Information
Contact: Eugene L. Maxwell, Director, Remote
Sensing Programs. (303) 491-5147 or 491-5601.

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FIGURE 5.4.2

Partial Map: LANDSAT LAND USE CLASSIFICATION -- 10% Threshold

FIELD 1 LINES 1 TO 142 HY 1 COLUMNS 1 TO 120 HY 1

FIELD 1 LINES 1 TO 142 HY 1 COLUMNS 12

LAND USE MAP

7.5 MINUTE QUADRANGLE

GUADALUPE MT., NEW MEXICO

SCALE 1:24,000

LANDSAT IMAGE DATES: May 15, 1974, November 26, 1974
July 7, 1974

CLASSIFICATION SUMMARY

(Classification Threshold 10%)

CLASS DESCRIPTION	SYMBOL	ACRES	PERCENT
PINYON-JUNIPER - open	A	1848	5
95P/SJ lush underneath			
PINYON-JUNIPER - open	B	2478	6
90P/10J soil underneath			
PINYON-JUNIPER - open	C	1140	3
70P/30J soil underneath			
PINYON-JUNIPER - closed	D	1208	3
cover-very little soil			
PINYON-SAGE - 50 sage/	E	7	<1
50 playon			
MIXED CONIFER - 50	F	1266	3
100P/50P/200P			
MIXED CONIFER - closed	M	240	<1
25J/50P/250P			
COTTONWOOD	T	0	0
WESTERN WHEATGRASS	"	2	<1
MEADOW	"	240	<1
GOOD CONDITION SAGE	"	7061	18
FAIR CONDITION SAGE	/	501	1
POOR CONDITION SAGE	-	6879	18
WINTERFAT	!	195	<1
PRAIRIEDOOD TOWN/SALTBU	!	226	<1
TRAILING POND	()	0	0

CLASSIFIED	23209	60
UNCLASSIFIED	15106	40
TOTAL AREA	38375	100

NOTES:

- THESE LAND USE CLASSIFICATIONS WERE MADE BY COMPUTER PROCESSING OF LANDSAT IMAGES. MULTISPECTRAL FILMS WERE PROCESSED AS A SINGLE MULTIVARIATE IMAGE.
- THE DATA WERE FILTERED USING A TWO DIMENSIONAL WEIGHTED AVERAGING TECHNIQUE. THIS MAY PRODUCE ERRORS OR UNCLASSIFIED BORDERS BETWEEN CLASSES HAVING LARGE RADIO-METRIC DIFFERENCES.
- EACH SYMBOL REPRESENTS AN AREA OF 1,1523 ACRES. SMALLER SIZE REGIONS WILL BE IGNORED OR CLASSED WITH THE SURROUNDING AREA.
- THE CLASSIFICATION THRESHOLD ESTABLISHES A LOWER BOUNDARY FOR THE DISCRIMINANT FUNCTION. IF THE DISCRIMINANT VALUES FOR ALL CLASSES FALL BELOW THIS THRESHOLD, THE PIXEL IS LEFT UNCLASSIFIED. IF THE CLASS SIGNATURES WERE OBTAINED FROM A DATA SAMPLE HAVING A GAUSSIAN DISTRIBUTION, THE THRESHOLD PERCENTAGE WOULD BE A TRUE PROBABILITY THRESHOLD.

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Sensing Programs, (303) 491-5147 or 491-5661.

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Whatever the ultimate cause, it was determined that the matrices would not invert for some classes when ratio variables were included. All such variables were, therefore, eliminated for the processing of the LANDSAT data. This undoubtedly reduced the separability of certain natural vegetation classes, since the separation of almost all rangeland and certain forest type classes are improved when ratio variables are employed.³

For certain classes, we also found that covariance matrix values covered a range from less than 10 to several hundred. This occurred because during some seasons there would be very little variability in certain spectral bands, whereas for another time of the year, the radiance values might become highly variable.

These problems were of a very serious nature because whenever the covariance matrix failed to invert properly, the classification results were completely meaningless. This being the first project for which we had undertaken multitemporal analysis of data, we had not previously encountered such difficulties. Not anticipating these problems, we had not allowed time for their solution; furthermore, since other difficulties had already caused project delays, we found ourselves with very little time to seek an optimum solution. Within the time available, the only solution was to undertake a modification of the covariance matrices. The first modification has already been noted; this was the elimination of all ratio variables. The second modification essentially involved the modification of signatures.

From the analysis of the training data, it was determined that the sample size and the lack of spatial distribution of our samples were probably, at least in part, the cause of both extremely small covariance and extremely large ones. This is merely a matter of having a sample size too small to adequately estimate covariance values. This statement is supported by the fact that these problems did not occur in those states and for those classes where a very large, widely distributed set of training data was available.

When the problem did occur, it was solved by computing a common covariance matrix for a group of classes having a similar reflectance characteristic. For instance, all of the forest type classes were grouped together (when necessary) to form a common covariance matrix. In this way, the sample sizes were increased and an invertible covariance matrix was obtained.

Better results would undoubtedly have been obtained if there had been time to establish larger sample sizes and a proper selection of classes themselves, in seeking a solution to these problems.

The cost problem associated with too many classes, and too many variables required some extraordinary modifications of our classification algorithm. It has been noted that equation (5.3) can be used to set a threshold for discriminant values, below which no class will be

³Maxwell, E.L. "Multivariate Systems Analysis of Multispectral Imagery" Photo. Engr. and Rem. Sens., Vol. XLII, No. 9, pp 1173-86, 1976.

selected. Using the same assumption, that the discriminant values should have a Chi Square distribution, the decision function given by equation (5.2) was preceded by a decision function

$$f(X_i | C_i) > T' \quad (\text{decide } i) \quad (5.4)$$

where the threshold values T' were selected for a 75 percent probability that the discriminant value belonged to the given Chi Square distribution. Using this combination of equation (5.4) and (5.2) whenever a class satisfied equation (5.4), the decision was made at that point and no additional classes were considered. If no class was sufficiently strong to meet the requirements of (5.4), all classes were analyzed and the class decision was based upon (5.2).

This decision algorithm was effective in reducing the cost of classification only if the most probable classes for a given quadrangle were analyzed first. Therefore, small samples of data were used to determine the dominant classes for a quadrangle. Specifically, pixels from every ninth column and every ninth line were selected for the initial analysis to determine the class order to be used in the final data processing. This is called a 9x9 test. After this determination was made, we also performed 4x4 tests (using every fourth column and every fourth line) to determine which classes could be eliminated from the final processing for a given quadrangle. This test was based on the hypothesis that if a class were not selected for a six percent sample of the quadrangle data (evenly distributed over the quad), it was unlikely that class had a significant population within the quadrangle. In effect, an a priori probability for the occurrence of classes was being determined. Those classes whose a priori probability was zero (based on a 4x4 test) were eliminated from the final processing of the quadrangle.

After all of the tests had been performed and the best selection of classes and class orders had been established, the final processing for each of three quadrangles within each state was undertaken. In some instances, the thresholding decision function, given by equation (5.4), was not used when it was determined that its performance was giving inconsistent results.

5.5 Results of LANDSAT Mapping Verification

A detailed verification analysis and comments about the classification results for each state are, of course, contained in the final reports prepared by each of the states (Appendices C through H). This section will comment briefly on procedures, the apparent classification results based on training data, problems encountered and obvious shortcomings of the results.

To obtain an accurate assessment of the quality and accuracy of any data collection or information gathering effort requires carefully designed and statistically valid sampling and analysis methodologies. Since each state undertook its own verification program, there exists a wide variation in the methods used and the accuracy of the data collection used for verification.

Ideally, a random selection of sites, from which verification data is obtained, should be used. Any other method of data selection will be found to produce a bias towards certain classes or certain field conditions. Unfortunately, the time and money required for such an ambitious assessment was not available. CSU prepared an overlay map showing 10 acre cells, which had been randomly selected by a computer program, for use by each of the states. Even under the best of conditions, it was not possible to obtain a sample size as large as would be desired.

However, it was realized that the random sampling scheme would not be applicable to certain land cover categories such as small area urban or industrial land uses. For these categories the best approach was to identify and verify most of the classes.

Methods used to collect the ground truth for verification varied widely, from vegetation type maps of the Forest Service, to photointerpretation of aerial photography, to actual onsite visits. Because of this variety of sources and the associated problems of accurate geographic referencing (for the 1.1 acre cells), the quality of verification data was variable. In some states the quality of the verification data was collected at the beginning of the project, when training data was collected, and in other states the verification data was collected after the computer classification mapping was finished. Neither method is entirely satisfactory: a simultaneous collection of verification and training data probably biases the verification results toward a favorable report; whereas collection of the data after computer classification mapping is completed may result in a more negative result than is deserved, because of differences in criteria for selection of class fields, and the time elapsed since the imagery date.

Accurate ground location of individual 1.1 acre LANDSAT pixels also presents a constant problem of verification accuracy. It would require a very time-consuming and expensive survey of verification site locations to know for sure that the mapped pixels and the verification spots are in the same location. This is one reason 10-acre cells were used for verification procedure.

In order to obtain a more complete analysis of accuracy, it would be desirable to assess the accuracy, both at the highest level of classification and at lower levels, as classes are aggregated.

States did not assign statistical confidence limits to their verification results. It can be said that, almost without exception, sample sizes were too small to achieve a high degree of confidence in verification accuracy. Basically, the difference of sampling schemes and analysis methods made it impossible to consolidate results from state to state. In reading the state results, as summarized in Figure 5.5, careful consideration should be given to the sample size. The technical literature indicates that a sample size of at least 50 is desirable. Since, in many instances, the accuracy figures are based on sample sizes of less than 10, we treat the results with a great deal of caution. Nevertheless, some general indication of the performance of the LANDSAT analyses is provided.

FIGURE 5.5

STATE VERIFICATION PROCEDURES AND RESULTS

STATE VERIFICATION PROCEDURES AND RESULTS

State	Simple or Complex Categories Used	Verification Sample Distribution Method (Statistically Random or Convenient Use)	Interpretation and Statistical Methods	Example Relative High Scoring Categories	Example Relative Low Scoring Categories	Comments
ARIZONA	Very many (81) categories, yet some are complex. Selection used also seasonal changes.	Used arbitrary sites based on much available field data.	Extensive treatment. Used diagonal matrix, detailed discussion.	Citrus Orchards Vineyards Grapes	Residential Pasture Mesquite	See Section 3.2 of Ariz report, Appendix C, for extended statistical and procedural coverage.
COLORADO	Well stratified forest, brush & meadowland categories.	Began with random overlay selected about half of sites, enlarged some sites	Set up computerized verification procedure for three types of errors. Produced diagonal matrix	Meadow Coniferous Deciduous Range	White fir Douglas fir Certain shrubs & grass (Irrigation) Ponderosa/ Meadow combination	See Section 3.2 and Appendix 8 of Colorado Report, Appendix D for extended statistics and evaluation
MONTANA	Stratified categories	Used random site overlay and extensive use of "V" forms, aerial photos	Simple frequency table, with narrative evaluation of probable causes of error	Dry hay Dry cereals	Mines Wheat Ponderosa hay Irrigated	See Section 3.2 of Montana Report, Appendix E.
NEW MEXICO	Many categories used -- some complex, some functional.	Used given random sites overlay, "V" forms, & field visits	No statistics reported	Sagebrush Meadows Conifers	Irrig. wheat Low Dens. Res. Commercial	See Section 3.2 of New Mexico Report, Appendix F
UTAH	Well stratified	Data collected early along with training data collection, used three methods of site selection. (1) Ocular examination (LANDSAT map with conventional maps & photos), (2) pre-selected sites, (3) random sites. Used aerial photos	Used diagonal error matrix and narrative evaluation of probable error causes	Water Marsh Alkali	Industrial New Residence Corn Chaparral	Through evaluation, in State Report, including cross-tabulations. See Section 3.2 of Utah Report, Appendix G
WYOMING	Some categories are complex & "functional"	Used random sites overlay and "V" forms, field visits	Used simple frequency statistics with narrative on probable causes of errors	Deciduous Grazing	Industry Commercial Golf Course Water (in some cases)	See Section 3.2 of Wyoming Report, Appendix H

These verification indications cover many procedural steps, from initial class definitions to training site selection, recording of land cover variables on a retrospective basis (in all states except Arizona), development of the new computer mapping program, handling multirate imagery, and numerous variables inherent in verification site selection and description. Indeed, verification procedure should be treated as a study in itself, in order to specify what is needed for an operational regional LANDSAT updated data bank. The entire subject of ground truth needs vigorous control. The six-state experience with this problem has led to certain recommendations by the Federation, particularly for the establishment of a system of Standard Test Sites.

5.6 State Classification Synopsis

Because individual states were given the option to test a variety of classification and verification procedures, the results are not consistent from state to state.

5.6.1 Classification Results From Arizona

On the basis of Level I detail, the results for Arizona appeared reasonable and consistent. The aggregation and simplification of desert shrub categories resulted in more informative and useful results than would have been the case if a finer category structure had been chosen at a cost of reduced accuracy.

It was apparent that rock classes were being confused with such development classes and shopping center, mobile homes, and the higher density residential categories. This is not surprising since most of these represent non vegetated land.

Agricultural classes were an exception to the maintenance of areal consistency. Many fields are shown with unlikely combinations of several crops. Field boundaries are usually inaccurate for two reasons. First, the problem of unavoidable within-pixel mixtures resulted in misclassifications. Secondly, spatial filtering tends to spread the boundaries between areas having different radiance characteristics.

Among the residential classes, the single family unit (SFU) types showed surprisingly appropriate distribution with the exception of commission error into barren areas. Commercial and shopping center classes performed in a similar manner to SFU's. Mobile homes were generally classed correctly wherever they existed, but the class was seriously overextended into other areas, producing large commission errors. Power plants and oil refineries were enigmas throughout the analysis, and showed expected inconsistency. Airport was, for practical purposes, entirely replaced by mobile homes. The factory class did not perform well at all, appearing in anomalous localities such as highway interchanges.

5.6.2 Classification Results From Colorado

Since CSU conducted the verification program for the Fox Creek quadrangle in Colorado, more information about the procedures used (their strengths and weaknesses) was obtained than for any other state.

The agricultural categories were distributed erratically due to the same problems of multidate definition which were observed in Arizona -- with three dates of measurements defining classes whose phenologies were at best distinct on only one date, the classifier tended to locate the categories according to compound field conditions rather than actual crop type. There were also uncertainties arising from questionable field descriptions, because of dependence on farmers' memories for ground truth. Wet pasture was distributed too widely being confused with small towns and possibly other crop types, which were omitted from the training program.

The valley floor natural cover classes seemed to perform quite well. Basalt butte, alkaline bare soil, greasewood, riparian grass, and cottonwood all were located in coherent and reasonably distributed patterns.

Development categories were successfully mapped largely to the extent that training areas comprised a large portion of their distribution. In other situations, small towns were found to replace gravelly areas on alluvial terraces, while the town of Manassa was almost entirely misclassified as pasture, alfalfa and plowed field. In addition, commercial classes were cropping up along roadways, possibly due to turn-out widenings. In any case, outside of the training areas, our development classes were very unpredictable.

In summary, the substandard results obtained for agricultural types could be improved through better multiseasonal ground truth. Development categories were poorly devised, and reselection by strictly visual criteria could improve results. In the natural cover categories, encouraging results were obtained for a majority of the classes and high error rates in some of these natural classes were caused more by faulty category selection than any other system problem.

5.6.3 Classification Results From Montana

By using a combination of supervised and unsupervised selection of training data for Montana, reasonable classification results were obtained. They undoubtedly do not represent the best results that could be obtained from LANDSAT multidate processing, however, and this fact should be kept in mind when reading the Montana state report.

5.6.4. Classification Results From New Mexico

The New Mexico mapping performance ranged from satisfactory to poor, largely controlled by the degree to which training signatures were extended geographically. The Santa Fe quad in particular was substandard, due to the fact that all of the training signatures for natural cover came from fields approximately 50 miles to the north. This in turn was the source of incompatibility between the extended natural types and the locally trained development classes, resulting in persistent mislocation of development classes on natural areas in the Santa Fe quad. The opposite extension problem was apparent in the Taos quadrangle. Old and new medium density residential seemed to be erroneously mapped over gravelly alluvial surfaces, and on forest-range boundaries.

Agriculture in New Mexico was represented by either irrigated meadow, alfalfa, or irrigated wheat. The latter was under-represented, and confusion was high between meadow and alfalfa.

In the northern quadrangles, the predominance of natural cover classified by local signatures yielded results which were encouraging at the Level I/II detail. Pinyon vs. grass/shrub range was particularly well differentiated according to comparisons of results vs. forest tinting (30%) on topographic maps. Within the forest types, major species breakdowns seemed to distribute themselves properly along altitudinal and aspect variations. Herbaceous classes were mapped with noticeable correlation to that portion of the moisture gradient which their training fields exemplified.

Guadalupe Mtn. was the highest map of the three, with the only serious problem arising from a lack of training on the Rio Grande gorge. There is some question as to exactly what information the sage and pinyon-juniper breakdowns convey, but they nevertheless differentiate between real ground conditions, and to that extent are inherently valuable.

In summary, the mapping performance within a class was so variable from quadrangle to quadrangle, that any single conclusion or accuracy estimate would have to be qualified by regional variation descriptions. Verification of the New Mexico results will be complicated manyfold by this need for careful stratification.

5.6.5 Classification Results From Utah

The classification results for Utah appeared to be quite reasonable and satisfactory. It was obvious that in the urban areas the residential, commercial, and industrial classes were being confused among one another and with certain other classes. One of the industrial classes, for instance, showed up in the mud flats of Salt Lake, where no industry existed. Apparently, the reflective characteristics of the mud flats was similar to concrete and macadam. In the final analysis, some urban classes were

not used in processing the data since it was apparent that the accuracy of classification was going to be too low to be of any value.

Classification of agricultural crops and natural vegetation cover types appeared to be in good order. In the Dromedary Peak quadrangle, for instance, it was noted that the different vegetation types seemed to be found primarily in fairly large homogeneous regions.

The division of the classes in the Dromedary quadrangle into subclasses based on slope and aspect was quite successful. By assigning the same symbol to the subclasses, the final map products looked quite reasonable, based on the information obtained from the training data.

CSU found it necessary to use modified signatures (average covariance matrices) to obtain satisfactory results.

5.6.6 Classification Results From Wyoming

The initial classifications for Wyoming were very poor. It was apparent even from a preliminary examination that the selection of classes and the selection of training data had not been adequate to achieve satisfactory results.

It should be noted that the Wyoming report was based on these initial results and does not, therefore, represent an assessment of the true potential of multivariate LANDSAT processing. This was particularly true since the key quadrangle for Wyoming, the Buffalo quadrangle, was probably the poorest of the three that were processed.

Because of the obviously bad results obtained for the Buffalo quadrangle, a decision was made to obtain new training data for a new selection of classes for that quadrangle and to reprocess the data. This reprocessing was completed just a short time before the completion of this report and shows very satisfactory classification results. Unfortunately, these results were not available in time to be included in the Wyoming state report.

The classes for the repeat analysis of the Buffalo quadrangle included nonirrigated and irrigated rangeland and hay fields segregated according to productivity or biomass values. These production classes or range condition classes performed quite well and show the effects of over-grazing and availability of irrigation water.

All of the classes were included in the final processing of the Buffalo quadrangle; no signature modification was necessary and only equation (5.2) was used for a decision algorithm.

6.0 COMPUTER COMPOSITE MAPPING

6.1 Approach

A complementary relationship between LANDSAT maps and other sources and forms of land use information is made possible through grid mapping and compositing. Such relationships for analysis and simulation are particularly useful if not essential, for full utility of these two powerful technologies in regional planning, in resource studies for agriculture and mineral industries, etc.

This project used several procedures of cellular mapping to supplement LANDSAT CCT products. It was necessary to map from other sources certain land use "activities" which could not effectively be mapped by LANDSAT and had no distinguishing reflectance characteristics -- essentially only man-made patterns. For a spatial data bank there is available a wealth of data such as population and housing census, building and zoning maps, agricultural crop and soil maps, utility system maps, etc. Most of this data is convertible into whatever grid cell pattern is adapted for LANDSAT CCT maps. In such flexible form, it is possible to reconstitute some of the complex relationships existing on the ground and in social and economic activity, which has been "abstracted" in various ways and through various media.

6.1.1 Compositing

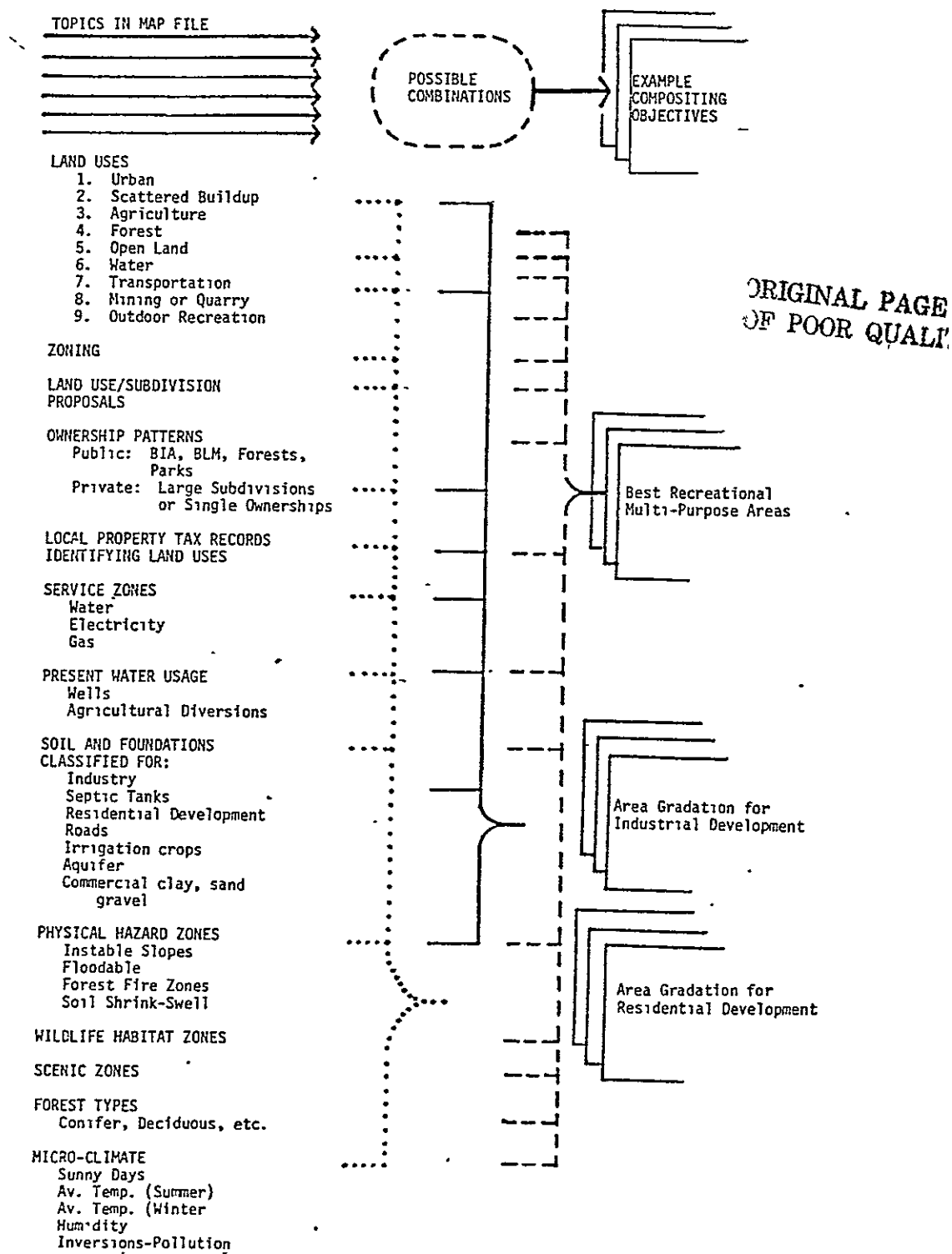
While data banks require many sources and forms of information, the optimum use of LANDSAT CCT maps in such a bank is to bring in the most current synoptic land surface state. For example, the several exercises in "urban construction feasibility mapping" carried out in Arizona, New Mexico, Utah, and Wyoming place most weight on maps of soils, slopes, and flood-prone areas, relying on LANDSAT mainly for constraints such as prime agricultural lands, drainage ways, etc. to be protected from urbanization. (See Figure 6.1.1.)

In general, computer mapping and manipulation processes can be divided into two major categories: (1) the grid or cellular system, and (2) the polygon system. The cellular system can be

FIGURE 6.1.1

USING A MAP FILE FOR VARIOUS COMPOSITING OBJECTIVES

When a cellular map file grows to a number of topics on resources and socio-economic factors, it readily lends itself to various compositing objectives. Typical objectives are shown to the right of the map file, which may be composited with logical weights. This quick referencing is useful in environmental impact studies, growth area simulation for utilities, transportation, recreation, etc.



subdivided into the dominant type cellular system and the percentile type cellular system. It is extremely important to ensure that the cell size used by the cellular system is able to provide adequate accuracy.

Programs written on the cellular approach tend to be shorter and easier to write. This reduces the development costs of the software, as well as the computer cost of running each program. Versatility is also an advantage; the cellular approach allows the addition of new programs more easily and at less expense. Some of the most manipulative facilities of the cellular format are:

- Conversion of any map legend or data scale into other symbols, reranking, ordinal ranking, etc. without altering the original stored symbol.
- Computation of frequencies of the original symbols in the total map areas or in the subareas, via a master mapping procedure for setting up the subunits for automated mapping of any data so cataloged.
- Logical selection to be applied to any pair of maps and carried to the next, etc., essentially using one map as a constraint upon the next.
- More complex relationships between a "dependent map" and a number of suspected independent maps may be disclosed through statistical programs of multiple regression, discriminant analysis or any chosen program for regional phenomena. This may answer an analytical problem or may supply relationships for a new simulation composite map.

In this region, the following applications of cellular map compositing have been made (see Appendix B for further information on applications):

- Urban development feasibility composites.
- Stripmining reclamation feasibility.
- Composite mapping revegetation scenarios.
- Power plant siting feasibility.
- Selecting parkland in a metropolitan county.
- Defining areas of housing restrictions in a floodable metropolitan county.
- Anticipating critical areas of land use conflict over an entire state.
- Conducting industrial optimum location search over a four-state region.
- Simulating changes in riverine vegetation and water conditions under various management alternatives.
- Allocating hospitals and field health services in a state according to composite indicators of local need.

6.1.2 Multisource Data

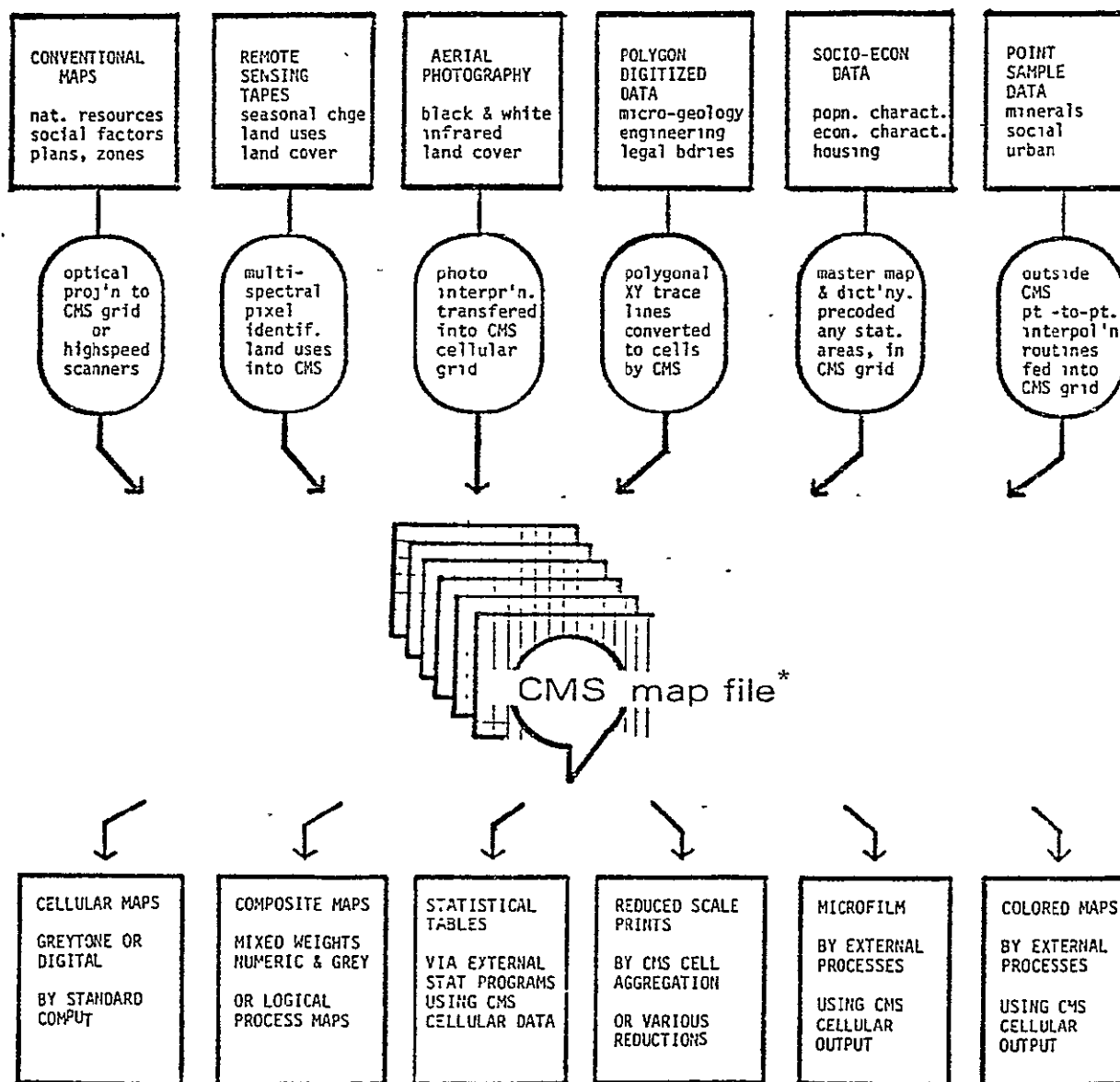
Most spatial information, in whatever original form, can be converted into cellular form, as illustrated in the following Figure 6.1.2. Some of the more common grid conversions may be described as follows:

- Any conventional map (such as topography, culture, or thematic patterns) may be optically projected upon a grid of appropriate fineness, encoded by one of several processes, and turned into data arrays stored in the cellular map file. A useful, visible beginning procedure for starting a cellular map file is to use manual mapping, encoding and keypunching; but larger jobs may use polygonal encoding or direct drum (raster) scanning. For example, air photo maps, after rectification and thematic photo interpretation, may be converted into grids by any of these procedures.
- Another common form of input is data tables or tapes for preset areas, census tracts, zip code zones, land ownership jurisdiction, etc. for which a master map with given area codes is created in cellular form, after which tabular data values are automatically located via these location codes.
- Another form of input is random sampling such as water well data, forest condition data, or climatic data. These data points, falling in certain cells, are interpolated into a smooth surface by certain subroutines in cellular mapping.
- With the general increase in available hardware for digitizing polygonal patterns, spatial engineering data and aerial photo interpretation are being digitized. The original polygonized format for national land use will become operational through the USGS LUDA mapping program. Then, in order to utilize various polygonal inputs for the purposes of uniform cellular mapping and analytical compositing among numerous maps in a data bank, the polygonal tape records can be read into the cellular format.
- In general, for regional data banking, using the LANDSAT picture elements or larger grid cells and a series of other topics, the grid format will be versatile and low in cost. This is further illustrated by Figure 6.1.3.

FIGURE 6.1.2

POSSIBLE INPUTS AND OUTPUTS

ORIGINAL PAGE IS
OF POOR QUALITY

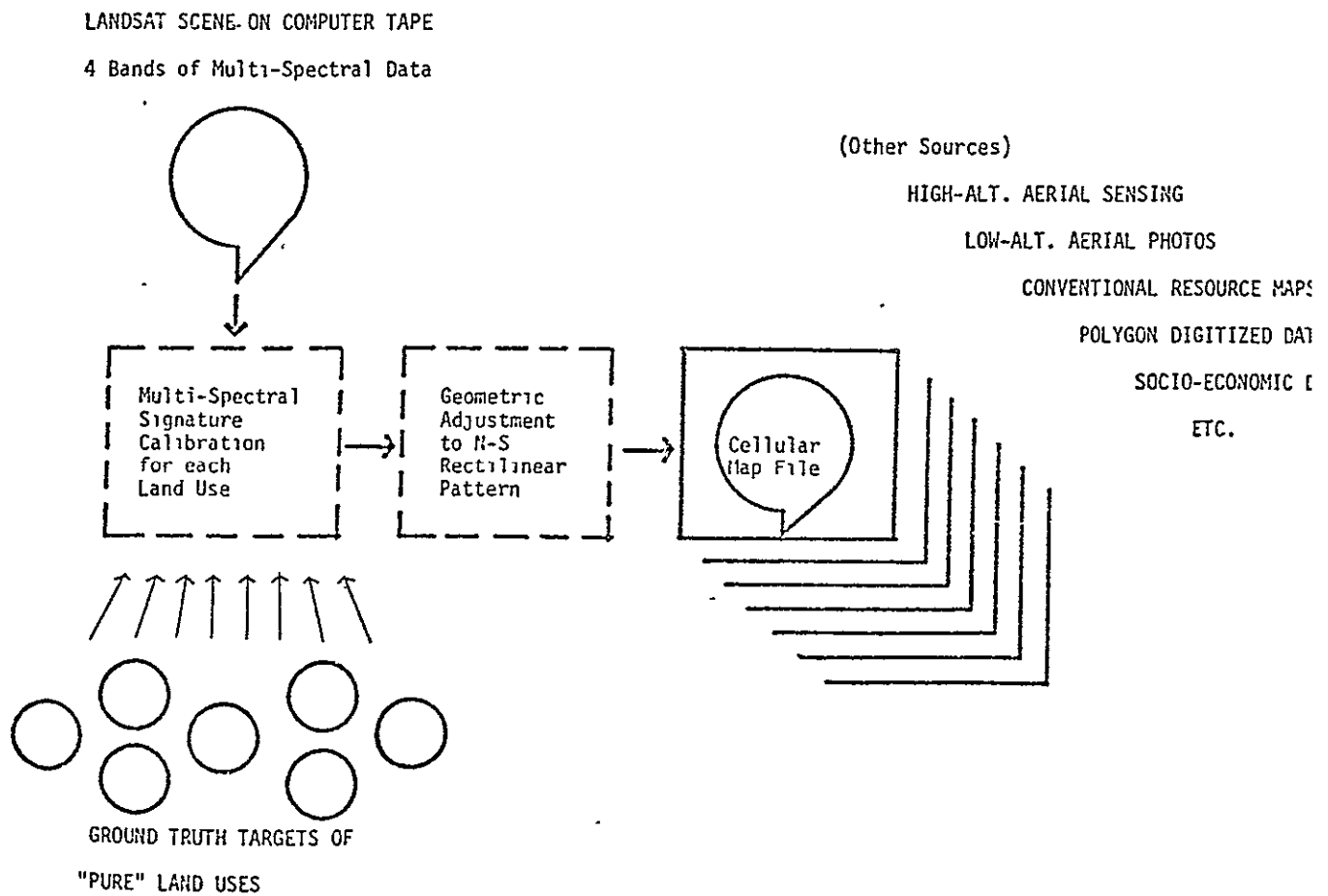


*Composite Mapping System

FIGURE 6.1.3

LINKING THE CELLULAR MAPFILE

WITH SATELLITE MULTISPECTRAL TAPES



The valuable role of the LANDSAT CCT inputs in a cellular map file is to provide the current land use and cover information, making worthwhile the assembly of numerous other data on resources and socio-economic factors, and offering rapid compositing service to various state and federal agencies, counties, etc.

6.1.3 Project Software

In developing this particular project, several versions of cellular mapping and procedure in compositing were advanced. An earlier version of a computer composite mapping system (CMS-I) was introduced into the region by the U.S. Department of Commerce via a 1970 economic study by four states: Colorado, Utah, New Mexico and Arizona. This enabled them to make an optimal industry location search over a large region for some 30 industries. Due to its peculiar language configuration which limited the program to certain computers, the original program was reprogrammed and features were added by the Federation -- this became the CMS-II program. In the meantime, two universities developed special versions of their own: (1) the Resources Analysis Program (RAP) of the Bureau of Business Research at the University of Utah, which uses polygonal inputs and a Calma digitizer; and (2) the Generalized Map Analysis Planning System (GMAPS) program of the Colorado School of Mines which runs in an interactive mode for convenient student utilization and fits onto a smaller core memory machine.

The GMAPS version of cellular mapping was utilized in this project by the Los Alamos Scientific Laboratories for compositing the various maps prepared by four states -- Arizona, Colorado, New Mexico, and Wyoming (see Appendix B). Montana and Utah then utilized their own systems for compositing (see Appendices E and G).

In the Energy Planning Division of the State of Montana, still another version of cellular mapping, the Environmental Resources Geo-Information System (ERGIS), was developed to run as part of a drum raster scanning process.

Thus, a variety of new applications of cellular mapping and integration of LANDSAT CCT maps were initiated in the region. Figure 6.1.3. shows the conceptual linkage of LANDSAT and multisource data files.

6.2 Procedures

6.2.1 LASL Compositing

The states of Arizona, Colorado, New Mexico, and Wyoming supplied data for computer compositing to LASL. Each state collected the desired ancillary data, coded that data onto a 1.1 acre representation cellular grid (see Figure 6.2.1), and punched that information onto computer cards. CSU supplied the already digitized LANDSAT data.

This "package" was then sent to LASL for processing. Supplier-processor interactions included editing and assigning values or weights to the data.

This project utilized for compositing the Generalized Mapping Analysis Planning System (GMAPS) implemented at Los Alamos in 1975. The system is functionally identical to the GMAPS program developed at the Colorado School of Mines.¹

Computer-aided versions of composite mapping represent an important extension of traditional manual graphic procedures. The use of a computer requires some modification to the procedures so that the mapped source data can be entered into computer storage. This process is called "map digitization." Source information is quickly digitized if the information is first plotted on a base map of suitable scale; then the map is overlaid by a coordinate grid and the conditions within each grid cell recorded. Not all cells need to be filled in by hand. The GMAPS program for a sequence of similar cells to be "filled in" by the computer which scans the lines from left to right. The computer can also duplicate identical lines. On an average, only about one-third of the cells needs to be hand coded. The GMAPS program performs a series of logical checks and issues appropriate error messages.

In general, this procedure is most efficient if arbitrary character codes are assigned to each condition portrayed on the map. No connotation of relative value is intended at this point. For example, areas coded "A" are not necessarily better or worse for any particular use than areas coded "B." Subsequently, as shown in Figure 6.2.1, these matrix analog codes can be converted to numerical values reflecting the capability of a particular coded condition to support a particular activity. Such valuation procedures are performed by the computer very rapidly, allowing a single data component to have a number of different patterns of values, as appropriate to the analysis.

¹Turner, A.K., "Computer Aided Environmental Impact Analysis Parts 1 and 2," Mineral Industries Bulletin, Vol. 19, Nos. 2 and 3, 1976, Colorado School of Mines.

8. RESULTANT LAND PATTERN

Site capacities from analysis maps can be easily visualized using a gradation of tones from dark to light.

7. ANALYSIS MAP

As the data is combined, descriptions of the site's capacity can be determined, mapped, and quantified. The diagram shows a hypothetical case of timber productivity with "6" showing high timber productivity and "2" showing low productivity.

6. OTHER DATA MAPS

Information on many resource variables is known for each grid cell and each is stored as a separate data file.

5. COMPUTER DATA DISPLAY MAP

Data can be displayed on computer printed maps as symbols or grey tones.

4. COMPUTER CARDS

Coded data is keypunched onto computer cards. Positions on computer cards correspond to those on the coding sheets.

3. DATA CODING

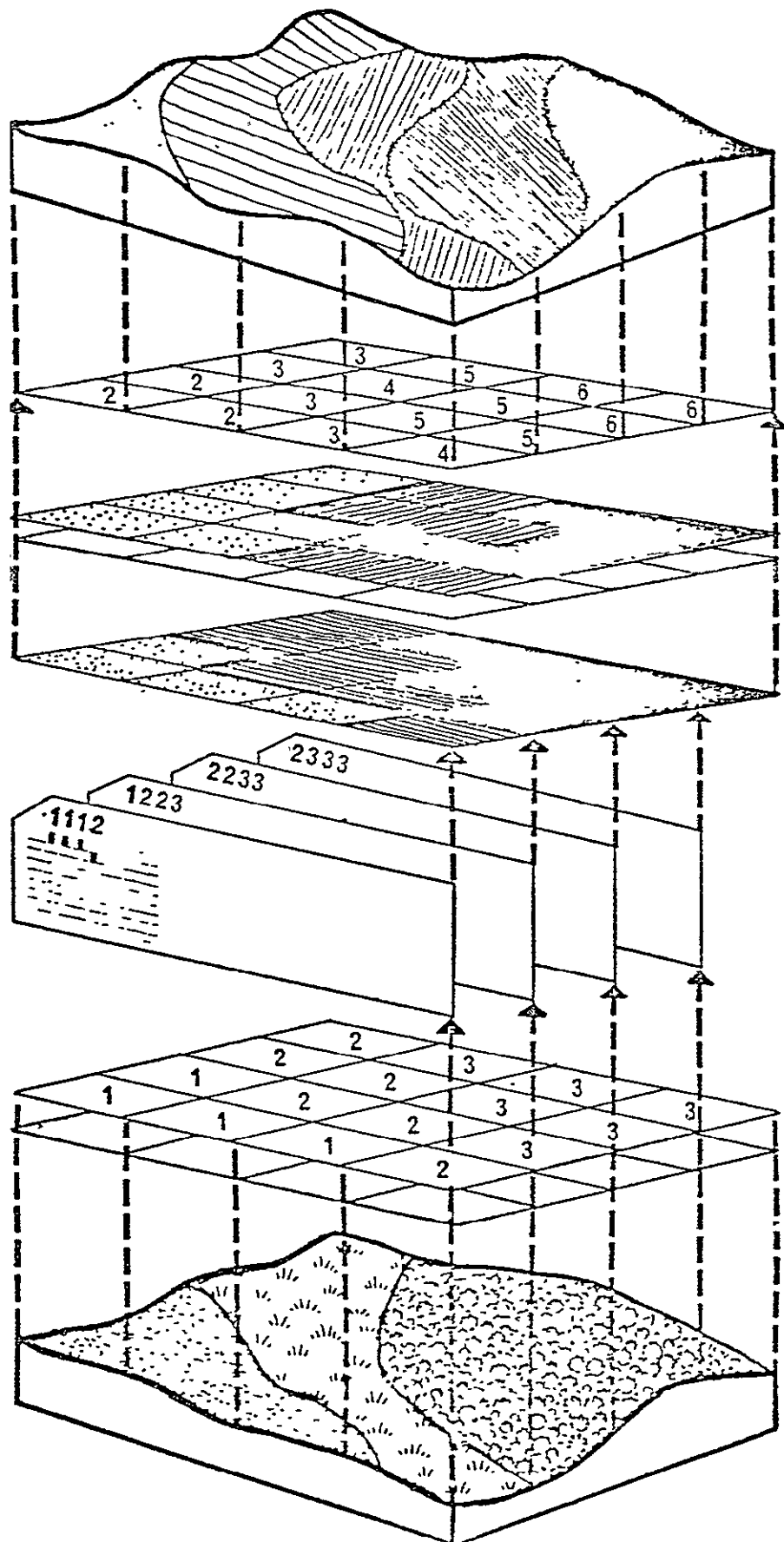
The coding process involves the determination of the predominant resource class within each grid cell and recording it with a numerical symbol. The example in the diagram shows: 1 = grassland; 2 = marsh, and 3 = forest.

2. GRID

The scale of the base map and the size of the grid cell are established according to the detail of the data available, and the detail of desired results. Thus, cell size could range from one acre to one square mile.

1. SITE

A site is composed of many natural land features including soil, water, and vegetation. Each of these is identified and recorded on a base map.



The GMAPS program allows the overlaying, or "compositing" of maps, using arithmetic and logical expressions. "Arithmetic compositing" is a simple extension of the tonal overlay procedures; but it allows for much more varied analyses using combinations of addition, subtraction, multiplication, and division in conjunction with the ability to weight some components more heavily than others.

The GMAPS program differs from the earlier programs because it is designed to interact from a teletype terminal in a time-sharing environment with a computer. This makes GMAPS very attractive to use because:

- the program asks a sequence of questions to which the user responds, thereby defining the operations and sequence of operations he wishes the computer to perform;
- the program allows the user to verify and correct commands, so that meaningless operations are eliminated;
- the system is easily used by laymen;
- the time-sharing concept gives the user access to a high-capacity computer at economical cost.

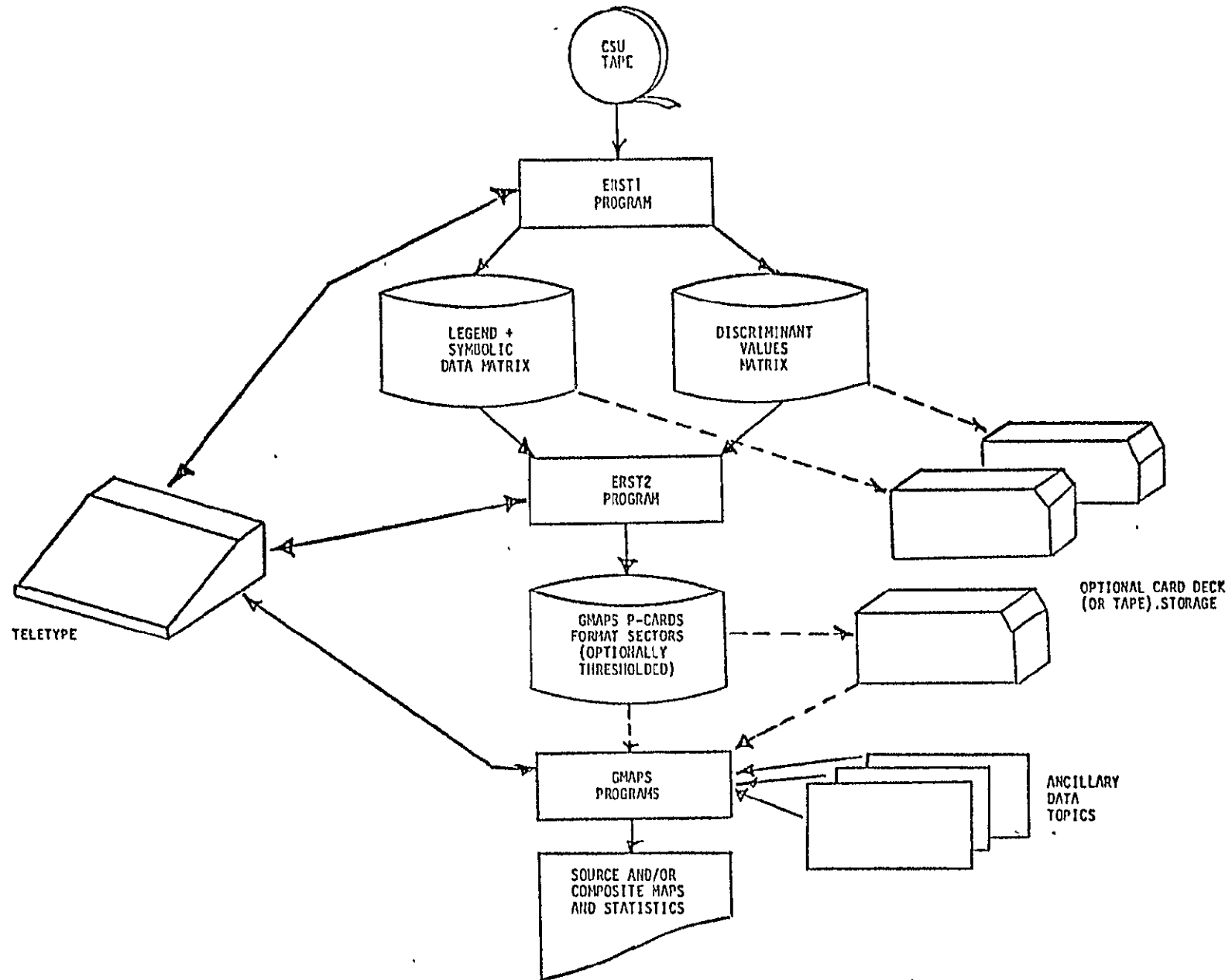
In making modifications to the original GMAPS program, LASL specified continued compatibility with the smaller machine (DEC-10) versions. This proved to be a very real advantage, not merely a theoretical one. For this project, initial compositing runs were begun at Los Alamos, but many of the composites were completed at the Colorado School of Mines.

The LASL versions of GMAPS are being expanded to take advantage of the larger computing power and more sophisticated data entry and display hardware available at the Laboratory. For this project, the ability to directly generate 35mm colorslides of the maps and composites was demonstrated to the state agencies. While LASL is not in the position to offer such services on a routine basis, several commercial firms can do so, and it therefore seemed appropriate to demonstrate these capabilities.

Interfacing procedures were required to convert the LANDSAT data received from CSU to a form compatible with GMAPS. Figure 6.2.2 shows how the interfacing was accomplished. There were, for purposes of convenience, two computer programs called ERTS1 and ERTS2.

The first program, ERTS1, accepted the CSU tapes and through interactive questioning to the user converted the five character CSU land-use codes found in the first tape record into easily understandable legend information. The remaining data on the CSU tape were divided into two files containing formatted record sequences. These records were designed to allow them to be data cards. One file sequence contained the legend information and the symbol strings corresponding to the land-use definitions for each cell (or pixel). The other file contained the discriminant values for each cell. Both files contained one record set for each line across the entire map width. In other words, each file contained a matrix in row-ordered form.

FIGURE 6.2.2
DATA INTERFACING



The second program, ERTS2, converted these two intermediate files into a single GMAPS input file. These files are organized into "sectors," a sector being a block of 120x120 cells. Within each sector, two sequences of 60-character records, corresponding to the left and right halves of the sector, are placed in sequence. These file structures are termed the "P-cards" format and form the common data source formats for GMAPS and CMS program types.

ERTS2 performed one other important function, the thresholding of the data. At the user's option, points with a low statistical significance may be thresholded out by comparing their discriminant value to the Chi-square value corresponding to the number of channels used in the classification and the desired threshold level. The procedure is identical to that defined in the RECOG system (a part of LMS) documentation.² If the discriminant value exceeded the Chi-square value, ERTS2 substituted a predefined "threshold" character for the existing classification.

This process allows for the generation of a large number of different thresholded variations of the basic LANDSAT derived land-use map data. This gives maps of various accuracies for certain land-use types. Each such product can be handled by GMAPS as a separate input source. It was primarily for this reason that the interfacing operation was divided into two stages, corresponding to ERTS1 and ERTS2.

It should be noted that both steps in the process were designed as interactive procedures, allowing direct interface with the user via the teletype terminal.

6.2.2 Montana Compositing

The Energy Planning Division (EDP) of Montana's Department of Natural Resources and Conservation as lead agency conducted the ancillary data collection, digitizing and compositing. CSU again supplied the LANDSAT digitized data.

EDP's equipment includes a raster scanner which reads "data" directly from maps by shining a light on the document and measuring the intensity of the reflected light. These light readings vary by color and therefore provide a "code" similar to the cellular process. The new data is written to a magnetic tape for computer processing.

The created map file had the same cell size and registration as the LANDSAT data. Compositing of the multisource map files was then conducted.

²T. Ellis, L.D. Miller, and J.A. Smith, User's Manual for RECOG (Pattern RECOgnition Programs), Science Series No. 38, Department of Watershed Science, College of Forestry and Natural Resources, Colorado State University, Fort Collins, Colorado.

6.2.3 Utah Compositing

Utah used a polygonal approach on a Calma digitizer, tape files therefrom to be applied in a new Resource Analysis Procedure (RAP) program developed by the Bureau of Economic and Business Research at the University of Utah. This is a second generation beyond CMS, allowing input either as cells or polygons.

Utah utilized the RAP to process the LANDSAT imagery in conjunction with other factor maps pertinent to the Farmington quad. The RAP program has gone beyond the CMS based systems in that it will permit input from various other media, and then internally make them all compatible. The reason for this was to broaden the input data bases for factor maps and eliminate some of the restrictions which are imposed by a strictly cellularized, card-oriented system. For example, by implementing a polygonal approach in RAP, steps 2, 3 and 4 as shown on figure 6.2.1 may be eliminated and maps may be produced at any scale desired. Polygonal input processing routines within RAP can handle maps digitized from several different projections (i.e., Lambert, U.T.M., etc.) and internally translate them to geographic coordinates for compatibility. Since RAP can maintain maps in a real-valued state, mathematical manipulation for compositing purposes has true meaning, whereas it does not for maps having ordinal, numerical values. A real-valued map would contain the actual value at each cell across a map topic, thereby permitting true compositing of characteristics and allowing for the generation of a large number of different threshold variations.

RAP's compositing features enable the user to produce data maps as a function of many other topic maps. A new topic map (composite) can be produced through the use of logical expressions, recoding, thresholding, arithmetic expressions, boolean expressions, mathematical functions, and weighting. RAP has the feature of including entire maps or only component parts of various maps in this compositing process. These new composited topic maps can then again be functional variables in other compositions. Real-valued, ordinal and non-numeric map topics may be used in the same compositing process.

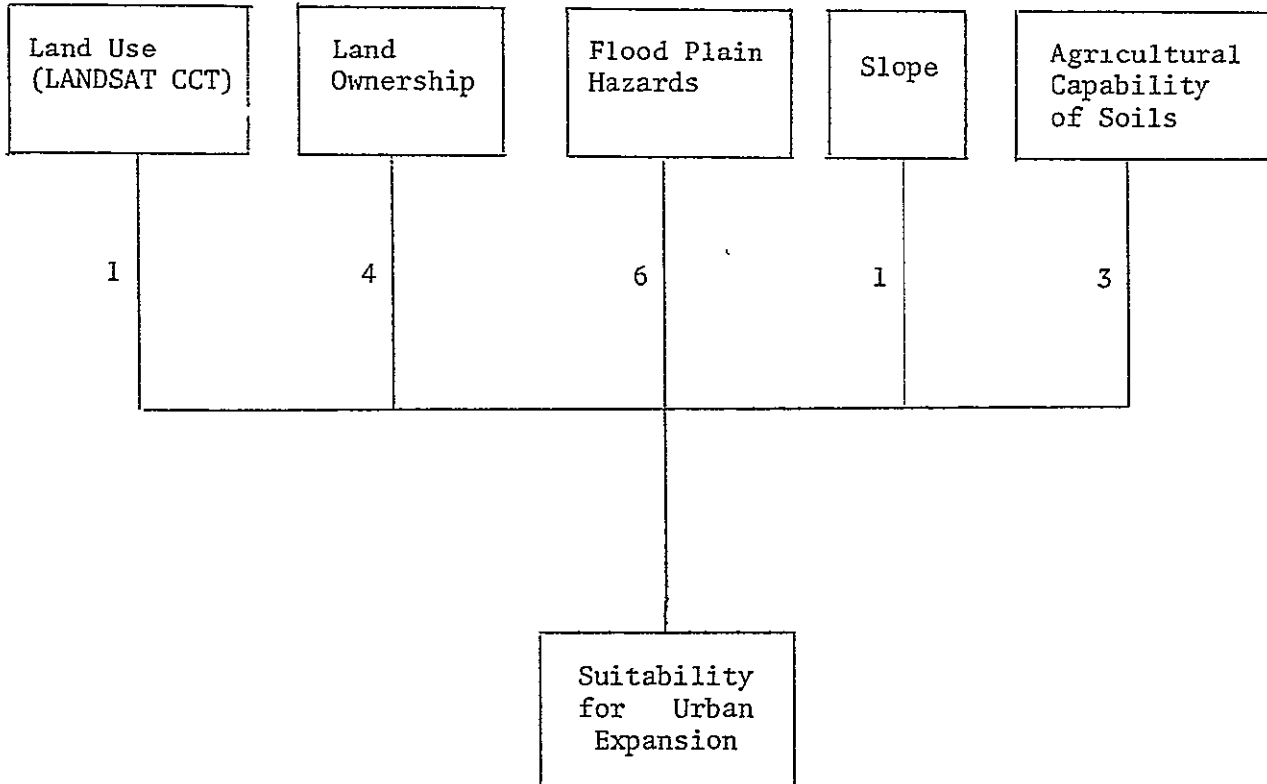
This project gave the planners in Utah the opportunity to implement the interface between CSU-produced LMS tapes and the RAP system. Along with this interface RAP will also interface with U.S. Forest Service COMLUP system files, USGS GIRAS (LUDA) polygonal data files, Bendix Corporation-produced LANDSAT imagery, IDS digitized data bases, SYMAP map files and the existing methods of the original CMS system.

For the user's convenience, RAP can be run in either batch mode or demand (interactive) mode. The latter operational mode enables the terminal operator to make real-time decisions concerning the manipulations of map topics. Demand mode is enhanced by immediate user awareness of error conditions so that meaningless commands can be corrected or eliminated. RAP will prompt the operator with appropriate messages when input is desired or various options present themselves.

RAP has maintained all the desirable features of the CMS system, such as aggregate area dictionary symbol conversion, map sector input via P-cards, internal and external symbol conversion, external data file input via master maps, boundary overlays, reduction of maps, shifting of origins, map interpolation with limited known points and statistical analysis. In addition a linear programming routine has been incorporated with the options of inputting data from topic maps for the purpose of optimizing spacial values. This feature, however, was not used in this demonstration.

FIGURE 6.3.2

ARIZONA COMPOSITE ANALYSIS



Negating factors include flood hazard, nonprivate land, prime agricultural land, and severe soil limitations for residential construction.

Current residential developments (from LANDSAT Topic Map) were classified as potentially available land, thereby allowing the suitability of such areas to be evaluated according to the site determining parameters.

6-2

6.3 Results

Each state developed demonstration compositing analyses for their comprehensive test sites, as shown below.

FIGURE 6.3.1

COMPREHENSIVE TEST SITE ANALYSIS		
<u>State</u>	<u>Comprehensive Test Site</u>	<u>Computer Composite Analysis</u>
Arizona	Hedgepeth Hills	Optimal locations for residential development
Colorado	Fox Creek	Index of revegetation capabilities
Montana	Colstrip, SE	Mined land reclamation feasibility
New Mexico	Santa Fe	Restrictions against urban development
Utah	Farmington	Constraints to nonagricultural development
Wyoming	Buffalo	Physical limitations to urban growth

In the following Figures, each state's compositing procedure is charted, followed by a reduced version of their final composite map. In the charts, input topics are indicated in the upper boxes, relative weights (values) below and the resulting composite in the lower box.

URBAN GROWTH SUITABILITY (ARIZONA SCALE)

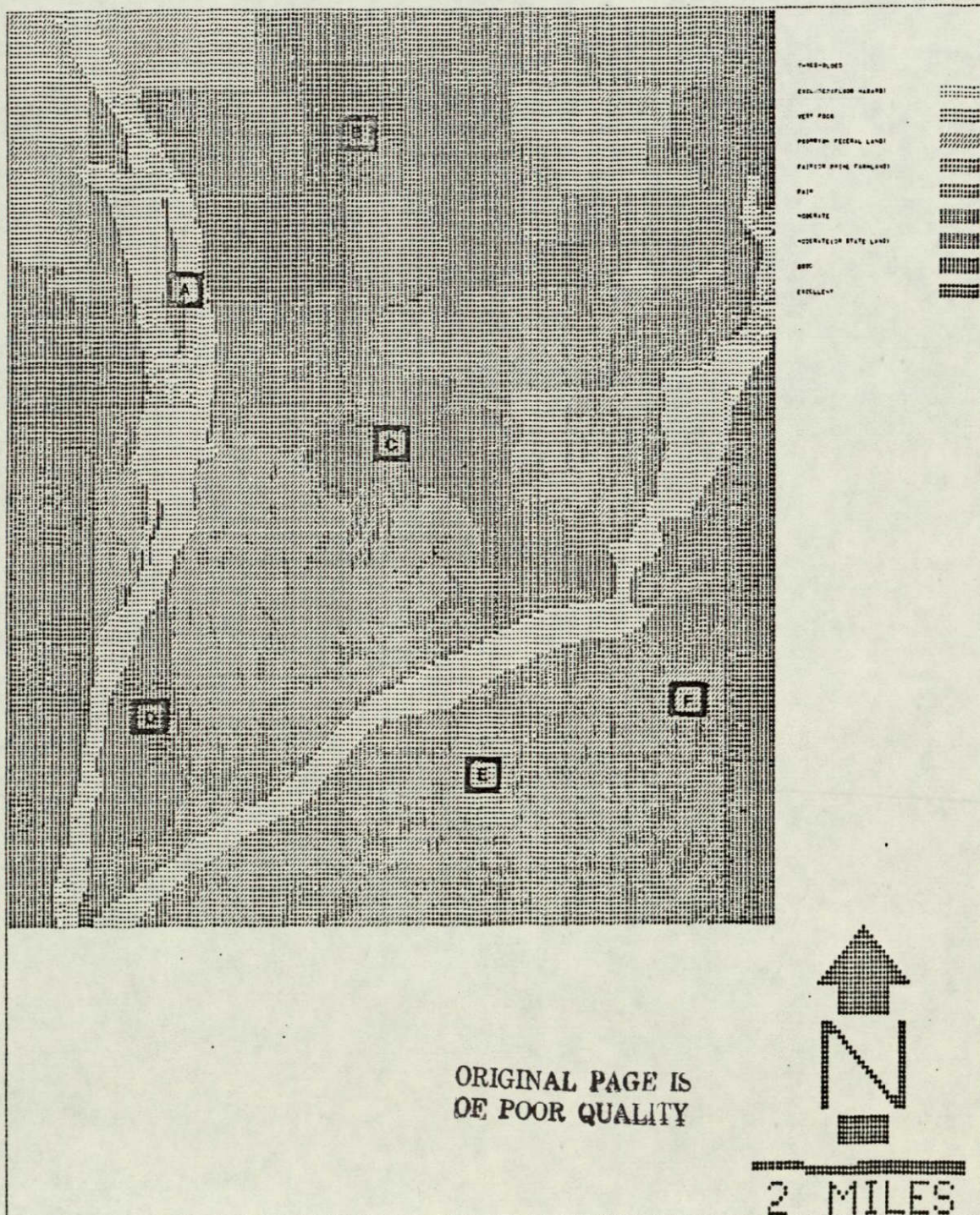
HEDGEPEETH HILLS QUADRANGLE, ARIZONA

EACH CELL REPRESENTS 1.1 ACRES

$$\text{URBAN} = 1.*\text{ERT52} + 4.*\text{LANDS}$$

$$+ 6.*\text{FLOOD} + 1.*\text{SLOPE} + 3.*\text{AGCAP}$$

$$+ 1.*\text{SDWOB}$$



LEGEND

FIGURE 6.3.4

COLORADO COMPOSITE ANALYSIS

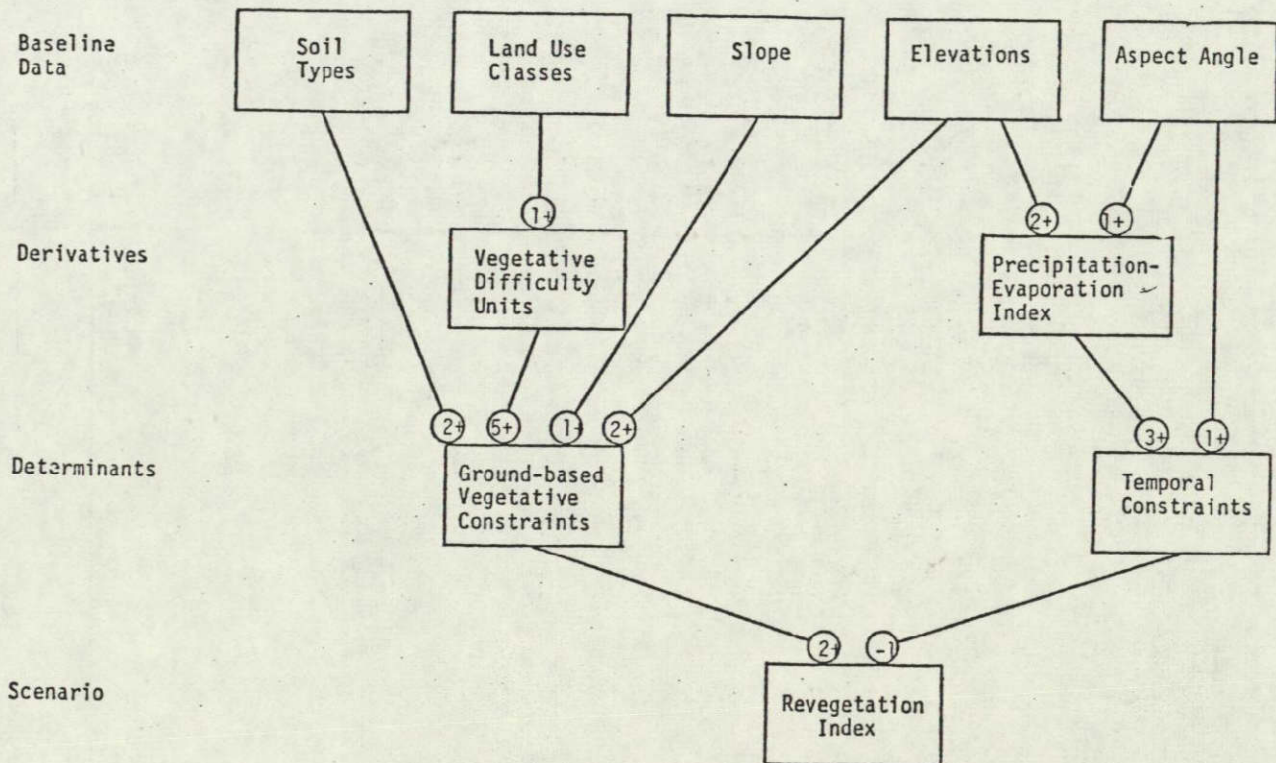


FIGURE 6.3.5

REVEGETATION INDEX NUMBER 2
FOX CREEK QUADRANGLE, COLORADO
EACH CELL REPRESENTS 1.1 ACRES
INDX2 = 2.*UCONS - 1.*CLMAT

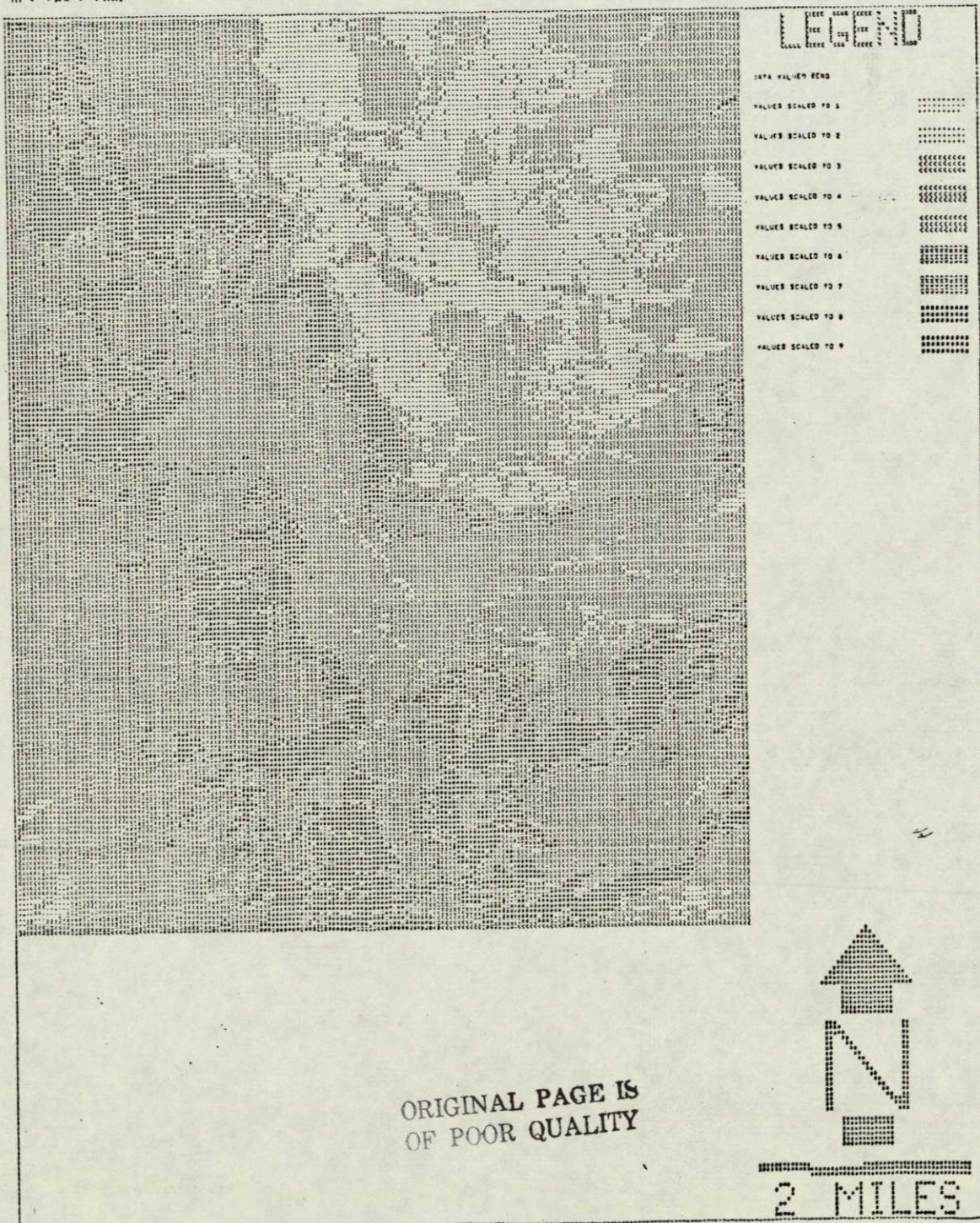
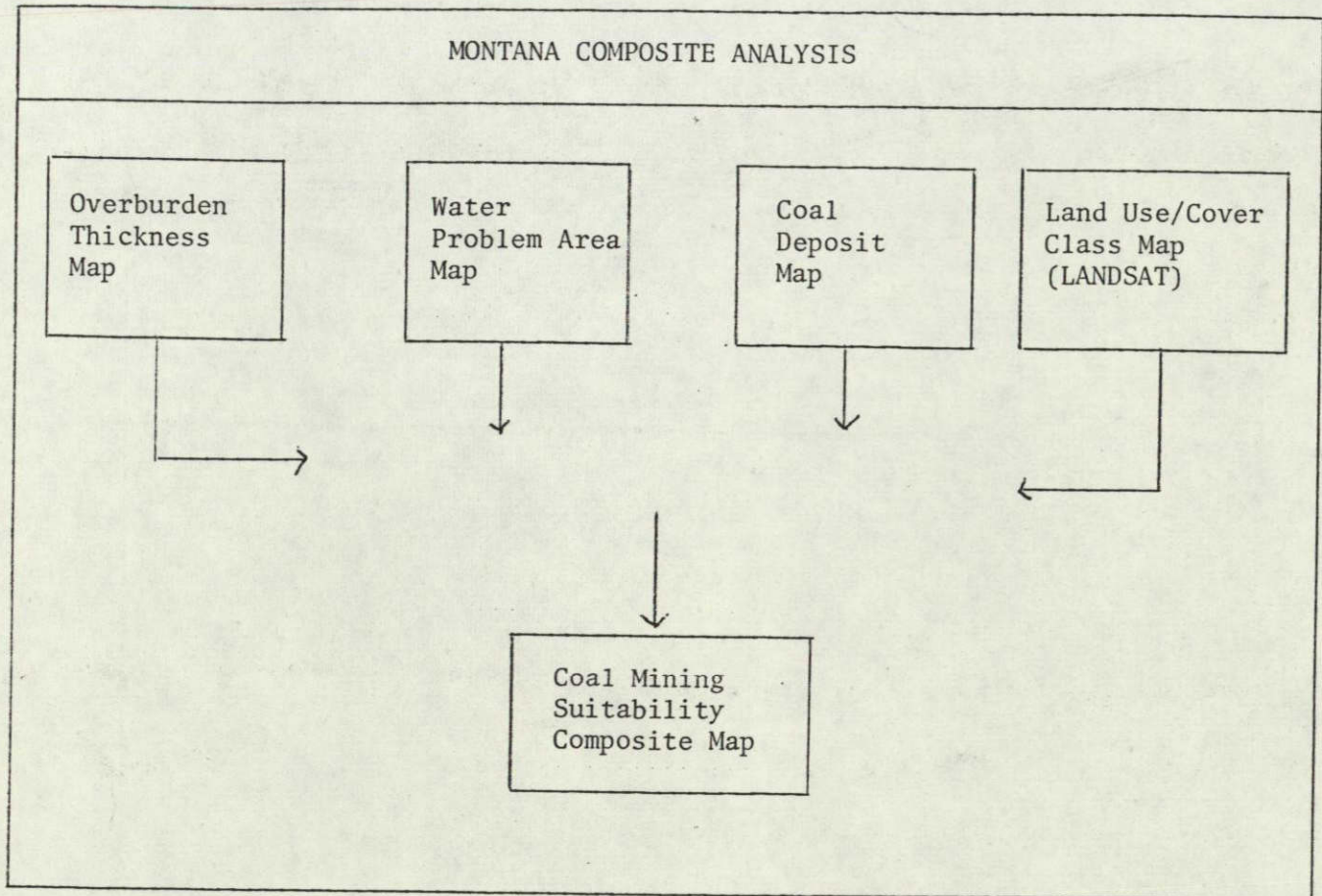


FIGURE 6.3.6



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Coal Mining Suitability Composite Map (Figure 6.3.7, following page)

XXXXXXXXXX		++++++	
XXXXXXXXXX	Absolutely Unsuitable	++++++	Moderate Suitable
XXXXXXXXXX		++++++	
EEEEEEEEEE		-----	
EEEEEEEEEE	Unsuitable	-----	Suitable
EEEEEEEEEE		-----	
OOOOOOOOO			
OOOOOOOOO	Moderate Unsuitable		
OOOOOOOOO			

FIGURE 6.3.7
Coal Mining Suitability Composite Map
(MONTANA)

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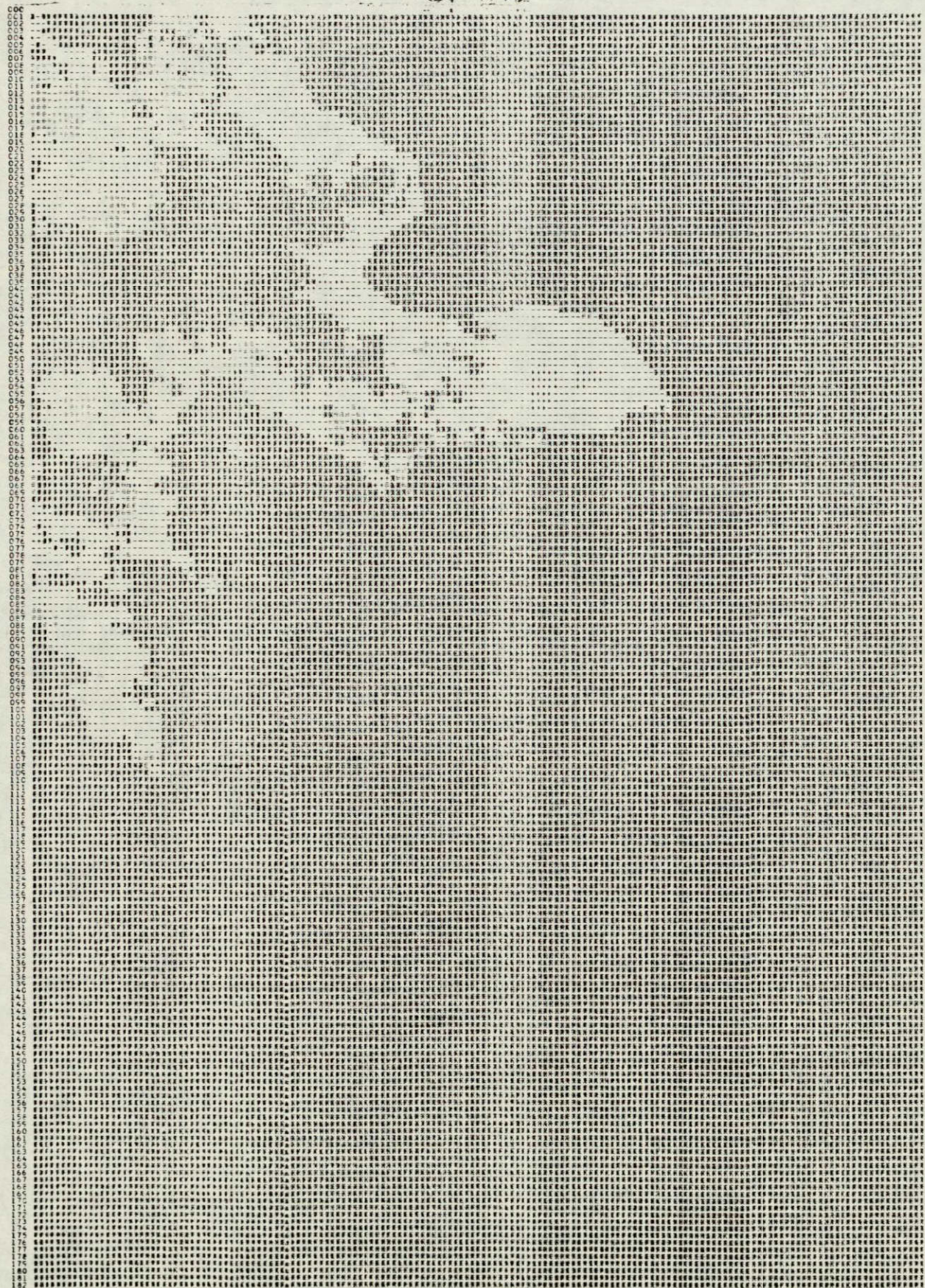
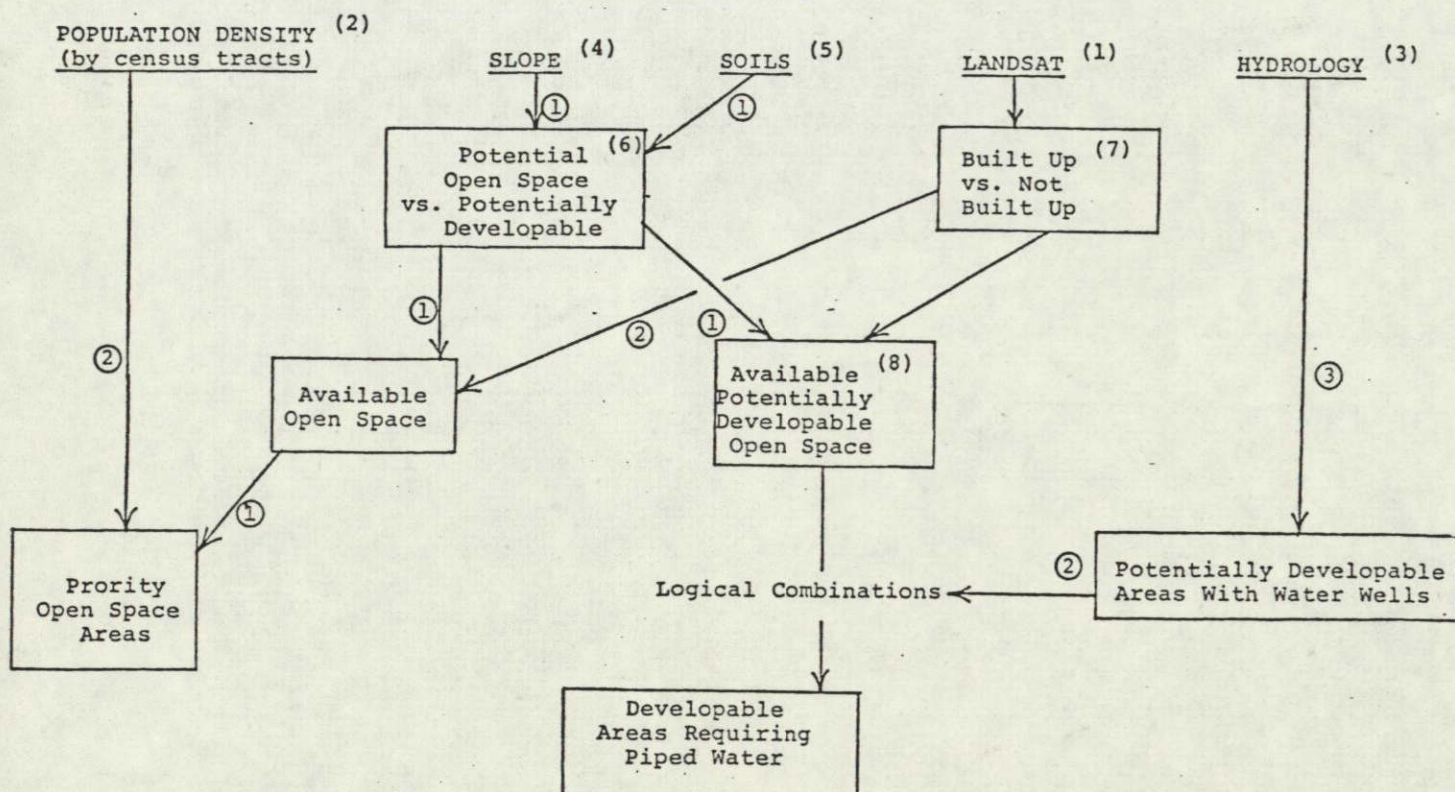


Figure 16 Coal Mining Suitability Composite Map
(Legend on next page)

FIGURE 6.3.8

NEW MEXICO COMPOSITE ANALYSIS



() Map Number Reference In Appendix 3

○ Weights Assigned To The Data Source During Compilation

FIGURE 6.3.9

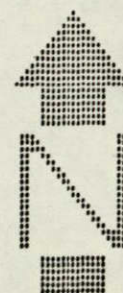
AVAILABLE POTENTIALLY DEVELOPABLE AREAS
IN THE SANTA FE QUADRANGLE
EACH CELL REPRESENTS 1.1 ACRES

$$BLOG2 = 1.1 * BLOG1 + 2.1 * BLOG1$$

MAP 8



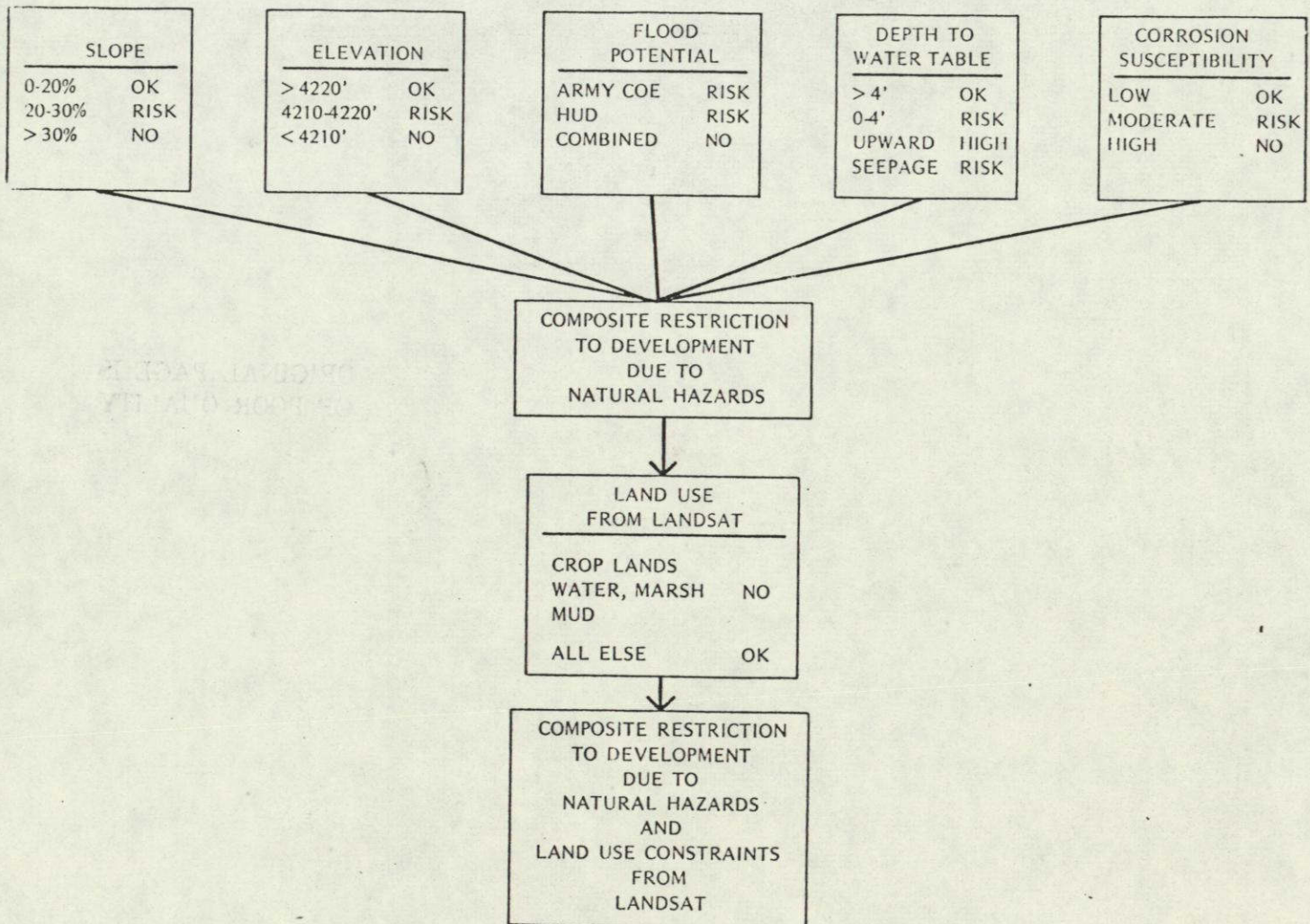
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2 MILES

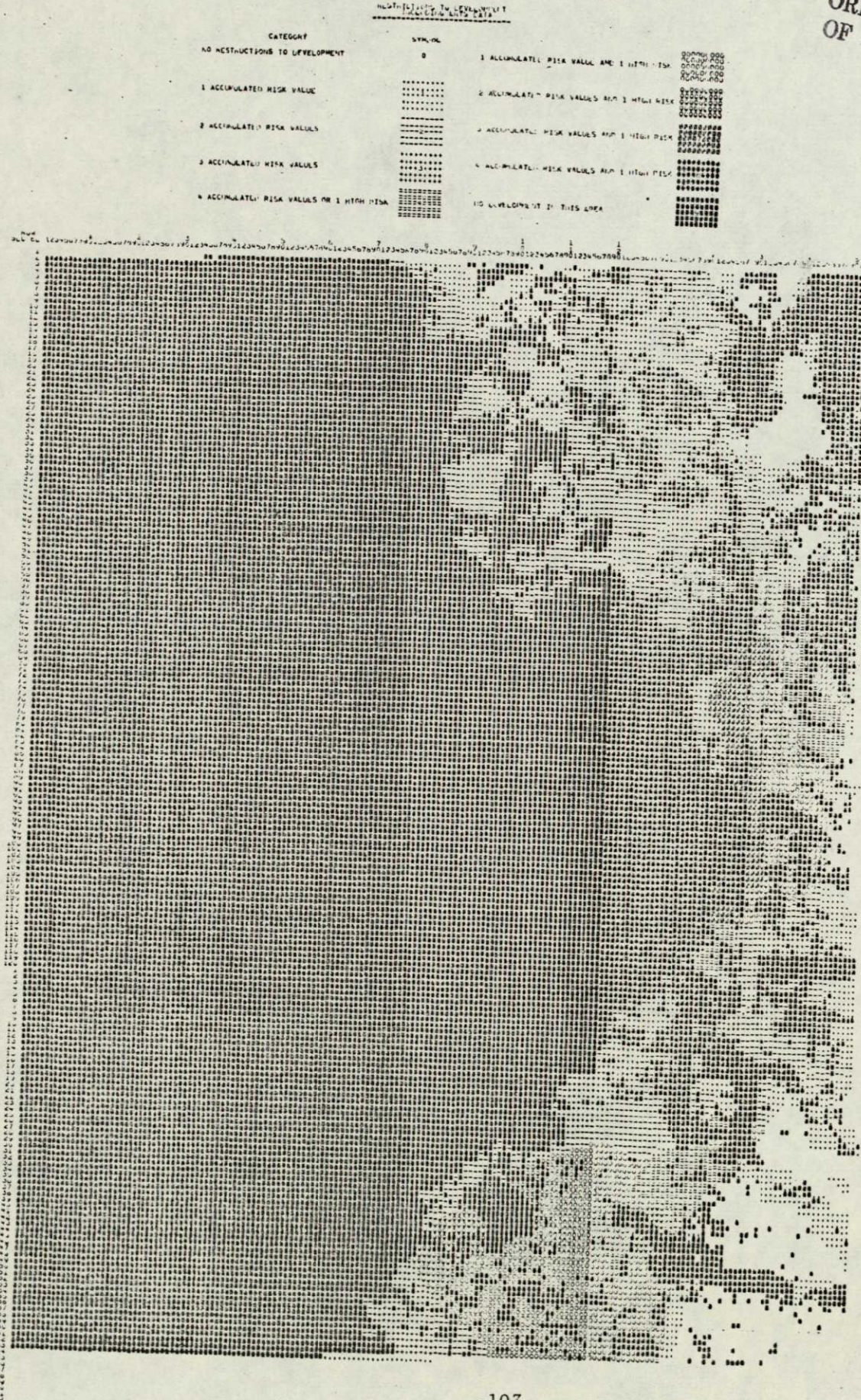
FIGURE 6.3.10

UTAH COMPOSITE ANALYSIS



DEVELOP-L

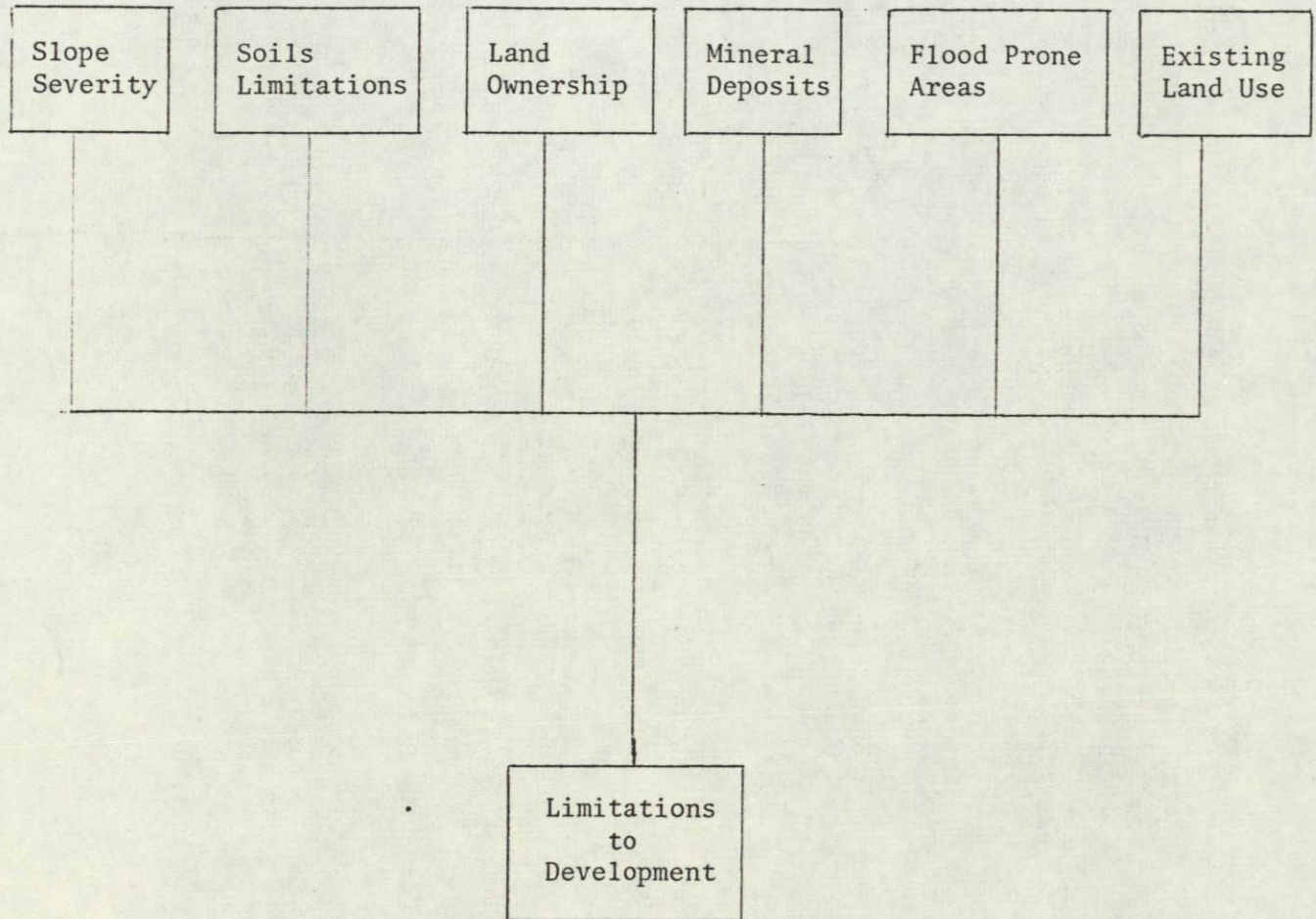
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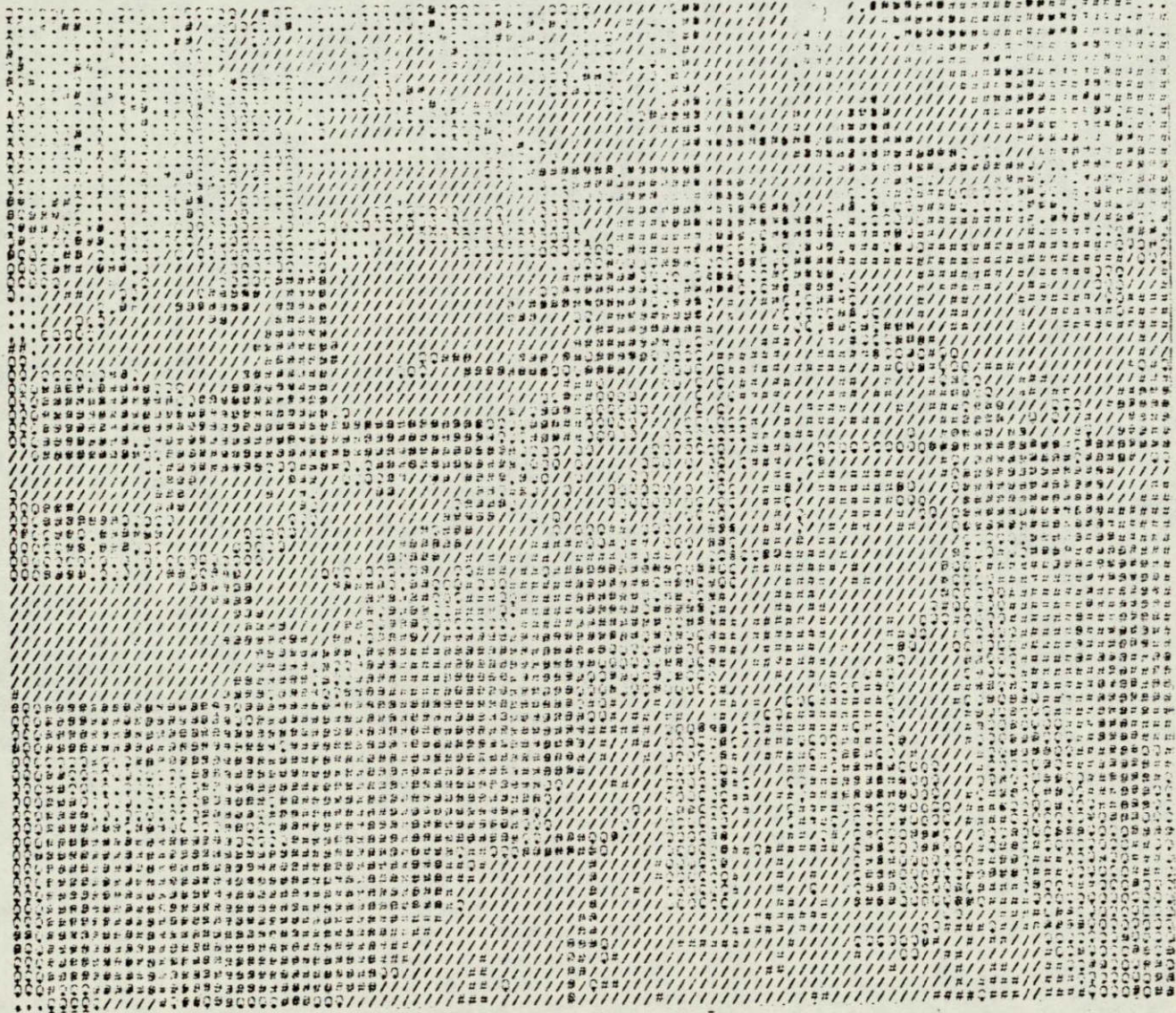
FIGURE 6.3.12

WYOMING COMPOSITE ANALYSIS



Only a portion of the complete test site was analyzed due to a lack of adequate data.

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VALUES SCALED TO 1      .....
VALUES SCALED TO 2      .....
VALUES SCALED TO 3      .....
VALUES SCALED TO 4      <<<<<<<<<
VALUES SCALED TO 5      <<<<<<<<<
```

```
VALUES SCALED TO 6      <<<<<<<<<
                          <<<<<<<<<
VALUES SCALED TO 7      0000000000
                          0000000000
                          0000000000
VALUES SCALED TO 8      0000000000
                          0000000000
                          0000000000
VALUES SCALED TO 9      @@@@@@@@@@
                          @@@@@@@@@@
                          @@@@@@@@@@
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Many people are involved in the policy, program, and resource management levels of a regional project of this nature. Listed below are the principal participants in the project. On the following page is shown the management structure of the Federation. The project advisory committee is listed in Figure 4.2. Many others contributed both formally and informally. Others are acknowledged in individual reports located in the appendices.

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