APPLICATION OF REMOTE SENSING TO SELECTED PROBLEMS WITHIN THE STATE OF CALIFORNIA

A report of work done by scientists
of three campuses of the University
of California (Berkeley, Santa Barbara
and Riverside) under NASA Grant NSG 7220
from the NASA Office of University Affairs

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APPLICATION OF REMOTE SENSING TO SELECTED PROBLEMS WITHIN THE STATE OF CALIFORNIA

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IN MEMORIUM

LEONARD W. BOWDEN

1933 - 1979

CO-INVESTIGATOR: RIVERSIDE CAMPUS

---HE WILL BE MISSED---

Table Of Contents

Page

Chapter 3 (Continued)

Page

CHAPTER 1

INTRODUCTION

Robert N. Colwell

CHAPTER 1

INTRODUCTION

Robert N. Colwell

Those who manage the natural resources of the state of California are charged with two responsibilities that often are somewhat in conflict with each other: (1) that of producing, within the area for which they have management responsibility, the maximum amount of various goods and services (food, fiber, recreation, etc.) and (2) that of enhancing, on that same area, the quality of the environment, including its overall aesthetic appeal, and the quality of its water, atmosphere, wildlife habitat, etc. There is an increasing demand that this two-fold responsibility be fully met in California, and it is in this respect that the use of modern remote sensing technology can play a vital part.

As a first step toward the more detailed defining of the resource manager's two-fold responsibility, policy decisions usually must be arrived at relative to the uses that should be made of the natural resources in any given area. Thereafter, laws usually are made at the municipal, county, state, and federal levels that will be in consonance with those policy decisions. Next, and also in keeping with those policy decisions, resource management plans must be developed and implemented. The making of these plans requires, in turn, the acquiring of information about the resources that are to be managed--

usually in the form of resource inventories of suitably high accuracy, and made at suitably frequent intervals, so that the resource manager will know at all times, both the amount and the condition of each kind of resource that is present within each portion of the area for which he has management responsibility. As will be apparent from the studies dealt with in this report, it usually is through the use of modern remote sensing technology that the required resource-related information can best be derived.

Although remote sensing scientists at the University of California and elsewhere have repeatedly demonstrated, in recent years, that modern remote sensing technology is potentially very useful to resource managers, the actual acceptance and use of this technology tends to lag far behind. Consequently, a primary goal of virtually all of the remote sensing-related research that is being conducted in California at the present time is that of gaining the acceptance and use of modern remote sensing technology by the managers of California natural resources. Consistent with that goal, the overall objective of work done under this grant is to demonstrate, by means of specific case studies, that information derived from the use of modern remote sensing techniques can lead to the development and implementation of more intelligent resource management measures than would otherwise be possible. All of our case studies deal with applications that can be made of remote sensing in California, while not excluding their application, with suitable modification, in other states as well.

In many cases, there is insufficient knowledge on the part of the resource managers of how remote sensing might be applied, but they have stated that, given one or more appropriate demonstrations of such applications, they would then hope to make remote sensing an integral part of their overall resource management process. From among the many possible cases fitting this description, only a few are dealt with in this progress report. These "case studies" are being performed by our remote sensing scientists on the Berkeley, Santa Barbara, and Riverside campuses, respectively, of the University of California. A description of progress made to date on these case studies will be found in Chapters 2, 3, and 4, respectively, of the present Progress Report.

From a reading of this document it will be apparent that our integrated project entails two major but inter-related categories of activity: (1) Basic research, as necessary to develop, in each problem-oriented situation, a remote sensing-derivable classification scheme that will enable us to help the resource manager solve the particular resource inventory/management problem that is being addressed, and (2) Applied research, as necessary to ensure that the resource manager with whom we are cooperating in any given instance is in full agreement that our resource classification scheme provides him with the information that he needs in order to solve his particular resource management problem. The applied aspect of our research is further designed, in each instance, to ensure the transfer of this technology to the user. We consider ourselves to have been successful in this endeavor when the user not only understands the technology that we have helped to develop but also accepts it to the extent that henceforth he actually uses it, (instead of his previously-used methods), as the information base from which to arrive at and implement resource management decisions.

But the ultimate evidence of our success in any given instance is to be found, not merely in the user's seeming acceptance and adoption of this new technology. Rather it is to be found in his progressing rapidly toward the time when he will routinely employ that technology, entirely at his own expense, using our University scientists either not at all or, at most, merely in an advisory capacity. Even by these rigorous standards we appear to be achieving genuine success. This fact will be apparent from a reading of the campus-by-campus progress reports, (abbreviated though they are) which are included in this document.

The map of the state of California, comprising Figure 1, on the following page, has been annotated in order to indicate the specific remote sensing research sites, both past and proposed, of our 3-campus project.

Because our primary goal under this NASA grant is to bring about the acceptance and adoption of modern remote sensing technology by California's resource managers, it is pertinent to highlight specific instances in which that goal is being achieved. In our recent progress

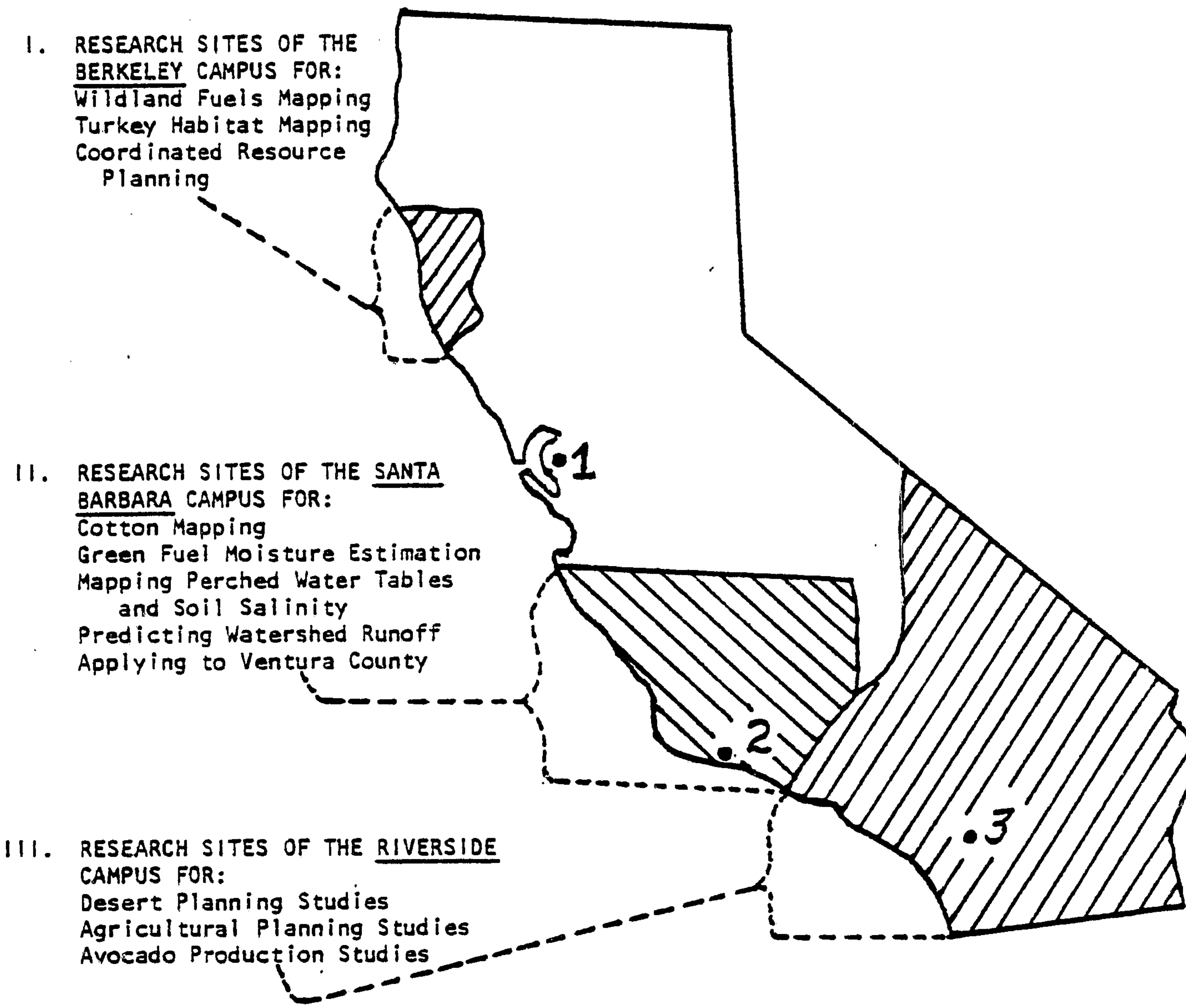

Figure 1. Map of the State of California showing general locations of study areas for remote sensing scientists of the Berkeley Campus (1); the Santa Barbara Campus (2); and the Riverside Campus (3) of the University of California.

reports we have provided abundant evidence (including numerous fully captioned aerial, space, and terrestrial photographs) that fuel management personnel in California are now making operational use of information which we are helping them to derive from Landsat imagery and U-2 photography. Documented in those reports is the fact that California's resource managers from several agencies are using this remote sensing-derived information operationally to determine, quite specifically, and in detail: (a) where there are dense and highly flammable brushfields that should be subjected to controlled burning; (b) where there should be mechanical removal of brush, and (c) where manual removal or chemical control of the brush must be resorted to. Also documented in those earlier reports is the fact that such determinations are being translated into action through the use of sizable amounts of manpower and equipment, specifically assigned by the resource management agencies for the purpose of implementing these decisions. In Mendocino County alone, for example, assets assigned for this purpose include 17 full time employees, 17 part time employees, and 2 bulldozers, plus the necessary brushrakes, drill seeders, fertilizer and seeds to rehabilitate areas following brush removal.

In the present progress report the photographic documentation pertains primarily (but not exclusively) to a totally different aspect in which remote sensing technology is being both accepted and translated into action by the resource managers, viz. the transplanting of wild turkeys (See Chapter 2, Part 2). As indicated by the photographic illustrations and the supporting text in that part of our report the following degree of acceptance and adoption of modern remote sensing technology by a user agency already has been brought about through our close cooperation with personnel of the user agency, -- in this case the California Department of Fish and Game: (1) the identification (from a computer assisted analysis of Landsat digital data of a 2 million acre wildland area) of unoccupied potential habitat sites in which conditions are highly suitable for the transplanting of wild turkeys; (2) the selection of one of these areas, the "Potter Valley" site, as the one in which transplanting would first be attempted; (3) the trapping of wild turkeys of the variety most suitable for that site, based on a more detailed remote sensing-aided analysis of the site, and (4) the actual transplanting of 19 wild turkeys in that site during February of this year. Both the user agency and the U.S. Fish and Wildlife Service have indicated a desire to expand and support future phases of this program.

It is our intent to feature, in future progress reports, other examples of the highly meaningful and beneficial acceptance of modern remote sensing technology by resource managers in the state of California, brought about largely through our efforts under this NASA-funded grant. The following are 4 such examples of our work that are now nearing the "technology acceptance" phase, in the fullest meaning of that term: (1) the selection of sites, from remote sensing-derived information, that are best suited to forest regenera-

14

tion by artificial means, followed by the actual planting of trees by resource managers in those sites; (2) the selection of sites, from remote sensing-derived information, where flood control structures are urgently needed, followed by the actual building of such structures at those sites; (3) the selection of sites, from remote sensing-derived information, wherein it is both necessary and feasible to remedy agricultural crop production problems arising from perched water tables and/or high soil salinity, followed by the actual taking of that remedial action, and (4) the monitoring, by means of remote sensing, of increasing avocado acreage and avocado production throughout southern California, resulting in regulatory action being taken by the concerned agencies.

In these and numerous other examples, (just as in the ones that we already have featured in our progress reports) we soon will be able to document the rapid progress that is being made toward another, associated goal of ours under this NASA grant, viz. that of having the resource managers with whom we have been working during any particular "demonstration" phase progress to the fully "operational" phase in which they will use entirely their own funds and personnel to derive the necessary information from data acquired by means of remote sensing.

As in our previous progress reports we include in this one a chapter dealing with "Special Studies", (Chapter 5). In this instance the special study reported upon consists of a discussion of some important remote sensing concepts that have been developed and/or tested under our present NASA grant.

This progress report concludes with a summary (Chapter 6) both of work accomplished during the past year by our 3-campus groups, (as reported upon in the preceding 5 chapters), and of the work which each campus proposes to perform during the coming year.

CHAPTER II

PART I

Fuel Mapping in Relation to the Management of Brushlands and Timberlands in California

Authors: Andrew S. Benson
Louisa Beck
Charles Henderson

University of California

Berkeley Campus

CHAPTER 2

NORTHERN CALIFORNIA STUDIES

Co-Investigator: Andrew S. Benson

PART I

Fuel Mapping in Relation to the Management of Brushlands and Timberlands in California

Authors: Andrew S. Benson
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PART II

Remote Sensing Aided Assessment of Wild Turkey Habitat

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CHAPTER 2

NORTHERN CALIFORNIA STUDIES

1.0 INTRODUCTION

This chapter constitutes an annual report on the investigations being carried out in Mendocino County, California (Figure 1) by personnel of the Remote Sensing Research Program, University of California, Berkeley Campus. These investigations deal with the use of modern remote sensing techniques as an aid in the mapping of wildland fuels (Part 1) and of wild turkey habitat (part 2). The objective of both these mapping efforts is threefold: first to provide regional information from which management priorities can be set, second to provide area-specific information from which management plans can be developed and implemented, and third to familiarize wildland managers with the application of modern remote sensing technology to their data gathering needs.

It must be stressed that the successes to date of this applications oriented research are due to the close working relations that have been developed over the past three years between the remote sensing specialists from the Berkeley Campus and the various land management personnel from Mendocino County. This interaction is vital because of the iterative nature of the research: the more the land managers work with the remote sensing derived information set, the more they become aware of its strengths and limitations; and the more the remote sensing specialists work with the land mangers the more they become aware of the "real world" constraints that are placed upon government agencies. One important net result of this interaction is that it

20

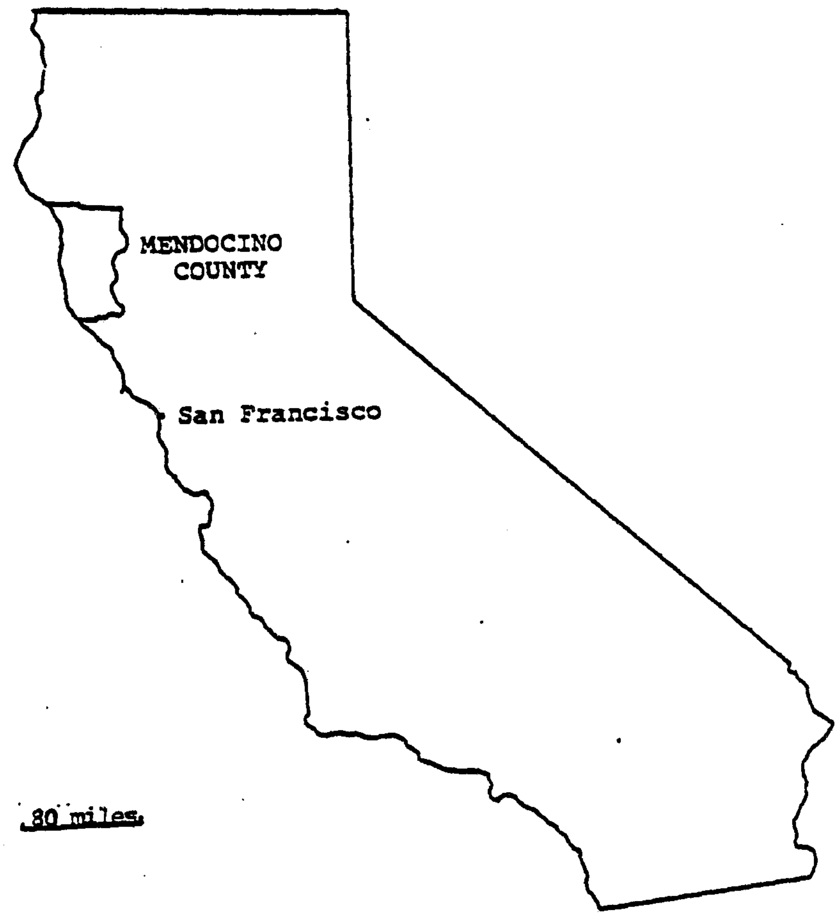


Figure 1. Location of Mendocino County in northern California. Investigations are being carried out here by personnel of the Remote Sensing Research Program, University of California, Berkeley Campus to demonstrate the usefulness of remote sensing derived information for planning and implementing fuel management plans (Section 2) and mapping wild turkey habitat (Section 3).

22

permits remote sensing scientists to modify their products to better meet the managers' information needs.

22

PART I

FUEL MAPPING IN RELATION TO THE MANAGEMENT OF BRUSHLANDS AND TIMBERLANDS IN CALIFORNIA

2.1 INTRODUCTION

2.1.1 HISTORICAL PERSPECTIVE

In February 1976, the Mendocino County Board of Supervisors, recognizing the need for a comprehensive fuel management plan, established the Fuel Control and Brush Range Management Committee (FMC). The primary mission of this committee, with representatives from county, state, and federal agencies, and private landowners, has been to develop and implement a fuel management plan in pilot areas throughout the county. The primary objective of fuel management in this area is to break up large homogeneous fields of brush into smaller brush-grassland mosaics. In this way, not only are fire hazards reduced, but "edge effect" around brush fields is increased so as to provide more shelter and forage for wildlife and domestic animals. In addition, soil stability is improved if stands of grass can replace the decadent brush.

Personnel from the Remote Sensing Research Program (RSRP) of the University of California's Berkeley campus, with the support of NASA's Office of University Affairs, have acted as technical advisors to the FMC since its inception. From the start it was recognized that some form of remote sensing data, in combination with other forms of ancillary data, would be needed as a base from which a management plan could be developed. Information acquired by means of remote sensing was needed because it was the type which could be (1) efficiently gathered for extensive inaccessible areas of the type encountered in much of Mendocino County, and (2) easily manipulated to meet both primary and secondary objectives relating to fuel management.

As a result of our effort in 1976-77, the wildland fuels present in the northeastern quarter of Mendocino County (see Figure 2) were mapped through the use of computer assisted analysis of Landsat digital data (Benson, et al, 1977). In addition property ownership boundaries that had been compiled by County personnel were overlaid on the fuel map to assist in fuel planning activities.

2.1.2 OBJECTIVES OF 1978-1979 CONTRACT PERIOD

Based on the success of this mapping effort, the FMC decided that it would be highly desirable to expand the fuel mapping to include the southeastern quarter of the County (Figure 2) with the aid of classified Landsat MSS data. A complete description of the classification procedure that was used is given in Section 2.2. The new study area extended south of the 1977 study area and was bounded on the east and south by the County boundary and on the north and west by the Russian River watershed boundary. The resulting classification products, both pictorial and tabular, are now being given to the appropriate fuel specialists in the FMC for evaluation. These most recent output products differed from those prepared last year in that a property ownership map was not overlaid on the fuel map. Although there is a need for property overlays in the preparation of fuel management plans, the manual compilation of such a map for the extensive area of the study site from County records would have been prohibitively expensive. In addition, during this compilation process so many changes in the ownership patterns would have

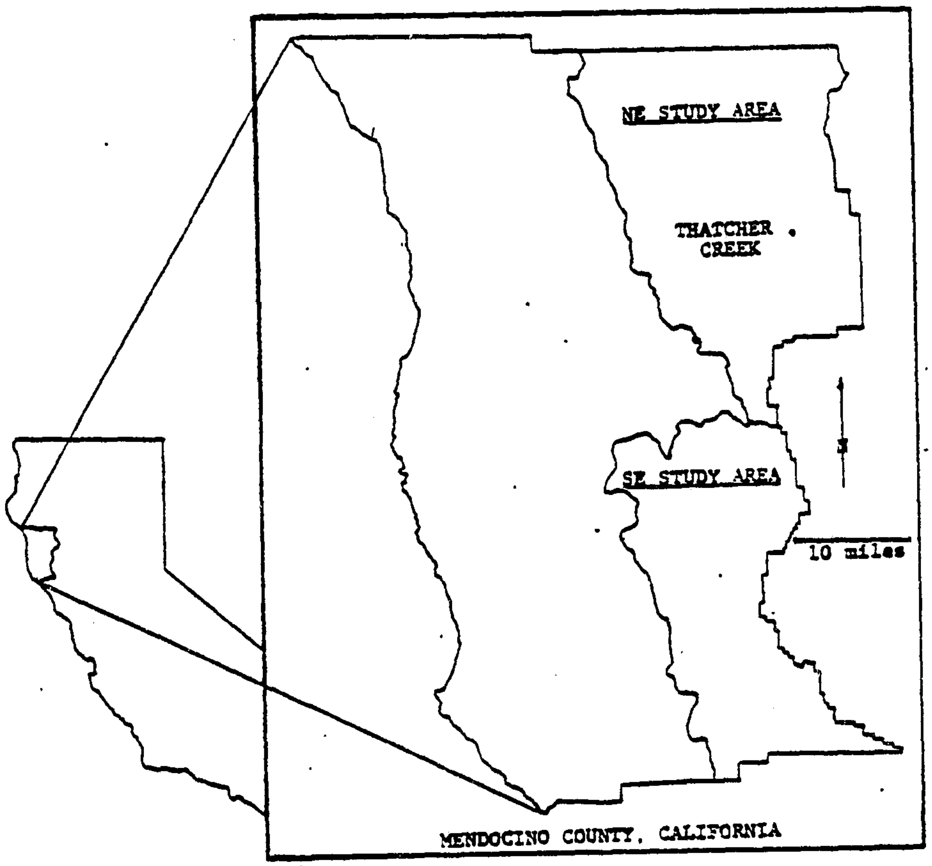


Figure 2. Location of the 476,000 acre northeastern study area and the 353,300 acre southeastern study area in Mendocino County, California. The distribution of wildland fuels within these two areas was mapped through the use of computer assisted analysis of Landsat-2 MSS data in 1977 and 1978 respectively by personnel of the Remote Sensing Research Program.

occurred that the resulting map would have been outdated before it was published. Therefore, property ownership maps will be prepared for smaller subareas within the larger study area in conjunction with the development of fuel management plans. In place of the property ownership overlay, a geographic grid based on the Universal Transverse Mercator (UTM) grid was overlaid on the fuels map. The UTM grid was selected because (1) it is easy to construct, (2) it is a square grid and hence all grid units are of the same size, (3) it is present on all U.S. Geological Survey map sheets, and (4) it is compatible with Landsat and other gridded and polygon data bases.

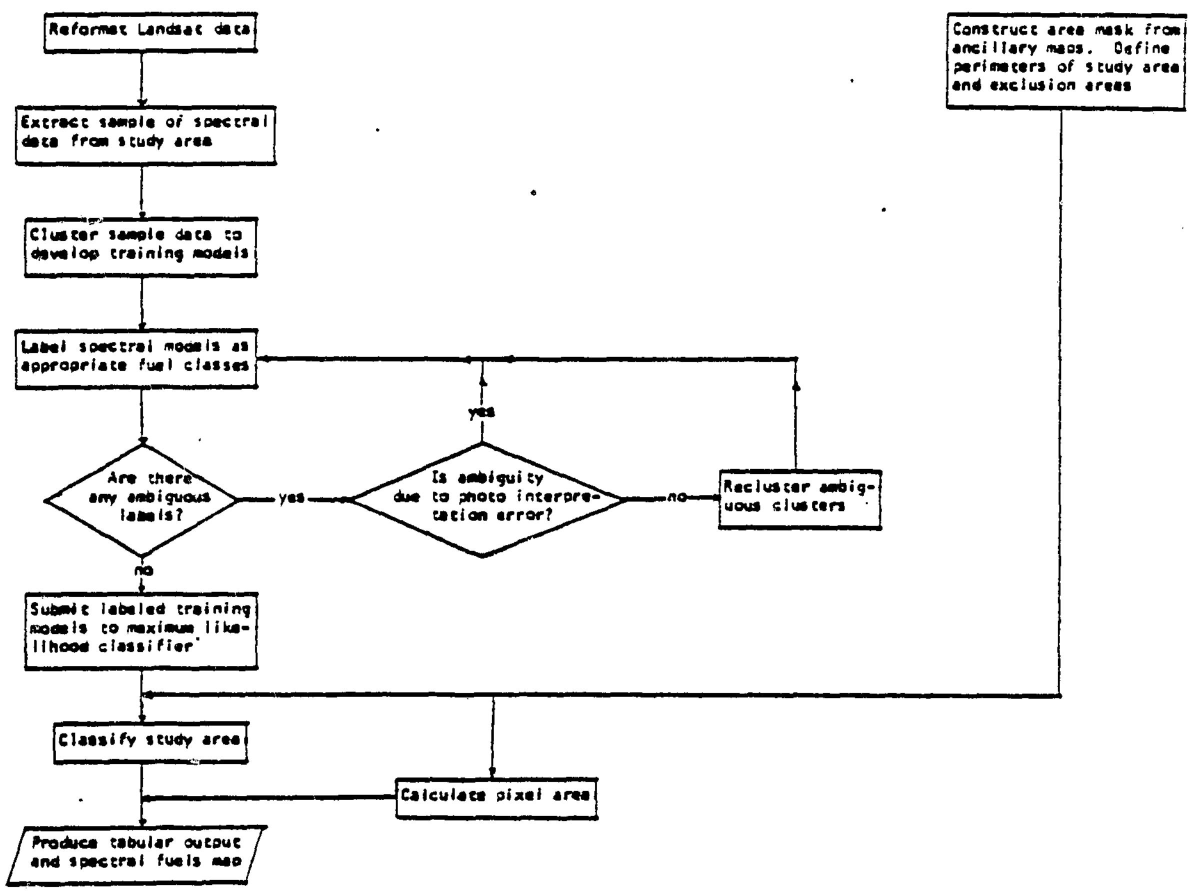
2.2 CLASSIFICATION OF THE SOUTHEASTERN STUDY AREA WITH LANDSAT-2 MSS DATA

The goal of the classification procedure was to produce a wildland fuels map for the southeastern study area from Landsat digital data. The output products were to be in a format that could be easily used by field personnel for making important management decisions, e.g. where to modify vegetation and where to locate fuel breaks within their respective jurisdictions. The output was to include: (1) a pixel-by-pixel classification map of all fuel classes, (2) a pixel-by-pixel classification map of selected fuel classes which represent particularly hazardous conditions, (3) an estimate of the acreage of each fuel type within the study area and (4) a UTM grid overlay for each map.

The transformation of raw Landsat digital data into major fuel types was accomplished using a "mixed" classification procedure. This approach uses a systematic sample of Landsat data from which statistical training models are automatically developed that describe all vegetation and ground conditions within the study area. These models are input to a maximum likelihood classifier which calculates the statistics for each Landsat pixel and assigns it to the training model class to which it is most similar. The final classification is written on magnetic tape for transformation into various output products.

The following paragraphs give a complete description of the five major tasks required in the mixed classification procedure as it was applied to the expanded study area: scene selection, preprocessing of Landsat and ancillary data, training selection, classification, and producing output products. Most of the details given below are specific to (1) the RSRP interactive display system which preprocesses the Landsat data, assists in training selection, and produces the final output products, (2) the Lawrence Berkeley Laboratory's (LBL) CDC 7600/6600 computer system which performs the major training and classification computations, and (3) the objectives of the project. With minor modification, however, these details could be adapted to other image processing systems and land use management objectives. They are included here to illustrate that a potential user of Landsat digital data does not simply order tapes from the EROS Data Center (EDC) and then expect meaningful classification results to be available minutes after receiving the data. Depending upon the ultimate user needs, the transformation of remote sensing data to management information usually involves many routine steps, in addition to skilled interaction of the analyst with the data, carried out in an orderly fashion so that the information needs are met in a cost-effective manner. We are acquainting the potential users with these facts and procedures by involving them, to an ever increasing extent, with the classification work we are doing. The classification process has been summarized in a flow chart in Table 1.

Table 1. The "mixed classification" procedure used to map the wildland fuels in southeastern Mendocino County through the use of computer assisted analysis of Landsat-2 digital data.



28

2.2.1 SCENE SELECTION

After the boundaries of the southeastern study area had been selected by members of the FMC, a geographic search for Landsat coverage of the area was requested from the EDC. The preferred time of year for the coverage was April through September in 1976 and 1977. Coverage from these months would minimize extensive shadowing on the image caused by low sun angles striking the mountainous terrain. The maximum acceptable cloud cover was set at 80 percent. While this may seem to be an exceptionally high percentage it must be noted that cloud cover percentages are based on the cloud cover appearing on the entire scene and not necessarily on the area being searched. Much of the particular Landsat scene that includes the test area was expected to include areas of the Pacific Ocean and the coastal zones along western Mendocino County which are frequently covered with fog during the summer mornings but which are well outside the test area. Hence, 80 percent cloud cover did not seem to be unreasonable.

Upon receipt of the listing of Landsat scenes meeting the above criteria from the EDC, the scenes were further screened on microfilm at the U.S. Geological Survey mapping facility in Menlo Park, California. Scene E-2522-18045 of 27 June 1976, was selected because (1) its overpass was close to the summer solstice (21 June), (2) the study area was cloud free (overall scene cloud cover rating was 10 percent), and (3) it was within one day of the scene used to classify the northeastern study area. The year 1976 was selected over the more recent coverage because it was the first summer of California's two year drought; hence vegetation and other ground conditions would appear more normal than in the following year.

2.2.2 PREPROCESSING OF LANDSAT AND ANCILLARY DATA

Major input data had to be preprocessed before image classification could proceed. This involved reformatting the Landsat digital data and constructing a mask for the expanded study area.

Eight weeks after the Landsat data tapes had been ordered from EDC, they were received at the RSRP. The tapes were reformatted in order to be compatible with the RSRP and LBL computer systems. To simplify this reformatting step, a 1433 point-by-875 line rectangle which covered the southeastern study area was extracted from Quadrants 2 and 3 of the Landsat scene. Only the data for this area, which represented 16 percent of the full scene, were reformatted. The data were then copied to a single "test" tape which was used in subsequent training and classification tasks.

The exact boundary of the study area was then defined in terms of Landsat coordinates through a process known as masking. This process was required so that only those points from within the expanded study area would be extracted from the reformatted test tape for classification. The five steps used in the masking process are given below:

1. The boundaries of the southeastern study area and of ten agricultural areas within the study area that were to be excluded from classification were delineated on a clear acetate overlay to a mosaic of six 15 minute quadrangle maps (scale 1:62500). In addition, 90 control points lying either within or immediately outside the study area were annotated on the overlay. These points corresponded to features that could be accurately located on both 7 1/2 minute orthophoto map sheets (and subsequently transferred to the 15 minute map base) and the Landsat image as displayed on the RSRP color monitor.

The boundary outlines and the distribution of control points are shown in Figure 3.

2. The overlay was photographically reduced to 3-by-3 inches so that it could be manually scanned on the RSRP digitizer which has a geometric resolution of 2000 points per inch in both X and Y directions. The digitizer's cursor was placed over each of the 90 control points, and X and Y scanner coordinates were recorded on magnetic tape. Then the cursor was traced around the perimeters of the expanded study area and exclusion areas, and the X and Y scanner coordinates of the resulting polygons were also recorded.

3. The expanded study area was displayed on the RSRP color monitor from the test tape. The Landsat coordinates -- point and line-- were determined for each of the 90 control points through the use of an interactive cursor.

4. Four regression models were run with the set of 90 paired scanner and Landsat coordinates using a linear least-squares curve fitting program developed by Daniel (1977). These runs were used to screen the data set for measurement and digitizing errors and to select the best equation for predicting the Landsat points and lines at or near the perimeter of the mask. The forms of the regression equations that were used are as follows;

Eq. 1. Landsat coordinate $= a + b_1X_s + b_2Y_s$

Eq. 2. Landsat coordinate $= a + b_1X_s + b_2Y_s + b_3X_sY_s$

Eq. 3. Landsat coordinate $= a + b_1X_s + b_2X_s^2 + b_3Y_s + b_4Y_s^2$

Eq. 4. Landsat coordinate $= a + b_1X_s + b_2X_s^2 + b_3Y_s + b_4Y_s^2 + b_5X_sY_s$

where a = intercept,
b = regression coefficient, and
s denotes scanner coordinate

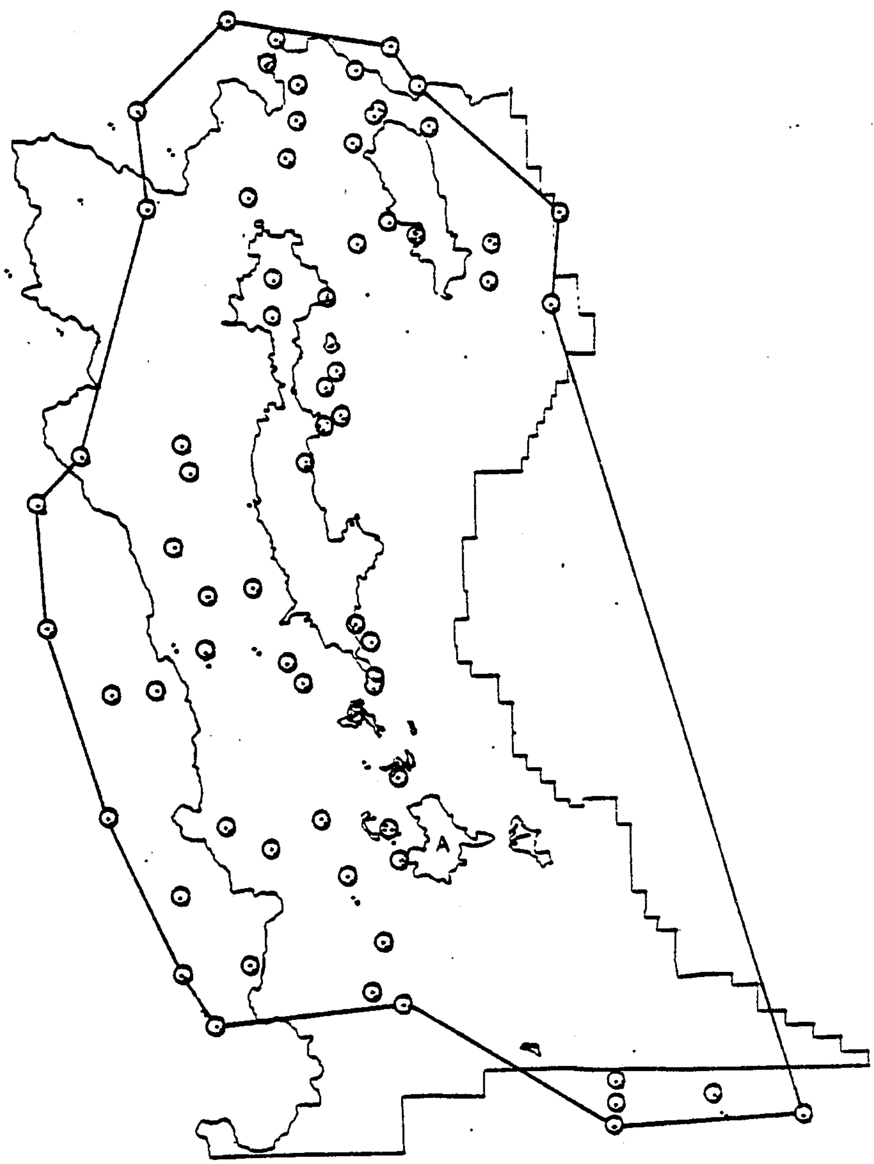


Figure 3. The boundary and exclusion outlines and the distribution of 90 control points which were used to construct a mask of the southeastern study area in Mendocino County, California. The 71 circled points were used to calculate the regression coefficients which were used to predict the Landsat point and line coordinates for the perimeter. The sixteen-sided polygon was used to calculate the ground area represented by a Landsat pixel. See text for details.

32

After four regression runs, 19 points were deleted from the original 90 point data set because of apparent measurement and/or digitizing errors. These confounding errors were attributed to one or more of the following factors: (1) inaccuracies associated with map projections of the 7½ minute and 15 minute quad sheets, (2) inaccurate feature location on the orthophoto map sheets and Landsat image, (3) inaccurate transfer of features to the 15 minute base map, (4) introduction of geometric distortion by photographically reducing the acetate overlay, and (5) errors in digitizing the control points. Since it was not practical to correct these errors, and because a sufficient number of evenly distributed observations remained, the sources of the errors were not determined. A listing of the final set of 71 observed scanner and Landsat coordinates is given in Table 2.

Based on the range of the residuals* and the analysis of variance (ANOVA), Equations 1 and 3 were selected as the predictor equations for Landsat Mask point and line coordinates respectively. The independent and dependent variables used in Equation 1 are listed in Table 2; those used in Equation 2 are listed in Table 3. The observed and fitted Landsat points and lines, ordered by residuals, are listed in Table 4. The summary of the analysis of variance is given in Table 5 along with an example of how the Landsat point and line residuals were calculated for control Point 11.

Interpretation of the ANOVA summary on Table 5 indicates that the regression equations provided good predictions of Landsat point and line locations. The ANOVA is interpreted as follows for a Landsat point. The total variability associated with the two independent scanner variables (X_s and Y_s) and the dependent variable (Landsat point) is 2,240,464. Of this total, the

* Residual = Observed Landsat coordinate - Fitted Landsat coordinate

Table 2. The listing of the 71 coordinate sets that were used as input to a regression analysis to predict Landsat point and line coordinates from the X and Y coordinates obtained from a digitizing scanner. This data set, as listed, was used as input for Equation 1 to predict Landsat points. Columns 2, 4, and 5 were filled with the appropriate transformed independent variable(s) as the Daniel program applied in Equations 2, 3, and 4 as listed in the text.

Independent Variables					Dependent Variables	
Scanner X		Scanner Y			Landsat point	Landsat line
1	2	3	4	5	6	7
795.000	-0.000	349.000	-0.000	-0.000	670.000	510.000
1031.000	-0.000	507.000	-0.000	-0.000	710.000	436.000
2140.000	-0.000	438.000	-0.000	-0.000	981.000	381.000
1538.000	-0.000	336.000	-0.000	-0.000	825.000	384.000
1573.000	-0.000	243.000	-0.000	-0.000	828.000	364.000
1280.000	-0.000	168.000	-0.000	-0.000	775.000	360.000
1661.000	-0.000	422.000	-0.000	-0.000	861.000	395.000
1892.000	-0.000	369.000	-0.000	-0.000	915.000	376.000
2029.000	-0.000	250.000	-0.000	-0.000	943.000	355.000
2394.000	-0.000	1200.000	-0.000	-0.000	1054.000	515.000
2434.000	-0.000	1245.000	-0.000	-0.000	1088.000	484.000
2114.000	-0.000	1013.000	-0.000	-0.000	1013.000	489.000
2643.000	-0.000	1305.000	-0.000	-0.000	1163.000	524.000
2685.000	-0.000	948.000	-0.000	-0.000	1150.000	454.000
2171.000	-0.000	598.000	-0.000	-0.000	959.000	409.000
2011.000	-0.000	975.000	-0.000	-0.000	983.000	485.000
1452.000	-0.000	368.000	-0.000	-0.000	837.000	465.000
1545.000	-0.000	1194.000	-0.000	-0.000	883.000	543.000
1537.000	-0.000	1337.000	-0.000	-0.000	890.000	570.000
1750.000	-0.000	1264.000	-0.000	-0.000	946.000	548.000
1887.000	-0.000	1258.000	-0.000	-0.000	957.000	504.000
1876.000	-0.000	662.000	-0.000	-0.000	929.000	430.000
1607.000	-0.000	716.000	-0.000	-0.000	865.000	452.000
1965.000	-0.000	560.000	-0.000	-0.000	943.000	408.000
1987.000	-0.000	535.000	-0.000	-0.000	948.000	402.000
1656.000	-0.000	566.000	-0.000	-0.000	867.000	421.000
1171.000	-0.000	1834.000	-0.000	-0.000	831.000	677.000
1202.000	-0.000	1943.000	-0.000	-0.000	845.000	696.000
1135.000	-0.000	2230.000	-0.000	-0.000	848.000	751.000
777.000	-0.000	1869.000	-0.000	-0.000	735.000	701.000
697.000	-0.000	2757.000	-0.000	-0.000	733.000	743.000
1258.000	-0.000	2423.000	-0.000	-0.000	891.000	783.000
1244.000	-0.000	2646.000	-0.000	-0.000	903.000	824.000
1057.000	-0.000	2790.000	-0.000	-0.000	865.000	859.000
830.000	-0.000	2537.000	-0.000	-0.000	740.000	832.000
877.000	-0.000	2803.000	-0.000	-0.000	821.000	868.000
1793.000	-0.000	1552.000	-0.000	-0.000	968.000	609.000
1806.000	-0.000	1724.000	-0.000	-0.000	983.000	632.000
1752.000	-0.000	1756.000	-0.000	-0.000	970.000	640.000
1723.000	-0.000	1769.000	-0.000	-0.000	964.000	643.000
1749.000	-0.000	1617.000	-0.000	-0.000	960.000	614.000
1664.000	-0.000	1905.000	-0.000	-0.000	957.000	672.000
1906.000	-0.000	2617.000	-0.000	-0.000	1065.000	796.000
1911.000	-0.000	2830.000	-0.000	-0.000	1078.000	830.000
1914.000	-0.000	2764.000	-0.000	-0.000	1076.000	822.000
1841.000	-0.000	2901.000	-0.000	-0.000	1067.000	851.000
1996.000	-0.000	3155.000	-0.000	-0.000	1122.000	892.000
1840.000	-0.000	2551.000	-0.000	-0.000	1046.000	785.000
1438.000	-0.000	2398.000	-0.000	-0.000	934.000	772.000
1569.000	-0.000	2700.000	-0.000	-0.000	987.000	823.000
1632.000	-0.000	2777.000	-0.000	-0.000	1007.000	835.000
852.000	-0.000	3292.000	-0.000	-0.000	847.000	960.000
1305.000	-0.000	3337.000	-0.000	-0.000	964.000	953.000
1166.000	-0.000	3639.000	-0.000	-0.000	936.000	1009.000
1124.000	-0.000	3913.000	-0.000	-0.000	955.000	1065.000
1256.000	-0.000	4115.000	-0.000	-0.000	1001.000	1298.000
1595.000	-0.000	3478.000	-0.000	-0.000	1144.000	953.000
1937.000	-0.000	3358.000	-0.000	-0.000	1122.000	932.000
1984.000	-0.000	3358.000	-0.000	-0.000	1130.000	931.000
1337.000	-0.000	3621.000	-0.000	-0.000	1107.000	987.000
1924.000	-0.000	3870.000	-0.000	-0.000	1147.000	1015.000
1879.000	-0.000	3944.000	-0.000	-0.000	1149.000	1052.000
1997.000	-0.000	4045.000	-0.000	-0.000	1181.000	1059.000
1691.000	-0.000	3327.000	-0.000	-0.000	1057.000	932.000
1495.000	-0.000	3424.000	-0.000	-0.000	1014.000	960.000
1392.000	-0.000	3877.000	-0.000	-0.000	1019.000	1053.000
3554.000	-0.000	4514.000	-0.000	-0.000	1602.000	1089.000
2829.000	-0.000	4361.000	-0.000	-0.000	1411.000	1088.000
2825.000	-0.000	4454.000	-0.000	-0.000	1416.000	1105.000
2818.000	-0.000	4541.000	-0.000	-0.000	1420.000	1121.000
3209.000	-0.000	4426.000	-0.000	-0.000	1510.000	1086.000

Table 3. A list of the four independent scanner variables and the dependent Landsat variables used to predict the Landsat line.

INDEPENDENT VARIABLES				DEPENDENT VARIABLES	
SCANNER X	SCANNER X^2	SCANNER Y	SCANNER Y^2	LNST POINT	LNST LINE
7.95000E+02	6.32025E+05	8.49000E+02	7.20801E+05	6.70000E+02	5.10000E+02
1.03100E+03	1.06296E+06	5.07000E+02	2.57049E+05	7.10000E+02	4.36000E+02
2.14000E+03	4.57960E+06	4.38000E+02	1.91844E+05	9.21000E+02	3.61000E+02
1.53300E+03	2.34544E+06	3.36000E+02	1.12896E+05	8.25000E+02	3.84000E+02
1.57300E+03	2.47433E+06	2.43000E+02	5.90490E+04	8.28000E+02	3.64000E+02
1.38000E+03	1.90440E+06	1.68000E+02	2.82240E+04	7.75000E+02	3.60000E+02
1.66100E+03	2.75892E+06	4.22000E+02	1.78084E+05	8.61000E+02	3.95000E+02
1.89200E+03	3.57966E+06	3.69000E+02	1.36161E+05	9.15000E+02	3.76000E+02
2.02900E+03	4.11684E+06	2.80000E+02	7.84000E+04	9.43000E+02	3.55000E+02
2.39400E+03	5.73124E+06	1.20800E+03	1.45926E+06	1.09400E+03	5.15000E+02
2.40400E+03	5.77922E+06	1.04500E+03	1.09202E+06	1.08800E+03	4.84000E+02
2.11400E+03	4.46900E+06	1.01300E+03	1.02617E+06	1.01300E+03	4.89000E+02
2.64300E+03	6.98545E+06	1.30500E+03	1.70302E+06	1.16300E+03	5.24000E+02
2.68500E+03	7.20922E+06	9.48000E+02	8.98704E+05	1.15000E+03	4.54000E+02
2.17100E+03	4.71324E+06	5.98000E+02	3.57604E+05	9.99000E+02	4.08000E+02
2.01100E+03	4.04412E+06	9.75000E+02	9.50625E+05	9.83000E+02	4.65000E+02
1.45200E+03	2.10830E+06	8.68000E+02	7.53424E+05	8.37000E+02	4.85000E+02
1.54500E+03	2.38703E+06	1.19400E+03	1.42564E+06	8.83000E+02	5.43000E+02
1.53900E+03	2.36852E+06	1.33700E+03	1.78757E+06	8.90000E+02	5.70000E+02
1.75600E+03	3.08354E+06	1.26400E+03	1.59770E+06	9.40000E+02	5.48000E+02
1.88700E+03	3.56077E+06	1.05800E+03	1.11936E+06	9.57000E+02	5.64000E+02
1.87600E+03	3.51938E+06	6.62000E+02	4.38244E+05	9.29000E+02	4.30000E+02
1.60700E+03	2.58245E+06	7.16000E+02	5.12656E+05	8.65000E+02	4.52000E+02
1.96500E+03	3.86123E+06	5.60000E+02	3.13600E+05	9.43000E+02	4.68000E+02
1.98700E+03	3.94817E+06	5.35000E+02	2.86225E+05	9.48000E+02	4.02000E+02
1.65600E+03	2.74234E+06	5.66000E+02	3.20356E+05	9.67000E+02	4.21000E+02
1.17100E+03	1.37124E+06	1.83400E+03	3.36356E+06	8.31000E+02	6.77000E+02
1.20200E+03	1.44480E+06	1.94300E+03	3.77525E+06	8.45000E+02	6.96000E+02
1.13500E+03	1.28823E+06	2.23000E+03	4.97290E+06	8.48000E+02	7.51000E+02
7.77000E+02	6.03729E+05	1.86900E+03	3.49316E+06	7.35000E+02	7.01000E+02
6.00000E+02	3.60000E+05	2.05700E+03	4.23125E+06	7.03000E+02	7.43000E+02
1.25800E+03	1.50256E+06	2.42300E+03	5.87093E+06	8.91000E+02	7.83000E+02
1.24400E+03	1.54754E+06	2.64600E+03	7.00132E+06	9.03000E+02	8.24000E+02
1.05700E+03	1.11725E+06	2.79000E+03	7.78410E+06	8.65000E+02	8.59000E+02
6.30000E+02	3.96900E+05	2.53700E+03	6.43637E+06	7.40000E+02	8.32000E+02
8.77000E+02	7.69129E+05	2.80300E+03	7.85681E+06	8.21000E+02	8.68000E+02
1.79300E+03	3.22405E+06	1.55200E+03	2.40870E+06	9.68000E+02	6.00000E+02
1.80600E+03	3.26164E+06	1.72600E+03	2.97908E+06	9.83000E+02	6.32000E+02
1.75200E+03	3.06950E+06	1.75600E+03	3.08354E+06	9.70000E+02	6.40000E+02
1.72300E+03	2.96873E+06	1.76900E+03	3.12936E+06	9.64000E+02	6.42000E+02
1.74900E+03	3.05900E+06	1.61700E+03	2.61469E+06	9.63000E+02	6.14000E+02
1.66400E+03	2.76890E+06	1.90500E+03	3.62903E+06	9.57000E+02	6.72000E+02
1.90600E+03	3.63284E+06	2.61700E+03	6.84869E+06	1.06500E+03	7.96000E+02
1.91100E+03	3.65192E+06	2.80000E+03	7.84000E+06	1.07800E+03	8.30000E+02
1.91400E+03	3.66340E+06	2.76400E+03	7.63970E+06	1.07600E+03	8.22000E+02
1.84100E+03	3.38928E+06	2.90100E+03	8.41580E+06	1.06700E+03	8.51000E+02
1.99600E+03	3.98402E+06	3.15500E+03	9.95402E+06	1.12200E+03	8.92000E+02
1.84600E+03	3.40772E+06	2.55100E+03	6.50760E+06	1.04600E+03	7.85000E+02
1.43800E+03	2.06784E+06	2.39800E+03	5.75040E+06	9.34000E+02	7.72000E+02
1.56900E+03	2.46176E+06	2.70000E+03	7.29000E+06	9.87000E+02	8.23000E+02
1.63200E+03	2.66342E+06	2.77700E+03	7.71173E+06	1.00700E+03	8.35000E+02
8.52000E+02	7.25904E+05	3.29200E+03	1.08373E+07	8.47000E+02	9.60000E+02
1.30800E+03	1.71086E+06	3.33700E+03	1.11356E+07	9.64000E+02	9.53000E+02
1.12600E+03	1.26788E+06	3.60900E+03	1.30249E+07	9.36000E+02	1.03900E+03
1.12400E+03	1.26338E+06	3.91300E+03	1.53116E+07	9.55000E+02	1.06500E+03
1.25600E+03	1.57754E+06	4.11500E+03	1.69332E+07	1.00100E+03	1.09800E+03
1.99500E+03	3.98003E+06	3.47800E+03	1.20965E+07	1.14400E+03	9.53000E+02
1.93700E+03	3.75197E+06	3.35800E+03	1.12762E+07	1.12200E+03	9.32000E+02
1.96800E+03	3.87302E+06	3.35800E+03	1.12762E+07	1.13000E+03	9.31000E+02
1.80700E+03	3.26525E+06	3.62100E+03	1.31116E+07	1.12700E+03	9.87000E+02
1.92400E+03	3.70178E+06	3.80000E+03	1.44400E+07	1.14700E+03	1.01500E+03
1.87900E+03	3.53064E+06	3.99400E+03	1.59520E+07	1.14900E+03	1.05200E+03
1.99700E+03	3.98801E+06	4.04500E+03	1.63620E+07	1.19100E+03	1.05900E+03
1.69100E+03	2.85948E+06	3.30900E+03	1.09495E+07	1.05700E+03	9.32000E+02
1.49000E+03	2.22010E+06	3.42400E+03	1.17238E+07	1.01400E+03	9.60000E+02
1.39200E+03	1.93766E+06	3.87700E+03	1.50311E+07	1.01900E+03	1.05000E+03
3.55400E+03	1.26309E+07	4.51400E+03	2.03762E+07	1.60200E+03	1.08900E+03
2.82900E+03	8.00324E+06	4.36100E+03	1.90183E+07	1.41100E+03	1.08800E+03
2.82500E+03	7.98063E+06	4.45400E+03	1.98381E+07	1.41600E+03	1.10500E+03
2.81800E+03	7.94112E+06	4.54100E+03	2.06207E+07	1.42000E+03	1.12100E+03
3.20900E+03	1.02977E+07	4.42600E+03	1.95895E+07	1.51000E+03	1.08600E+03

Table 4. The ordered residuals for Landsat point (a) as predicted from the first order regression equations using the data in Table 2, and the ordered residuals for Landsat line (b) as predicted from the second order regression equation using the data in Table 3. See text for details.

(a)

ORDERED BY RESIDUALS

OBS. Point	FITTED Point	ORDERED RESID.	SEQ
943.000	945.162	-2.162	1
670.000	671.922	-1.922	2
740.000	741.466	-1.466	3
867.000	868.385	-1.385	4
957.000	958.356	-1.356	5
957.000	958.236	-1.236	6
1122.000	1123.165	-1.165	7
1076.000	1077.032	-1.032	8
948.000	949.016	-1.016	9
865.000	865.989	-.989	10
983.000	983.879	-.879	11
1094.000	1094.819	-.819	12
1181.000	1181.809	-.809	13
1067.000	1067.790	-.790	14
1019.000	1019.691	-.691	15
1078.000	1078.645	-.645	16
929.000	929.627	-.627	17
960.000	960.568	-.568	18
1147.000	1147.503	-.503	19
1007.000	1007.457	-.457	20
1014.000	1014.444	-.444	21
970.000	970.437	-.437	22
1150.000	1150.436	-.436	23
1065.000	1065.390	-.390	24
1163.000	1163.370	-.370	25
845.000	845.347	-.347	26
1001.000	1001.341	-.341	27
837.000	837.251	-.251	28
934.000	934.140	-.140	29
955.000	955.121	-.121	30
1144.000	1144.108	-.108	31
999.000	999.103	-.103	32
1057.000	1057.097	-.097	33
1046.000	1046.075	-.075	34
964.000	964.048	-.048	35
1149.000	1148.993	.007	36
981.000	980.863	.137	37
891.000	890.826	.174	38
943.000	942.775	.225	39
890.000	889.751	.249	40
1122.000	1121.750	.250	41
865.000	864.707	.293	42
936.000	935.675	.325	43
987.000	986.671	.329	44
821.000	820.605	.395	45
1107.000	1106.539	.461	46
1510.000	1509.498	.502	47
1130.000	1129.492	.508	48
703.000	702.480	.520	49
831.000	830.453	.547	50
847.000	846.446	.554	51
848.000	847.444	.556	52
1602.000	1601.434	.566	53
1416.000	1415.433	.567	54
915.000	914.399	.601	55
1420.000	1419.393	.607	56
735.000	734.350	.650	57
1411.000	1410.330	.670	58
968.000	967.292	.708	59
964.000	963.282	.718	60
861.000	860.185	.815	61
940.000	939.156	.844	62
1013.000	1012.096	.904	63
903.000	901.961	1.039	64
983.000	981.955	1.045	65
883.000	881.867	1.133	66
825.000	823.824	1.176	67
1088.000	1086.622	1.378	68
828.000	826.463	1.537	69
710.000	708.423	1.577	70
775.000	773.342	1.658	71

(b)

ORDERED BY RESIDUALS

OBS. Line	FITTED Line	ORDERED RESID.	SEQ
1089.000	1090.796	-1.796	1
960.000	961.699	-1.699	2
824.000	825.641	-1.641	3
1065.000	1066.610	-1.610	4
402.000	403.607	-1.607	5
868.000	869.513	-1.513	6
430.000	431.432	-1.432	7
454.000	455.379	-1.379	8
751.000	752.367	-1.367	9
960.000	961.133	-1.133	10
408.000	409.087	-1.087	11
1098.000	1099.071	-1.071	12
485.000	485.988	-.988	13
859.000	859.881	-.881	14
504.000	504.867	-.867	15
1009.000	1009.851	-.851	16
421.000	421.841	-.841	17
364.000	364.776	-.776	18
643.000	643.630	-.630	19
1052.000	1052.624	-.624	20
408.000	408.566	-.566	21
603.000	603.519	-.519	22
783.000	783.510	-.510	23
632.000	632.475	-.475	24
614.000	614.301	-.301	25
548.000	548.210	-.210	26
696.000	696.206	-.206	27
543.000	543.197	-.197	28
376.000	376.192	-.192	29
640.000	640.107	-.107	30
677.000	677.103	-.103	31
823.000	823.101	-.101	32
570.000	570.094	-.094	33
835.000	835.049	-.049	34
932.000	931.998	.002	35
822.000	821.976	.024	36
932.000	931.874	.126	37
1086.000	1085.847	.153	38
772.000	771.835	.165	39
892.000	891.828	.172	40
785.000	784.807	.193	41
395.000	394.796	.204	42
1015.000	1014.770	.230	43
485.000	484.769	.231	44
931.000	930.719	.281	45
452.000	451.683	.317	46
1121.000	1120.680	.320	47
355.000	354.494	.506	48
484.000	483.465	.535	49
384.000	383.463	.537	50
524.000	523.432	.568	51
1050.000	1049.388	.612	52
851.000	850.256	.744	53
672.000	671.231	.769	54
515.000	514.221	.779	55
1105.000	1104.216	.784	56
436.000	435.197	.803	57
953.000	952.090	.910	58
489.000	488.050	.950	59
953.000	951.977	1.023	60
381.000	379.866	1.134	61
796.000	794.865	1.135	62
830.000	828.801	1.199	63
987.000	985.783	1.217	64
1088.000	1086.738	1.262	65
1059.000	1057.732	1.268	66
743.000	741.680	1.320	67
510.000	508.460	1.540	68
701.000	699.397	1.603	69
360.000	358.239	1.761	70
832.000	829.953	2.047	71

OBSERVED COORDINATES FOR CONTROL POINT 11

Landsat point: 670 Scanner X: 795
Landsat Line : 510 Scanner Y: 849

REGRESSION FIT FOR LANDSAT POINT USING TWO INDEPENDENT SCANNER VARIABLES -- X_s and Y_s

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F-Value	Root Mean Square Error
Regression	2,240,415	2	1,120,207.50	1,155,843	0.85
Residual (error)	49	68	0.72		
TOTAL	2,240,464	N-1 = 70			

Landsat point prediction equation = $417.6705 + 0.249745(X_s) + 0.065611(Y_s)$
Observed Landsat point 11 = 670

Fitted Landsat point 11 = 417.6705 + 0.249745(795) + 0.06561-(849) = 671.922

Landsat point 11 residual = 670 - 671.922 = -1.922

REGRESSION FIT FOR LANDSAT LINE USING FOUR INDEPENDENT SCANNER VARIABLES -- X_s, X_s^2, Y_s, and Y_s^2

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F-Value	Root Mean Square Error
Regression	4,145,079	4	1,036,269.750	1,085,616	0.98
Residual (error)	63	66	0.955		
TOTAL	4,145,142	N-1 = 70			

Landsat line prediction equation = $383.2441 - 0.042774(X_s) + 1.41395 \times 10^{-6}(X_s^2) + 0.186493(Y_s) - 5.704632 \times 10^{-9}(Y_s^2)$
Observed Landsat line 11 = 510

Fitted Landsat line 11 = $383.2441 - 0.042774(795) + 1.41395 \times 10^{-6}(795^2) + 0.186493(849) - 5.704632 \times 10^{-9}(849^2)$
= 508.460

Landsat line 11 residual = 510 - 508.460 = 1.540

Table 5. Summary of the analysis of variance based on a first order regression equation using two independent variables to predict the Landsat point, and a second order regression using four independent variables to predict the Landsat line. An example of the calculation of the Landsat line and point residuals for Control Point 11 is included.

regression equation accounts for 2,240,415. The average mean square error for each observation is 49/68 = 0.72, so that one expects to predict the true Landsat point to within ± 0.85 pixels using Equation 1. By the same reasoning, one expects to predict the true Landsat line to within ± 0.98 pixels (= $0.955^{1/2}$), using Equation 3. Taking into consideration that one can only measure a Landsat pixel to the nearest point and line, these average expected errors are very acceptable. The ability to predict Landsat coordinates to such a high accuracy for this study was due to the availability of orthophoto map sheets. Using these geometrically rectified photo maps, it was a simple task to locate a large number of ground features that could also be seen on Landsat imagery; from these observations, a reliable regression relationship was developed.

5. The regression coefficients for the Landsat lines and points were input to the data handling program, MAPIT, which determined those pixels which fell outside the study area, those which fell within the study area, and those which fell within the exclusion areas. This information was transferred to magnetic tape for use in the classification process. Of the 1,253,875 pixels on the test tape, only 24 percent had to be classified because 74 percent fell outside the study area and 2 percent fell within the exclusion areas. An example of the MAPIT line printer output is shown in Figure 4.

2.2.3 SELECTION OF TRAINING AREAS

The most critical task of any automated classification procedure is the selection of an adequate training set from which to model the ground conditions within an area. The approach used in this study was controlled clustering. With this approach, several rectangular areas were selected from within,

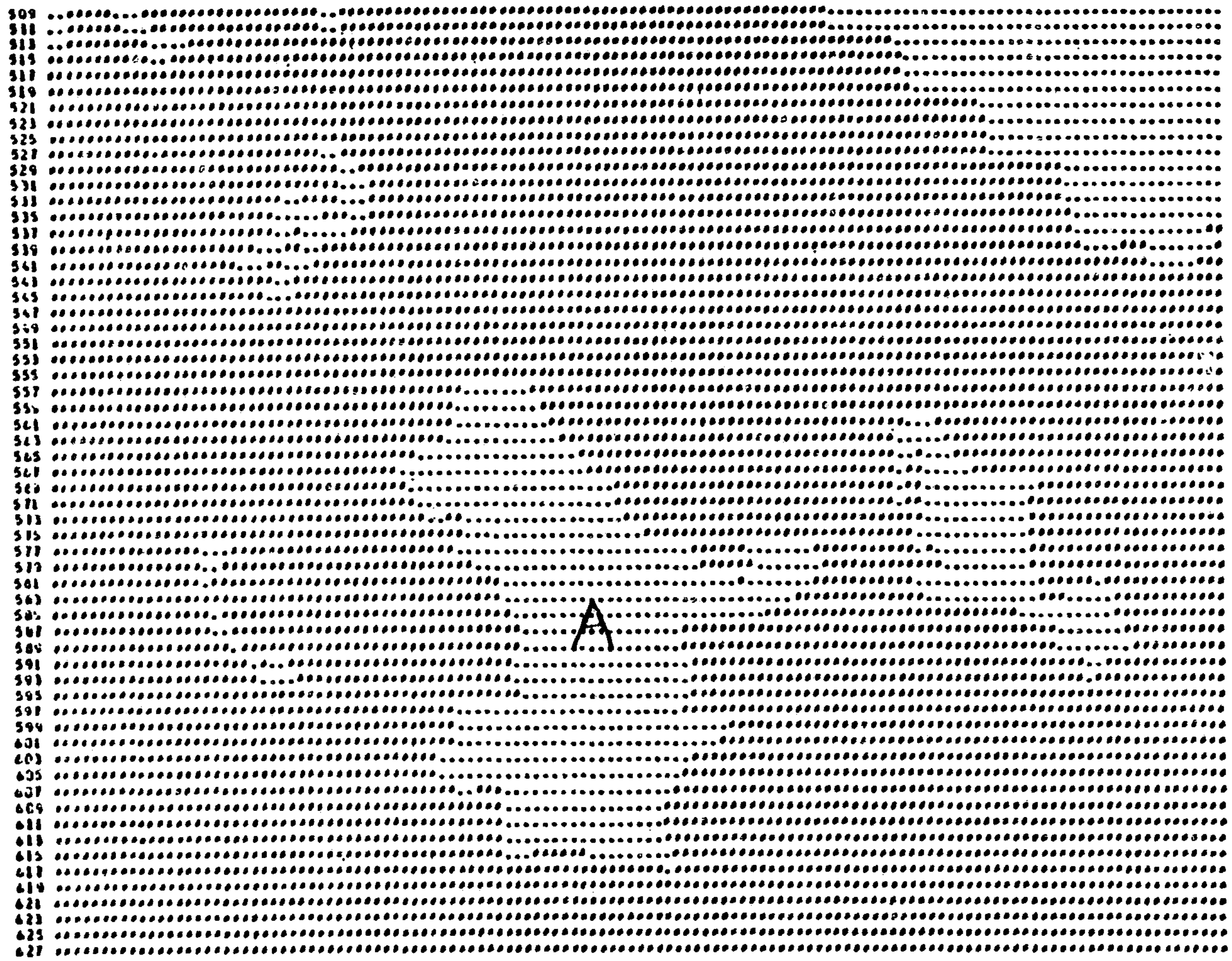


Figure 4. This portion of the mask output from MAPIT corresponds to the area surrounding Letter A in Figure 3. Those pixels represented by "." were not classified because they either fell outside the study area or within an exclusion area; those pixels represented by # were classified. The column of numbers along the left hand side of this output represent Landsat line numbers relative to the test tape.

and immediately surrounding, the expanded study area such that they encompassed all existing ground conditions. The spectral data from these rectangles were clustered to form training statistics, and then these clusters were labeled and submitted to the maximum likelihood classifier for final classification of the entire study area.

In order to ensure that all wildland conditions within the southeastern study area were represented in the spectral training set, the area was divided into fifteen blocks. These blocks were defined by the areas covered by the 15-7½ minute orthophoto map sheets that were available for most of the area as shown in Figure 5. To achieve a spectral sample of approximately ten percent of the study area, 60 point X 50 line rectangles were selected from the blocks. In total 23 training rectangles were extracted from all the blocks. Four rectangles fell outside the study area, but as they included good spectral training of ground conditions within the area, they were included in the sample. It should be noted in Figure 5 that some of the study area was excluded from the spectral sample because there was no orthophoto coverage for these quadrangles. Careful visual inspection of the raw data product indicated that there were no conditions present in this area that had not been represented in the other sample blocks.

In order to minimize the processing costs of clustering the training rectangles, the 23 rectangles were extracted from the reformatted magnetic tape and rewritten as one file, 60 points-by-1150 lines. It was estimated that this reorganization of the 23 rectangles into one file reduced computing and subsequent data handling costs by 10 percent.

The 69,000 data points or picture elements (pixels) from the file were submitted to the algorithm ISOCLAS which automatically generated cluster

40

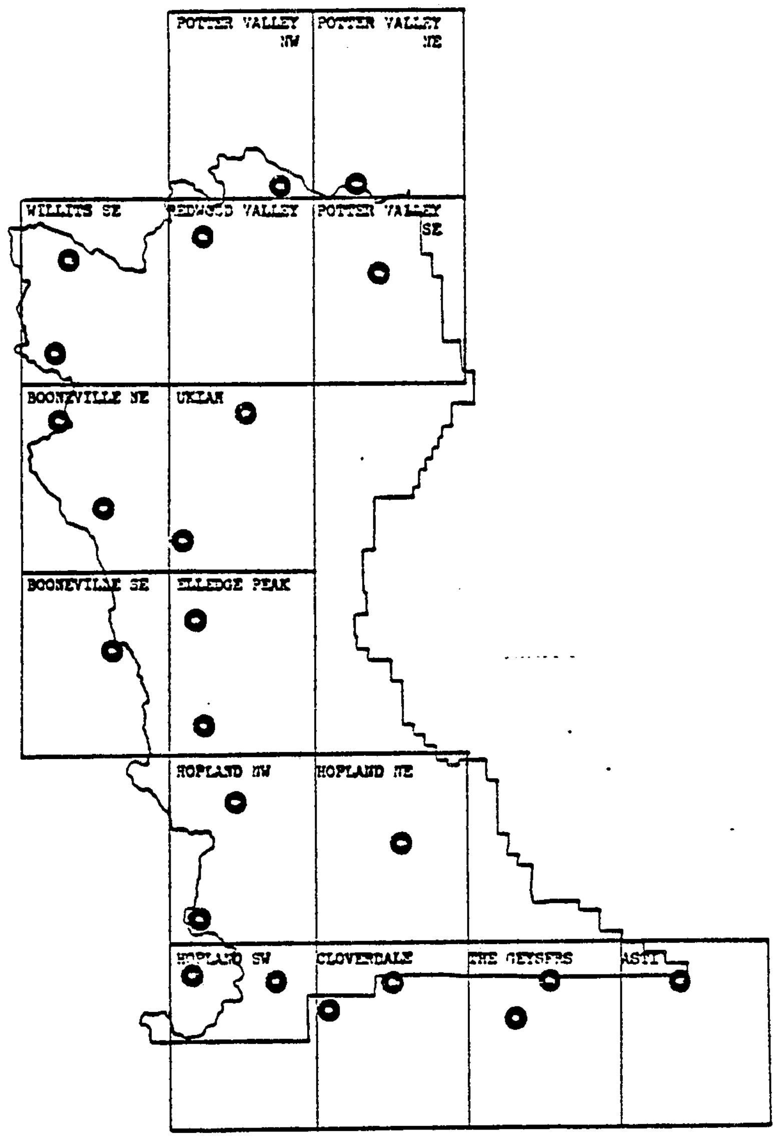


Figure 5. This grid, based on the orthophoto map sheets available for the study area, was used to ensure that all wildland conditions would be included in the spectral training sample. The circles (o) located within the grid blocks represent the center of the 60 point x 50 line rectangles selected for training the maximum likelihood classifier.

statistics. These statistics were generated through a series of iterations in which the data from the four Landsat bands were clustered about the band means as follows. In the first iteration the 69,000 pixels were considered as one cluster. In the second iteration the first cluster was split into two clusters of 28,054 and 40,946 pixels based on an allowable standard deviation about the band means and other input parameters. In the third iteration the clusters were split again, based on an allowable standard deviation, thus creating four clusters of 12,084, 18,035, 18,247, and 20,634 pixels, respectively. These iterations continued until one of three possible terminating criteria were met: (1) a maximum of 20 clustering iterations were completed, (2) an average standard deviation for the four bands of 1.6 was achieved, or (3) no more than 3 percent of the data points were assigned to clusters that were different from the last iteration. The clustering parameters and terminating criteria are listed in Table 6. These input values were determined to be optimal based on experience from previous studies in which wildland environments had been classified with Landsat data. Note that the terminating criterion that halted the data processing with 34 clusters was ISTOP which was set at 20 iterations. At this number of iterations AVSTED and PERCENT were greater than the critical values of 1.60 and 3 respectively.

As an example of the data processing performed by ISOCLAS, the output from the 20 iterations for training rectangle 19 is shown in

Table 6. Clustering Parameters* and Terminating Criteria Input** to the Clustering Algorithm ISOCLAS

	INPUT	RESULTS
DLMIN*	3.2	3.2
STDMAX*	3.2	3.62
MAXCLAS*	40	34
NMIN*	30	54
PERCENT**	3	5.18
AVSTED**		1.90
ISTOP***	20	20

Description

DLMIN: Combine those clusters whose intercluster distance is less than 3.2.

STDMAX: Split any cluster with the average standard deviation for all bands greater than .667 x 3.2 = (2.13).

MAXCLAS: Generate no more than 40 clusters from the data set.

NMIN: Delete any cluster containing less than 30 points.

PERCENT: Stop processing when less than 3 percent of the data points are assigned to clusters different from the previous iteration.

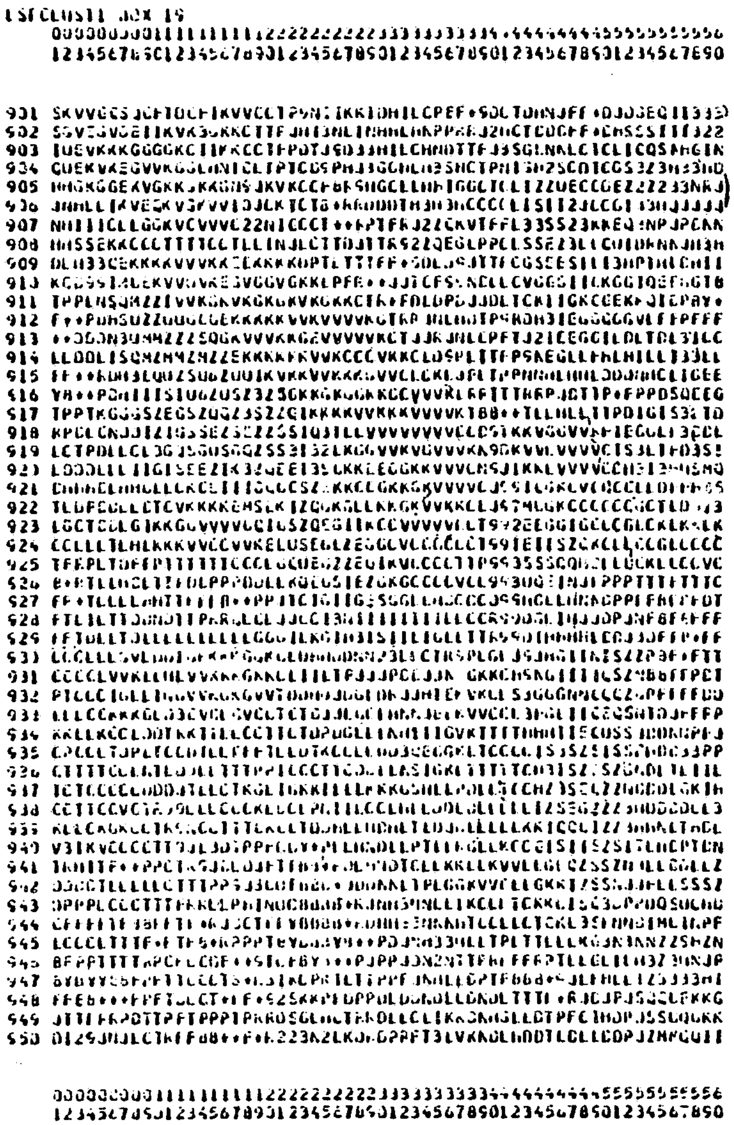
AVSTED: Stop clustering when the average band standard deviation is less than or equal to STDMAX/2.

ISTOP: Perform no more than 20 clustering iterations on the data set.

Figure 6. This output was also written on a magnetic tape to facilitate labeling of the clusters. All but three of the 34 clusters generated from the 69,000 pixels were present in this pixel rectangle.

After clustering of the training rectangles had been completed, and prior to submitting the training statistics to the classification algorithm, each of the 34 clusters had to be labeled as representing one of the fuel classes listed in Table 7. These classes were defined by the FS, CDF, and BLM personnel who have major land management and fire control responsibilities within the expanded study area. This fuel mapping classification included all major fuel types present in the expanded study area and those which were expected to be encountered in the next year's work in southeastern Mendocino County. Although this fuel mapping classification represented a compromise between the existing FS and CDF statewide classification systems, it was flexible enough so that it could be integrated easily into either of the systems at a later time if desired.

To facilitate the labeling procedure, the clusters were ranked on the basis of the ratio of two times the mean cluster value in the infrared band (Band 7) to the mean cluster value in the red band (Band 5). This ratio (hereafter referred to as the vegetation indicator, VI), is an indicator of general vegetation condition in that it retains most of the spectral information regarding vegetation development while tending to normalize the influence of such confounding factors as solar radiation and topography (Hay, et al. 1977). Therefore, one would expect that similar vegetation conditions would have



(a)

CLUSTER MAP SYMBOL	VI* CLUSTER VALUE	BLOCK PIXEL COUNT	PERCENT OF CLUSTER	PERCENT OF BLOCK	LABEL
W	.019	0	0	0	______
5	.359	0	0	0	______
7	.932	1	2	+0	______
9	1.044	49	25	2	______
B	1.141	17	20	1	______
+	1.215	55	8	2	______
$	1.219	3	3	+0	______
Y	1.239	10	4	+0	______
A	1.269	65	7	2	______
2	1.344	22	5	1	______
J	1.362	83	6	4	______
8	1.433	36	6	1	______
6	1.468	2	1	+0	______
P	1.520	123	4	4	______
F	1.543	109	6	4	______
N	1.589	95	4	3	______
D	1.764	208	5	7	______
3	1.833	92	3	3	______
Z	1.927	72	5	2	______
H	1.975	135	4	5	______
T	2.039	228	8	8	______
S	2.328	96	3	3	______
L	2.394	326	7	11	______
I	2.529	172	3	6	______
C	2.905	248	9	8	______
M	2.508	14	2	+0	______
4	2.937	0	0	0	______
U	3.302	25	1	1	______
Q	3.316	60	2	2	______
G	3.416	187	4	6	______
E	3.688	78	2	3	______
K	3.756	225	6	8	______
V	4.287	145	4	5	______
O	4.736	19	1	+0	______
		3000			

*Vegetation Indicator (VI) = $\frac{2 \times \bar{X}_{Band\ 7}}{\bar{X}_{Band\ 5}}$

(b)

Figure 6. (a) This lineprinter output is an example of the clustering results for training rectangle 19. The numbers at the top (01 - 60) and at the left (901 - 950) refer to the line and point coordinates of the clustered file. (b) This table summarizes the distribution of the clusters within this rectangle. Of the 34 clusters generated for the whole file all but three (W, 5, and 4) were present in this rectangle. Summarizing the data in this format simplifies the labeling procedure for the image analyst.

Table 7. Mendocino County Fuel Mapping Classes

FUEL CLASS	COMPOSITION
1. Brush	
a. manzanita and ceanothus	*Arctostaphylos* sp., *Ceanothus* sp.
b. chamise	*Adenostoma fasciculatum*
2. Hardwood	
a. woodland with scattered grass	*Quercus* sp.,
b. hardwood/conifer	*Pinus* sp., *Quercus* sp., *Arbutus Menziesii*
c. hardwood/brush	*Quercus* sp., *Acer* sp., *Arbutus Menziesii*, 1a, 1b
d. hardwood	*Quercus* sp., *Acer* sp., *Arbutus Menziesii*
3. Conifer	
a. commercial	*Pinus ponderosa*, *Pseudotsuga Menziesii*, *Abies concolor*, *Libocedrus decurrens*
b. knobcone pine	*Pinus attenuata*
c. conifer/brush	3a, 3b, 1a, 1b
d. conifer/hardwood	3a, 3b, 2d
4. Barren	
a. stream course	
b. rock outcrop/bare soil	
c. serpentine with light grass	
5. Water	
6. Urban	
7. Grassland	
a. grassland	*Avena* sp., *Hordeum* sp., *Festuca* sp., *Trifolium* sp., *Lolium* sp.
b. grass/hardwood	
c. grass/brush	

46

similar VI values. The band means and resulting ranked ratios for the labeled clusters are given in Tables 8a and 8b, respectively.

Cluster labeling was a time consuming, interactive process which required the input of both field personnel from Mendocino County who were familiar with the ground conditions within the study area, and personnel from the RSRP who had the technical expertise in remote sensing. Simply stated, the process involved displaying the cluster map on a color monitor and relating the spatial distribution of each cluster to the distribution of vegetation and ground conditions as interpreted from U-2 and conventional scale aerial photography.

It must be emphasized that the labeling process had to be carried out prior to the classification of the southeastern study area. This order of processing ensured that any clusters with ambiguous labels would be identified and reclustered with more sensitive parameters if necessary. For this area, no ambiguous labels occurred.

2.2.4 CLASSIFICATION OF THE EXPANDED STUDY AREA

The expanded study area was classified using the program CALSCAN*. CALSCAN used a maximum likelihood statistic to classify each pixel as one of the 34 labeled clusters that were input as training. The likelihood statistic was calculated from the four spectral values associated with each pixel and the mean, variance, and covariance values

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* CALSCAN is the RSRP version of LARYSAA adapted to the CDC 7600/6600 system.

Table 8a. Mean reflectance values of Landsat MSS Bands 4, 5, 6, and 7 for 34 clusters derived from a 69,000 pixel training set. (Note that Clusters 23 and 26 were deleted after the last iteration because they had only 26 and 15 points, respectively.)

CLUSTER	GREEN BAND 4	RED BAND 5	INFRARED BAND 6	INFRARED BAND 7
1	34.75	60.64	71.71	34.59
2	18.87	22.37	58.47	32.49
3	22.55	30.64	51.69	27.03
4	15.26	14.18	46.98	26.15
5	26.32	40.28	59.66	31.07
6	16.37	16.57	50.87	28.30
7	19.87	25.63	48.05	25.32
8	17.47	19.87	46.50	25.13
9	24.72	35.79	48.98	24.38
10	16.42	16.47	54.93	30.93
11	19.16	23.76	52.44	28.44
12	14.14	13.14	35.76	19.11
13	22.48	29.70	46.36	23.60
14	16.82	16.17	66.85	38.28
15	24.64	37.05	54.61	28.15
16	15.21	14.21	42.98	23.56
17	27.69	41.45	53.69	26.29
18	17.03	18.89	41.69	21.99
19	22.50	30.33	57.68	30.93
20	14.11	13.05	39.31	21.55
21	16.47	16.03	59.82	34.36
22	15.62	9.46	4.36	.09
24	31.83	52.75	66.76	32.68
25	17.47	19.94	37.71	19.21
27	22.98	29.53	41.31	19.84
28	19.30	24.28	43.23	22.25
29	12.67	11.50	31.50	16.89
30	19.20	15.86	11.82	2.85
31	17.49	18.98	29.73	13.94
32	26.90	30.98	35.74	14.30
33	28.63	45.77	64.05	32.80
34	28.90	41.58	45.33	21.70
35	22.39	24.51	33.79	14.94
36	29.39	46.80	58.40	28.42

Table 8b. The ranking of the 34 clusters given in Table 8a based on the Vegetation Indicator (VI) value, i.e. the ratio of 2 times the mean of Band 7 to the mean of Band 5. The cluster labels refer to the fuel classes listed in Table 7.

RANK	CLUSTER	VI VALUE	FUEL CLASS LABEL
1	22	.019	5
2	30	.359	5
3	32	.923	4a
4	34	1.044	4a
5	1	1.141	7a
6	36	1.215	7a
7	35	1.219	7a
8	24	1.239	7a
9	17	1.269	7a
10	27	1.344	7a
11	9	1.362	7a
12	33	1.433	7a
13	31	1.468	7a
14	15	1.520	7a
15	5	1.543	7a
16	13	1.589	7c
17	3	1.764	7c
18	28	1.833	7c
19	25	1.927	1b
20	7	1.975	1b
21	19	2.039	7b
22	18	2.328	1a
23	11	2.394	3c
24	8	2.529	2c
25	2	2.905	3d
26	12	2.908	3a
27	29	2.937	3d
28	20	3.302	3d
29	16	3.316	3d
30	6	3.416	2d
31	4	3.688	2d
32	10	3.756	2b
33	21	4.287	2d
34	14	4.736	2d

associated with the training classes. The picture element was assigned to the fuel class for which it had the maximum likelihood statistic. The classified results were summarized in a tabular format by fuel class and written on magnetic tape in order to produce hard copy photographic output.

2.2.5 PRODUCTION OF OUTPUT PRODUCTS

The first step in transforming the tabulated data from the classification output to meaningful management information was the calculation of the area on the ground that was imaged by one Landsat pixel. Although the nominal area value associated with a pixel is 0.45 hectares (1.11 acres), the actual value within a scene may vary by 2-4 percent. This variation can be due to a number of factors such as the mean ground elevation of the area below the scene and/or the fluctuation of attitude of the spacecraft. The four step procedure listed below was used to calculate the pixel area to be associated with the expanded study area. An example of these calculations is given in Table 8. The tabulated acreage information for each fuel class within the expanded study area is given in Tables 9a and 9b.

Table 8. Calculation of pixel area from UTM and Landsat coordinates measured from a 16-sided polygon (see Figure 3) surrounding the southeastern study area.

VERTEX i	LANDSAT COORDINATES X (point)	LANDSAT COORDINATES Y (line)	UTM COORDINATES X (east)	UTM COORDINATES Y (north)
1	710	436	474,164	357,725
2	775	360	479,390	362,957
3	943	355	488,981	361,249
4	981	381	490,609	358,817
5	1150	454	498,688	351,231
6	1163	524	498,060	345,713
7	1602	1089	511,699	297,035
8	1420	1121	500,710	296,683
9	1181	1059	488,426	304,207
10	1001	1098	477,414	303,207
11	955	1065	475,457	306,274
12	847	960	471,451	315,701
13	740	832	468,103	327,060
14	703	743	467,731	334,402
15	735	701	470,353	337,231
16	748	507	474,944	351,841

Landsat Polygon Area

$X_i(Y_{i+1} - Y_{i-1})$ *

$X_i(Y_{i+1} - Y_{i-1})$	
710(360-507)	= -104,370
775(355-436)	= - 62,775
943(381-360)	= 19,803
981(454-355)	= 97,119
1150(524-381)	= 164,450
1163(1089-454)	= 738,505
1602(1121-524)	= 956,394
1420(1059-1089)	= - 42,600
1181(1098-1121)	= - 27,163
1001(1065-1059)	= 6,006
955(960-1098)	= -131,790
847(832-1065)	= -197,351
740(743-960)	= -160,580
703(701-832)	= - 92,093
735(507-743)	= -173,460
748(436-701)	= -198,220

$$A_{Landsat} = \frac{791,875}{2} \text{ pixels}$$

UTM Polygon Area **

$X_i(Y_{i+1} - Y_{i-1})$ *

$X_i(Y_{i+1} - Y_{i-1})$	
6,434(66,275-55,159)	= 71,520,344
11,660(64.567-61,043)	= 41,089,840
21,251(62,135-66,275)	= - 87,979,140
22,879(54,549-64,567)	= - 229,201,822
30,958(49,031-62,135)	= - 405,673,632
30,330(353-54,549)	= -1,643,764,680
43,969(1-49,031)	= -2,155,800,070
32,980(7,525-353)	= 236,532,560
20,696(6,525-1)	= 135,020,704
9,684(9,592-7,525)	= 20,016,828
7,727(19,019-6,525)	= 96,541,138
3,721(30,378-9,592)	= 77,344,706
373(37,720-19,019)	= 6,975,473
1(40,549-30,378)	= 10,171
2,623(55,159-37,720)	= 45,742,497
7,214(61,043-40,549)	= 147,843,716

$$A_{UTM} = \frac{-3,643,781,367}{2} \text{ meter}^2$$

$$A_{pixel} = 4602.28 \text{ meter}^2 = .46023 \text{ hectare} = 1.137 \text{ acre}$$

*Note: If i+1 is greater than 16, then i+1 = 1. If i-1 is less than 1, then i-1 = 16.

**Note: For convenience of calculation, the UTM coordinates have been transformed as follows:

X_i = UTM_{east} - 467,730 meters

Y_i = UTM_{north} - 296,682 meters

Table 9a. Acreage of fuel mapping classes in the southeastern study area, Mendocino County, California, as classified from Landsat-2 digital data.

FUEL Mapping Class	Number of Sprectral Models Representing:	Number of Pixels Classified As:	Number of Acres* Classified As:	Percent of Southeastern Study Area
1. Brush				
a. Manzanita and Ceanothus	1	13,205	15,014	5
b. Chamise	2	25,777	29,308	9
2. Hardwood				
a. Woodland w/scattered grass	0	0	0	0
b. Hardwood/conifer	1	15,058	17,121	5
c. Hardwood/brush	1	19,938	22,670	7
d. Hardwood	4	31,027	35,278	11
3. Conifer				
a. Commercial conifer	1	3,058	3,477	1
b. Non-commercial conifer	0	0	0	0
c. Conifer/brush	1	17,210	19,568	6
d. Conifer/hardwood	4	26,421	30,040	9
4. Barren	2	1,538	1,749	1
5. Water	2	1,423	1,618	1
6. Urban	0	0	0	0
7. Grassland				
a. Annual grassland	11	67,659	76,928	24
b. Irrigated pasture/riparian	1	12,854	14,615	5
c. Grassland/brush	2	46,562	52,941	16
	34	281,730 pixels	320,327 acres	100

*Acres per pixel = 1.137 as determined from the procedure given in Table 8.

Table 9b. Acreage of major fuel classes in the southeastern study area, Mendocino County, California, as classified from Landsat-2 digital data.

Fuel Class	Number of Sprectral Models Representing:	Number of Pixels Classified As:	Number of Acres* Classified As:	Percent of Southeastern Study Area
Brush	3	38,982	44,322	14
Hardwood	6	66,023	75,069	23
Conifer	6	46,689	53,085	16
Barren	2	1,538	1,749	1
Water	2	1,423	1,618	1
Urban	0	0	0	0
Grassland	15	120,075	144,484	45
	34	281,730 pixels	320,327 acres	100

*Acres per pixel = 1.137 as determined from the procedure given in Table 8.

59

CALCULATION OF LANDSAT PIXEL AREA FROM UTM COORDINATES

1. On a map sheet on which the Universal Transverse Mercator (UTM) grid has been superimposed, construct a ten to twenty sided polygon surrounding the study area of interest. The vertex of each line intersection of the polygon must coincide with features that can be accurately located on the Landsat image.
2. Measure the UTM and Landsat coordinates for each vertex.
3. Calculate the respective areas enclosed within the UTM and Landsat polygons using the following formula (after Bouchard and Moffitt, 1960, page 205):

$$A = \left| \sum_{i=1}^{n} X_i (Y_{i+1}^{*} - Y_{i-1}^{**}) \right| \qquad (0.5)$$

* If i+1 is greater than n, then i+1 = 1

** If i-1 is less than 1, then i-1 = n

where A = area of the polygon in meter^2 and pixels respectively

i = the ith vertex

n = total number of vertices in the polygon

X = east UTM coordinate and Landsat point respectively

Y = north UTM coordinate and Landsat line respectively

54

Note: When the areas for the polygons are calculated in a clockwise vertex-to-vertex progression the value for the UTM area will be negative and that for the Landsat area will be positive (and vice versa in a counter-clockwise progression). The sign differences do not affect subsequent area values because the absolute values of A are used to calculate pixel area. These apparently ambiguous values are the inherent result of how the two different coordinate systems are constructed; in the UTM system coordinate values increase from left to right and from bottom to top while in the Landsat system coordinate values increase from left to right and from top to bottom.

4. Calculate Landsat Pixel Area from the relation:

$$A_{Landsat} \text{pixels} = A_{UTM} \text{meter}^2$$

$$1 \text{ pixel} = \frac{A_{UTM}}{A_{Landsat}} \text{ meter}^2 \times (1 \times 10^{-4} \text{hectare/meter}^2)$$

$$= \frac{A_{UTM}}{A_{Landsat}} \text{ meter}^2 \times (2.471 \times 10^{-4} \text{acre/meter}^2)$$

Based on the results of last year's work, it was felt that the most valuable photographic output product would be a Landsat fuel classification map that had been overlaid with a UTM grid of the raw

Landsat data. Both of these products were produced on the RSRP film processor IGOR (image ganged optical reproducer). This device simultaneously exposes three black-and-white negatives with a separate light emitting diode (LED). In the case of the raw data products, the intensity of the three LED's output is governed by the spectral response of Landsat Bands 4, 5, and 7, respectively. In the case of color coded classification output, the intensity of the LED's is governed by the mix of the three primary colors, one assigned to each LED, that is required to produce a maximum of 40 colors. The resulting three negatives are then photographically combined, along with any ancillary data, by triple-exposing one frame of color film with each IGOR negative through an appropriate filter. A schematic of this procedure is given in Figure 7. The photographic products for raw and classified data are shown in Figures 8a and 8b; classification output for Fuel Type 1b (chamise) is shown in Figure 8c.

2.2.5 DISCUSSION OF RESULTS

An initial evaluation of the output products by personnel from the RSRP indicates that the classification procedure produced the required management information, viz., the regional distribution of wildland fuels in southeastern Mendocino County, California, in a cost-effective manner. A more rigorous evaluation will be conducted during the next year as these products, or their refinements, are incorporated

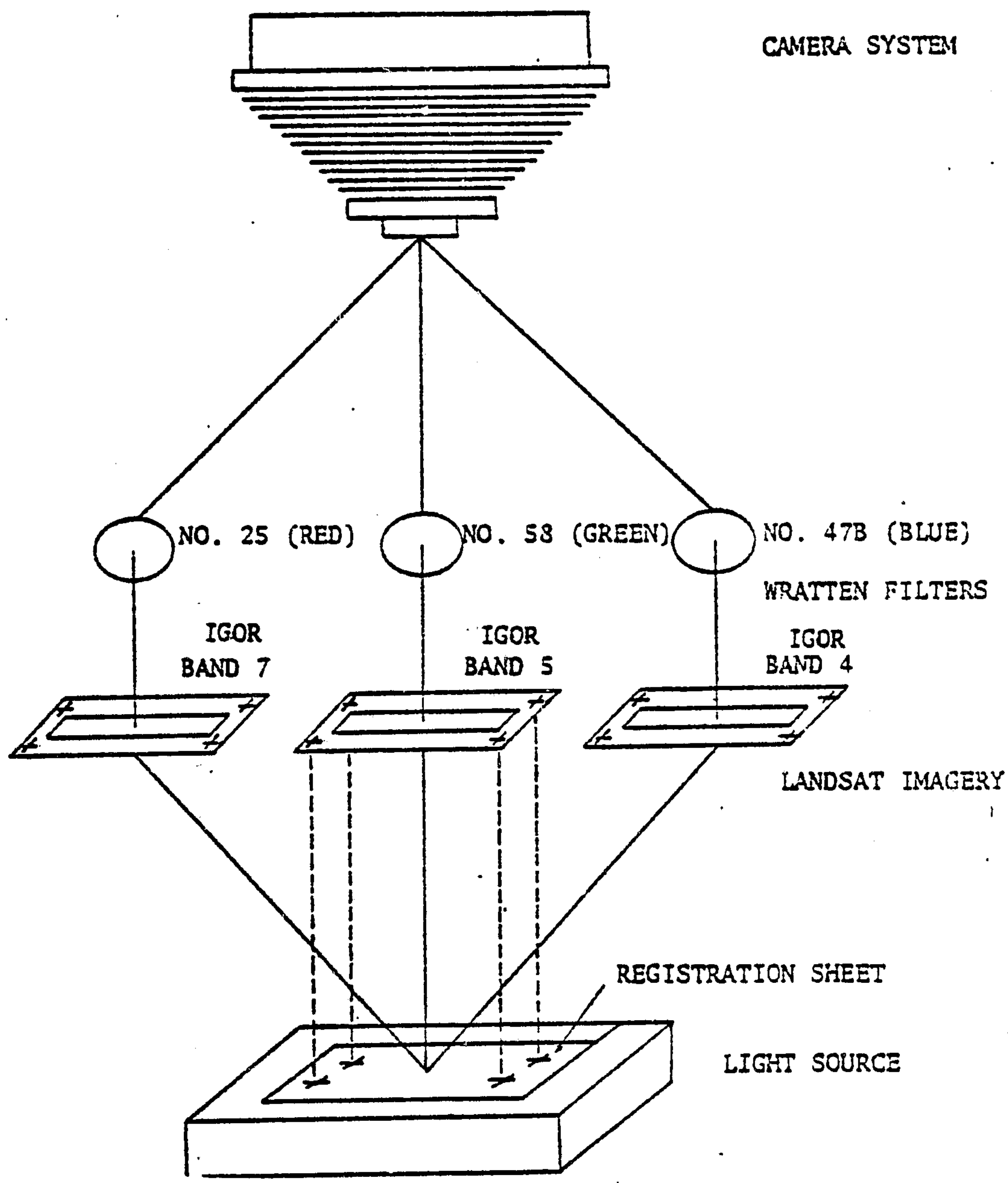

Figure 7. This schematic illustrates the photographic technique for producing a color composite from Landsat IGOR negatives.

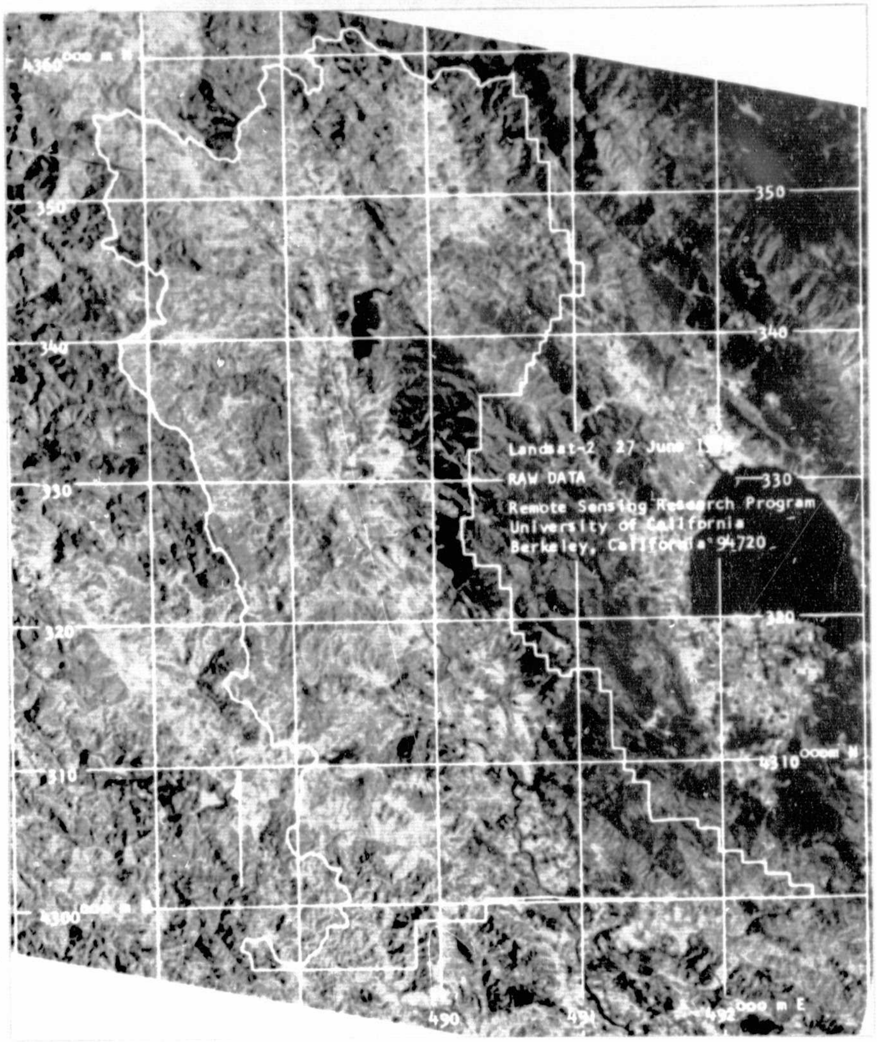

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Figure 8a. Landsat-2 image of the 320,327 acre southeastern study area in Mendocino County, California as produced from digital tapes on the RSRP film processor.

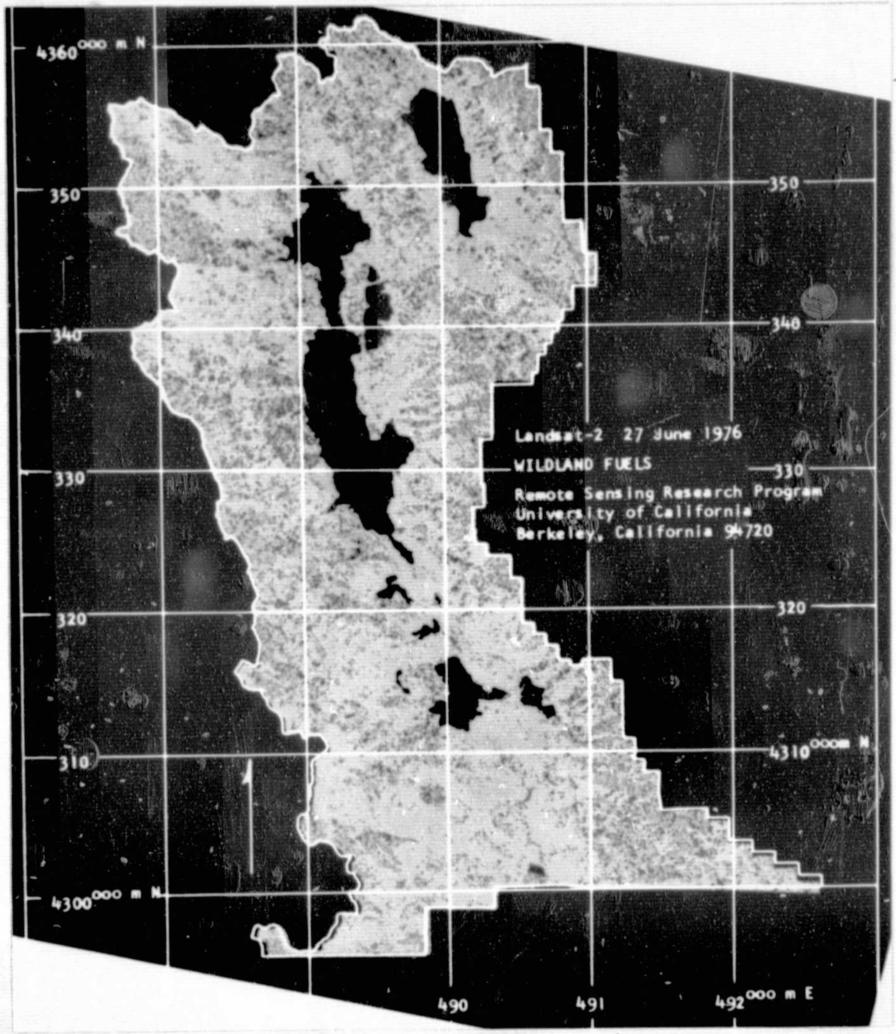


Figure 8b. Classified Landsat-2 data of the 320,327 acre southeastern study area in Mendocino County, California. The nine fuel classes represented here are: grassland (gray), conifer/hardwood (yellow green), hardwood (red), chamise (yellow), hardwood brush (gold), hardwood/conifer (red brown), conifer brush (light green), commercial conifer (dark green), water (dark blue), and barren (turquoise).

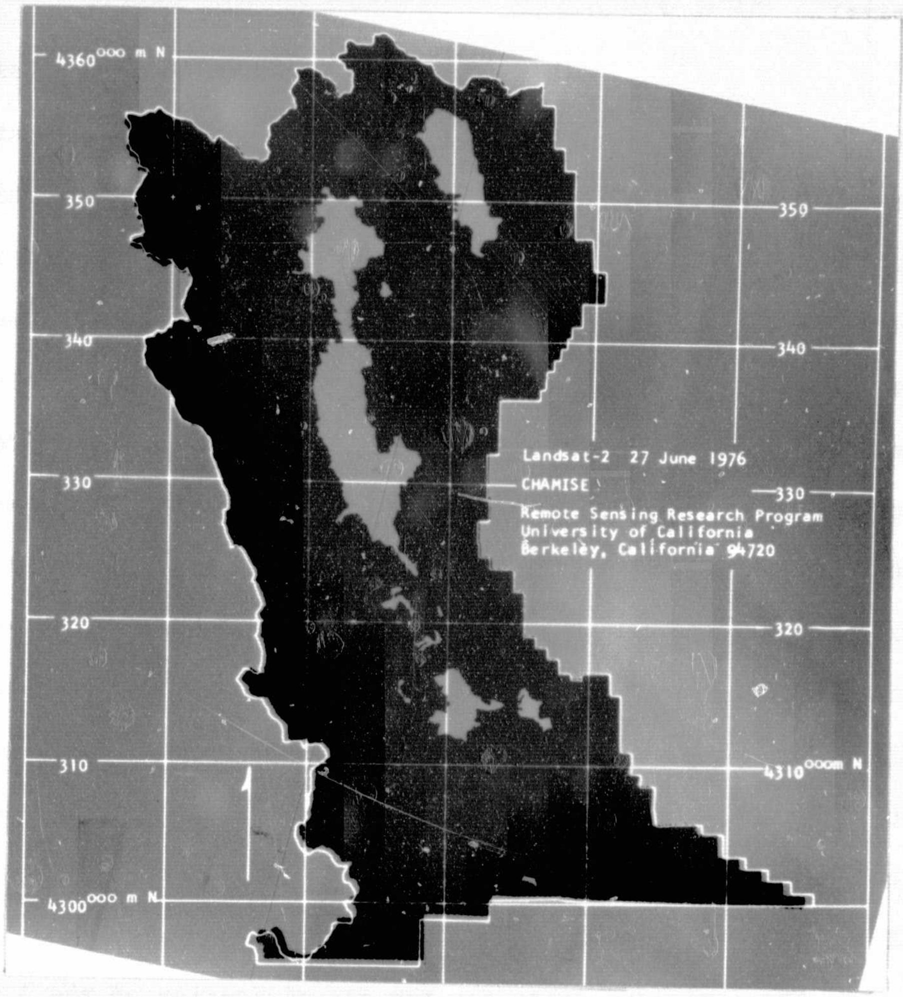


Figure 8c. Classified Landsat-2 data of the 320,327 acre southeastern study area in Mendocino County, California. This image illustrates the distribution of chamise (gray) throughout the study area. Of the nine major fuel classes within Mendocino County, chamise is the one of most concern to land management personnel.

into operational fuel management plans for individual watershed management units (see Section 2.3 for a description of watershed management units).

For the most part, the distribution of the fuel classes as shown in Figures 8 b and c was similar to the vegetation patterns seen on the raw Landsat data and supporting U-2 photography. Three of the fuel classes, as listed in Table 7, did not appear in the final classification. This was expected since these classes, which were defined prior to the classification procedure, were defined to include all major fuel types present in the entire eastern half of Mendocino County. Some misclassifications did occur, although they were not considered serious with respect to management information needs. Examples of these misclassifications were: (1) Class 2a -- woodland with scattered brush -- was identified as Class 7c -- grassland/brush, Class 2b -- hardwood/conifer, or Class 2c -- hardwood/brush; and (2) no Class 3b -- noncommercial conifer -- was identified because of the inability of the classification procedure to differentiate it from Class 3a -- commercial conifer.

The estimated costs for the classification of the 320,000 acre southeastern study area are given in Table 10a. These figures should be compared with the costs incurred last year when the 476,000 acre northeastern study area was classified using a similar procedure (see Figure 10b). It should be noted that while this year's classification effort was less expensive on a per acre basis than was that of last

Table 10a. Classification costs in dollars for the 320,327 acre southeastern study area in Mendocino County, California.

CLASSIFICATION TASK	MATERIALS	PERSONNEL[1] ($17/hour)	COMPUTER SYSTEMS		TOTAL
			RSRP[2]	LBL[3]	
Scene Selection	$200	$ 51	-	-	$ 251
Preprocessing					
1. Tape reformat	-	102	$ 120	-	222
2. Masking	-	170	160	$ 65	395
Selection of Training Sites	-	1700	1200	-	2900
Classification	-	85	-	195	280
Production of Output[4]	120	255	40	-	415
Subtotal	$320	$2363	$1520	$260	$4463
Risk (15% of Subtotal)[5]	48	355	228	39	670
Overhead (50% of Subtotal)	160	1187	760	130	2232
TOTAL	$528	$3900	$2508	$429	$7365

COST PER ACRE = $7365/320,327 = $0.023

1. $17 includes salaries and employee benefits.
2. Remote Sensing Research Program interactive system costs (= $20/hour).
3. Lawrence Berkeley Laboratory costs calculated on a per job basis.
4. Includes 6- 8"x10" prints from IGOR masters.
5. Risk includes unforeseen costs such as computer downtime, improperly developed film, and employee sick leave.

Table 10b. Classification costs in dollars for the 476,000 acre northeastern study area in Mendocino County, California.

CLASSIFICATION TASK	MATERIALS	PERSONNEL ($15/hour)[1]	COMPUTER SYSTEMS RSRP[2]	COMPUTER SYSTEMS LBL[3]	TOTAL
Scene selection	$200	$ 45	-	-	$ 245
Preprocessing					
1. Tape reformat	-	90	$ 120	-	210
2. Masking	-	120	120	$ 25	265
3. Property map overlay[4]	65	5340	-	-	5405
Selection of Training Sites	-	2250	1200	90	3540
Classification	-	30	-	130	160
Production of Output[5]	30	45	40	-	115
Subtotal	$295	$7920	$1480	$245	$9940
Risk (15% of subtotal)[6]	44	1188	222	37	1491
Overhead (50% of subtotal)	148	3960	740	123	4971
TOTAL	$487	$13068	$2442	$405	$16402

COST PER ACRE = $16402/475,637 acres = $0.034/acre

1. $15/hour includes salary and employee benefits.
2. Remote Sensing Research Program interactive system costs (= $20/hour).
3. Lawrence Berkeley Laboratory system costs calculated on a per job basis.
4. Two additional map overlays were produced at a cost of $2230 (140 man hours and $130 materials).
5. Includes 3- 8x10 inch prints from IGOR masters.
6. Risk includes unforeseen costs such as hardware downtime, software systems failure, improperly developed film, and employee sick leave.

year ($0.023 vs. $0.034), this year's output product did not include the costly compilation of a property ownership map. If this compilation cost is not included in the total, the total cost per acre of last year's effort is reduced substantially to $0.016 per acre.

The 40 percent net increase in costs from last year can be attributed to two factors: (1) personnel and computer processing costs have increased approximately 30 percent due to inflation, and (2) the southeastern study area, although only two-thirds the acreage of the northeastern study area, exceeded the LBL computer/classification limit of 1024 Landsat points. Because of this, most of the processing procedures had to be duplicated for the western and eastern halves of the study area, and then their output products combined for the final output. This duplication of effort was the major reason for increased classification costs. It also emphasized the caveat that when a potential user of Landsat data is estimating the costs of classifying large areas, he must not only consider the area's total acreage (viz., the total number of Landsat pixels to be processed) but also its dimensions (e.g., can the available computer facility process the data in one run or must two or more runs be performed).

Based on the good results from this year's and last year's classification work in eastern Mendocino County, personnel from the RSRP are confident of the utility of the "mixed classification" approach to classifying wildland vegetation complexes. This approach has three major advantages over the more conventional supervised and unsupervised

64

classification techniques:

1. It would be prohibitively expensive to classify such a large area (the entire eastern half of Mendocino County) using an unsupervised classification algorithm. On the other hand, it is extremely doubtful that a skilled analyst could account for all of the spectral variability within the area which would be required to provide a valid training set for a supervised classifier algorithm. However, the systematic selection of training blocks throughout the area, performing an unsupervised classification on the data within those blocks, and then labeling the resulting clusters as training for the supervised classifier, produces a classified map which accounts for all spectral variability at a reasonable cost.

2. The output products given in Figures 8b and 8c were designed for wildland fuel management personnel. However, the basic data for producing such maps, i.e. the spectral cluster maps as shown in Figure 6a, can be easily relabeled to meet alternative management requirements. This relabeling process does not require the use of an interactive color display system, because skilled field personnel who are familiar with the use of aerial photography, Landsat color prints, and/or orthophoto map sheets can relabel clusters by comparing vegetation distribution on one of these products with the cluster distribution shown on the line printer output. After the clusters have been relabeled, new output maps can be produced by a number of commercial processors from the original classification tape.

3. Finally, the cluster data from the training blocks provide an ideal stratification base from which further, more refined spectral models can be developed with the unsupervised clustering algorithm. For example, 19 of the clusters listed in Table 8b were either water, bare soil, or grassland. For fuel management objectives these labels are quite sufficient. However, of the remaining 16 classes, many are somewhat ambiguous, viz, hardwood conifer, conifer brush, etc. Therefore, the most logical processing to follow, if more refined labels are needed, is to recluster the spectral data for those pixels that are not labeled 4, 5, or 7. The resulting new clusters would then be labeled hopefully into more discrete fuel class types.

2.3 DEVELOPMENT OF WATERSHED RESOURCE MAPPING IN MENDOCINO COUNTY, CALIFORNIA

As a result of activities of Mendocino County's Fuel Management Committee (FMC) during 1975-1979, there has emerged a clear need to interface remote sensing-derived information with other kinds of information, much of which has been previously compiled in map form. The FMC and the California Department of Forestry (CDF) have acknowledged that in order to bring private land owners into the regional fuel modification program and coordinated resource management process, the same data from which management decisions will be made should be made readily available to, and in a form that can be understood by, the lay public. For these reasons, the FMC established the Mendocino County

66

Watershed Mapping Team (WMT). The objective of the WMT is to compile a series of maps of the multiple resources that are present in the watershed management units for the northeastern study area.

Between September 1977 and September 1978 two federally funded CETA (Comprehensive Education and Training Act) positions were made available for the mapping project. After one year, the CETA mapping team had created 1:62500 scale overlay maps of the entire northeastern study area and of the implemented control burn area in the Thatcher Creek Drainage. In July 1978, the mapping effort was intensified in order to provide the members of the FMC with the needed overlay maps of the watershed management units within the northeastern study area in such a format that they could be inexpensively reproduced and made available to the public (as mandated by California's Control Burning Act, Assembly Bill AB1006).

Because County personnel initially did not have the skills necessary to interface the remote sensing-derived products with compiled map products, personnel from the RSRP provided the necessary advisory and supervisory personnel for a six month period. Initial supervision by RSRP personnel consisted of 6 days per month: since March 1979 the supervision has been reduced to one day per month.

In October 1978 three CETA positions were made available again through the Mendocino County Manpower Office. The grant application was submitted by the CDF as the sponsoring organization. This CETA grant, lasting 18 months, will utilize $27,600 for participant salary, The map room is located in the Mendocino County Court House, and utilities are being furnished by the County Farm Advisors Office and the County Administrative Office. Office and mapping supplies are being provided by the CDF.

Based on the preliminary fire break map that had been prepared by FS and CDF personnel, the northeast study area was divided into 16 watershed management units. Each unit was comprised of a group of contiguous watersheds in such a way as to encompass 30-40,000 acres (See Figure 9). It was determined that these units would represent discrete "control burn implementation areas" and that maps for each unit would be made available to property owners and the general public.

During the current funding period, the WMT has been compiling 1:24,000 scale mylar overlay maps depicting the following resource characteristics:

<u>Vegetation/Fuel Characteristics</u>. This information is used to evaluate Landsat classifications and quantifications and to provide a detailed polygon-oriented map of the vegetation. The preliminary procedure has been to map broad vegetation/fuel stratifications within each Watershed Management Unit. These 'strata' include Brush (B), Grass (G), Woodland (Oak Mix) (W), Brush/Woodland Mix (BW), Commercial Conifer (C), and Recently Logged Conifer (RLC). Following stratification will be a within-strata classification inferred from transect data to be forthcoming. It is anticipated that a high correlation between manual photo interpretation and the Landsat classification will

68

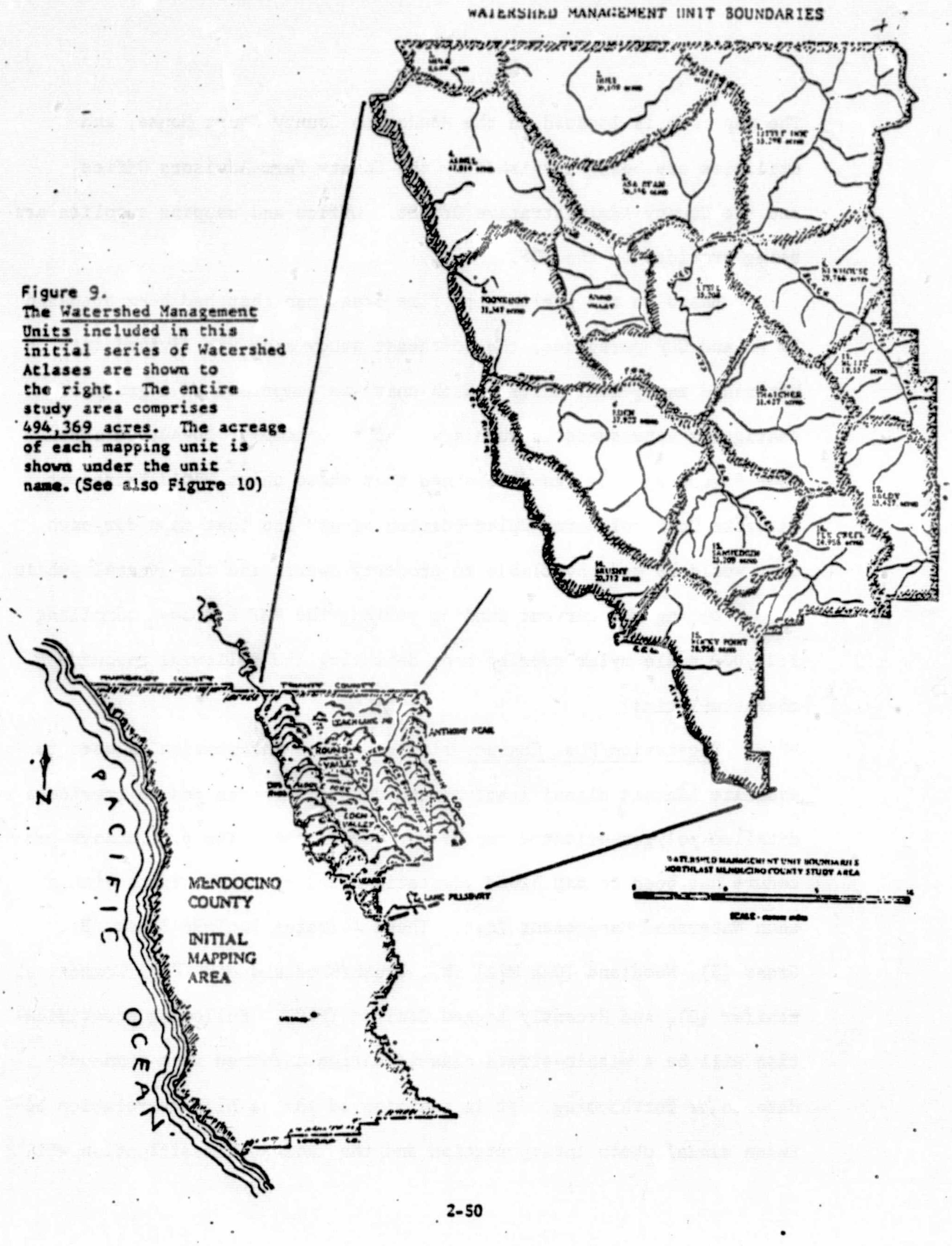


Figure 9.
The Watershed Management Units included in this initial series of Watershed Atlases are shown to the right. The entire study area comprises 494,369 acres. The acreage of each mapping unit is shown under the unit name. (See also Figure 10)

be established.

Soils Characteristics. The mapping of soils has involved rescaling the most current Soil Conservation Service (SCS) soils classification to the 1:24,000 map base. The most current published maps are from work done in the early 50's. Problems have arisen where National Forest Soils adjoin SCS maps. Since large divergent classification schemes were used, interpolation between the two map types has been difficult.

Property Ownership Maps. Property ownership stratification, including private, corporate, industrial, state, County, and federal, is published as part of the atlas. A complete listing of property owners and their addresses has not been published, but has been compiled and is being kept as part of the resource management files. Property ownership is one of the most crucial resource parameters because all control burning is subject to approval of affected private property owners, in addition to public property management staff. Proposed fuel break locations must be accurately identified on the property ownership map, owners contacted and, hopefully, control burn contracts arranged.

Slope Maps. These maps are drafted using a manual method which (1) determines areas of like slope, (2) compares these areas to a standard contour interval/slope template, and (3) groups slope percentages into desirable slope classes. This method is proving to be competitive with USGS slope maps; although accuracy may not come up to quite the same standards, cost/slope class is well below USGS costs. Slope maps created by the Watershed Management Team cost under $200.00 for a total of 8 slope classes. USGS slope maps cost a minimum of $120.000 for each slope class, or a total of at least $960.00 for 8 slope classes.

Aspect Maps. These maps are drafted manually into 12 cardinal directions following the 12 directions of the clock face: 12 = north-face slope, 3 = east face slope, 6 = south face slope, 9 = west face slope, etc. A guide template has been manufactured and used in conjunction with a drafting maching to identify areas of like aspect. The polygons of similar aspect are made of the fewest possible number of sides for ease in future digitizing. Most polygons are irregular triangles, squares, and pentagons. It has been found that aspect tends to arrange itself well into these simple polygons. Future comparison of these aspect mapping efforts with digital terrain data made available by USGS and taken from 1:125,000 scale maps will enable us to make an evaluation of the digitized maps.

Drainage and Micro Watershed Boundaries. These boundaries delineate the watershed drainage pattern throughout the Watershed Management Units. Such information will be quantified and used to evaluate the projected water run-off and siltation measured at the mouth of any tributary. Fish and Wildlife personnel have expressed an interest in these maps. If used in conjunction with soils and vegetation maps, these maps could provide valuable permeability data to evaluate the construction of small check dams and earthen reservoirs.

Road Maps. These maps include roads available for fire fighting crews and roads no longer open but of potential value for fuel breaks.

Incline Plane Relief Graphics. Such graphics provide a method of relief presentation transforming topographic contour intervals into a series of parallel lines which trace the intersection of inclined planes and the topography. This method has been replicated by computer algorithms. It serves here as the frontice piece of each Watershed Atlas and is intended to orient the property owner or concerned citizen to the 'lay of the land' for quick reference when using the other resource maps.

Proposed Management Action Maps. These maps depict the location and type of each proposed fuel break and of the follow-on revegetation measures proposed. Such a map is the last in each Watershed Atlas and is supported by the sum of the preceding maps. It is intended that a property owner will be able to identify the position of the proposed fuel break on his property and on adjacent parcels. He can then evaluate the proposed burn, mechanical clearing or other management action that is proposed based on the same parameters used by the California Department of Forestry resource managers.

Once maps for each Watershed Management Unit are compiled they are photo-reduced to a scale of 1:100,000 and prepared for Xerox reproduction. Mapping progress to date includes completed resource atlases for Thatcher, Etsel, Newhouse, Eden, Asa Bean, Asbill, and

Poonkinney Watershed Management Units. Maps of the Thatcher and Etsel WMU's have been photographically reduced and made available to the general public. Xerox copies of all the maps for each Watershed Management Unit are collated and packaged as a Resource Atlas. As a Resource Atlas for each Watershed Management Unit is completed, it is made available to government agencies and the public at cost. The complete Resource Atlas for the Etsel Watershed Management Unit is shown in Figure 10. As indicated by the cover sheet of that Atlas, many user agencies cooperated in its production. Quite properly our RSRP is listed last, having served primarily as the catalyst for bringing about the acceptance, by these user agencies, of modern remote sensing technology.

The California Department of Forestry personnel implementing the control burn project have used these maps to correlate slope, soil, and existing vegetation in order to determine the appropriate method of fuel modification (manual, mechanical, fire, etc.) and the appropriate revegetation (natural regrowth, introduced grass, other).

Most recently the Watershed Mapping Team has begun large scale aerial photo interpretation for detailed vegetation/fuel maps to accompany Landsat-derived vegetation classifications. Also, using high flight U-2 aerial photography acquired by NASA/AMES Airborne Missions and Application Division, the Watershed Mapping Team has begun mapping exposed soil, landslides and river bar gravel and wash. It is our hope that initial remote sensing utilization by the Watershed Mapping Team will blossom into an ongoing remote sensing and resource mapping effort in Mendocino County.

74

ETSEL

WATERSHED MANAGEMENT UNIT

R E S O U R C E A T L A S
(Partial)

Prepared by

The Watershed Mapping Team
County Courthouse, Ukiah CA 95482

David Hayes
Troy Mull
Caron Eskridge
Connie Harrison
Roger Hansen CDF – Sponsor
Chuck Henderson RSRP – Supervisor

In Cooperation With

The California Department of Forestry / Willits CA
The Cooperative Extension, University of California / Mendocino County
The United States Forest Service / Mendocino National Forest
The Bureau of Land Management / Ukiah CA
The Remote Sensing Research Program, University of California / Berkeley CA

Figure 10.

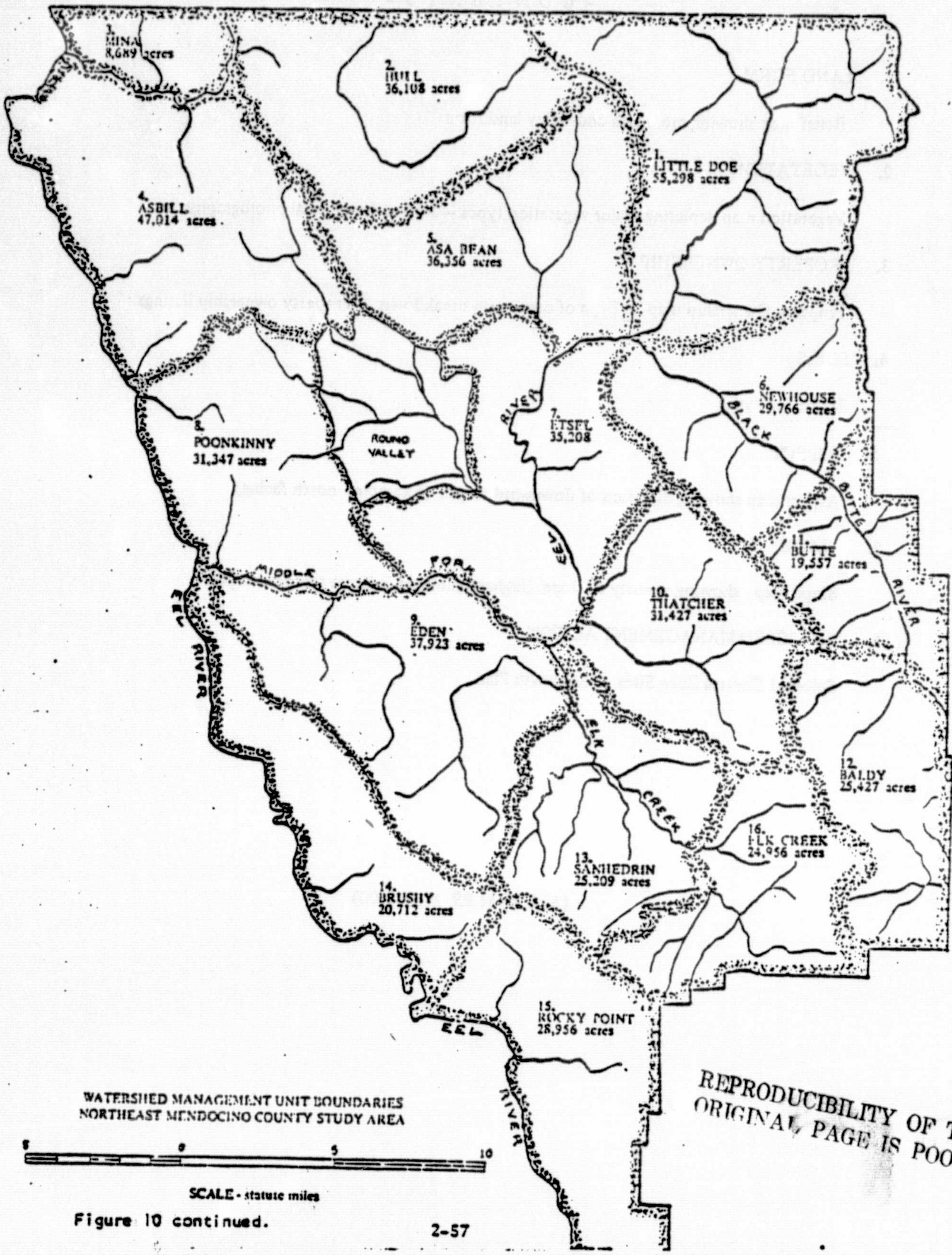


Figure 10 continued.

- C O N T E N T S -

1. LAND FORM

Relief map showing mountain and valley land form

2. VEGETATION

Vegetation map depicting major vegetation types – derived from aerial photography

3. PROPERTY OWNERSHIP

Property Ownership map / Type of ownership breakdown / Property ownership listings

4. SOILS

Major soil types

5. ASPECT

Aspect map showing direction of downward slopes (Example: north facing)

6. SLOPE

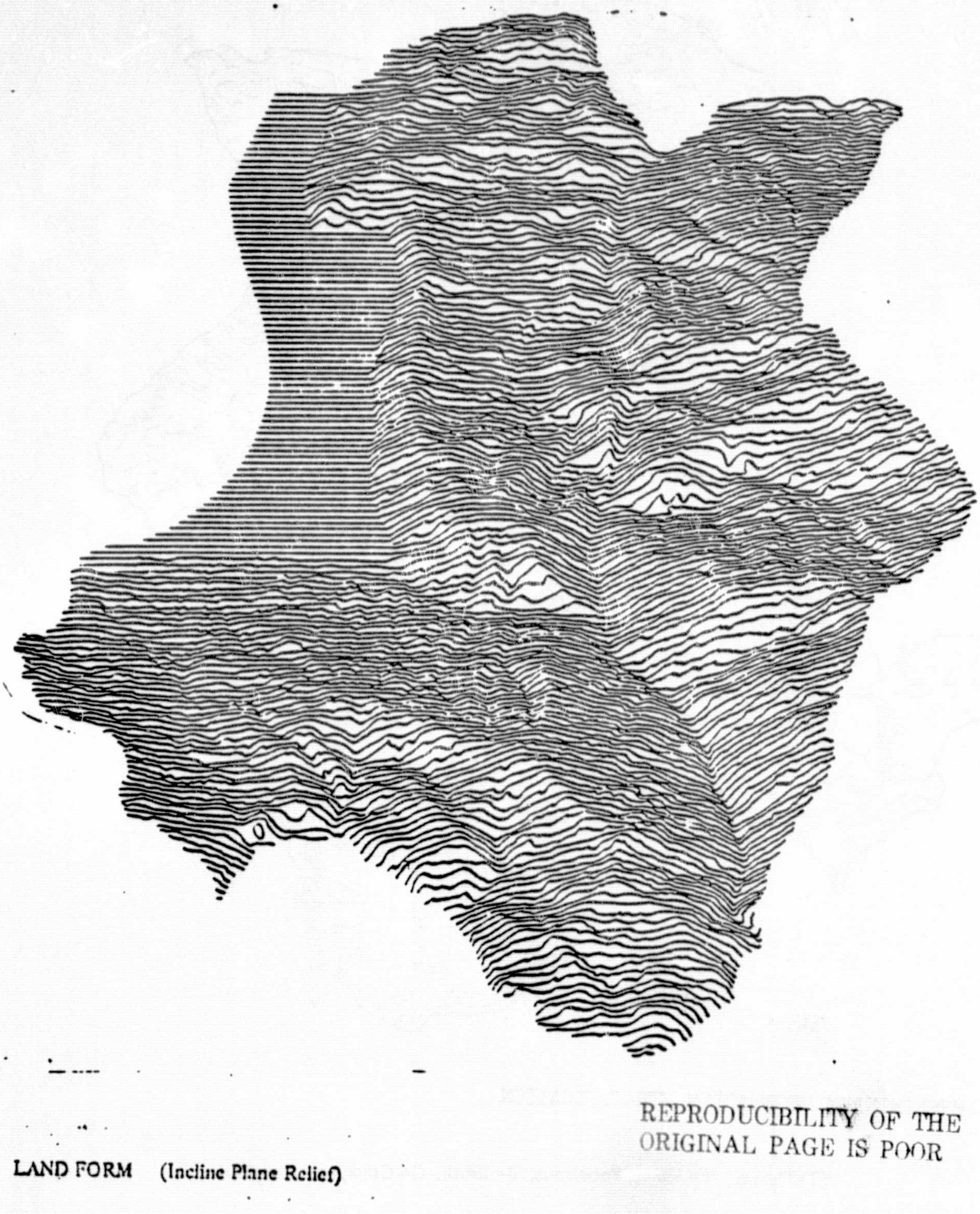
Slope map showing severity of slope (highest numbers indicate steepest slopes)

7. PROPOSED MANAGEMENT ACTION

Selected Control Burn Sites / Regrowth Plan

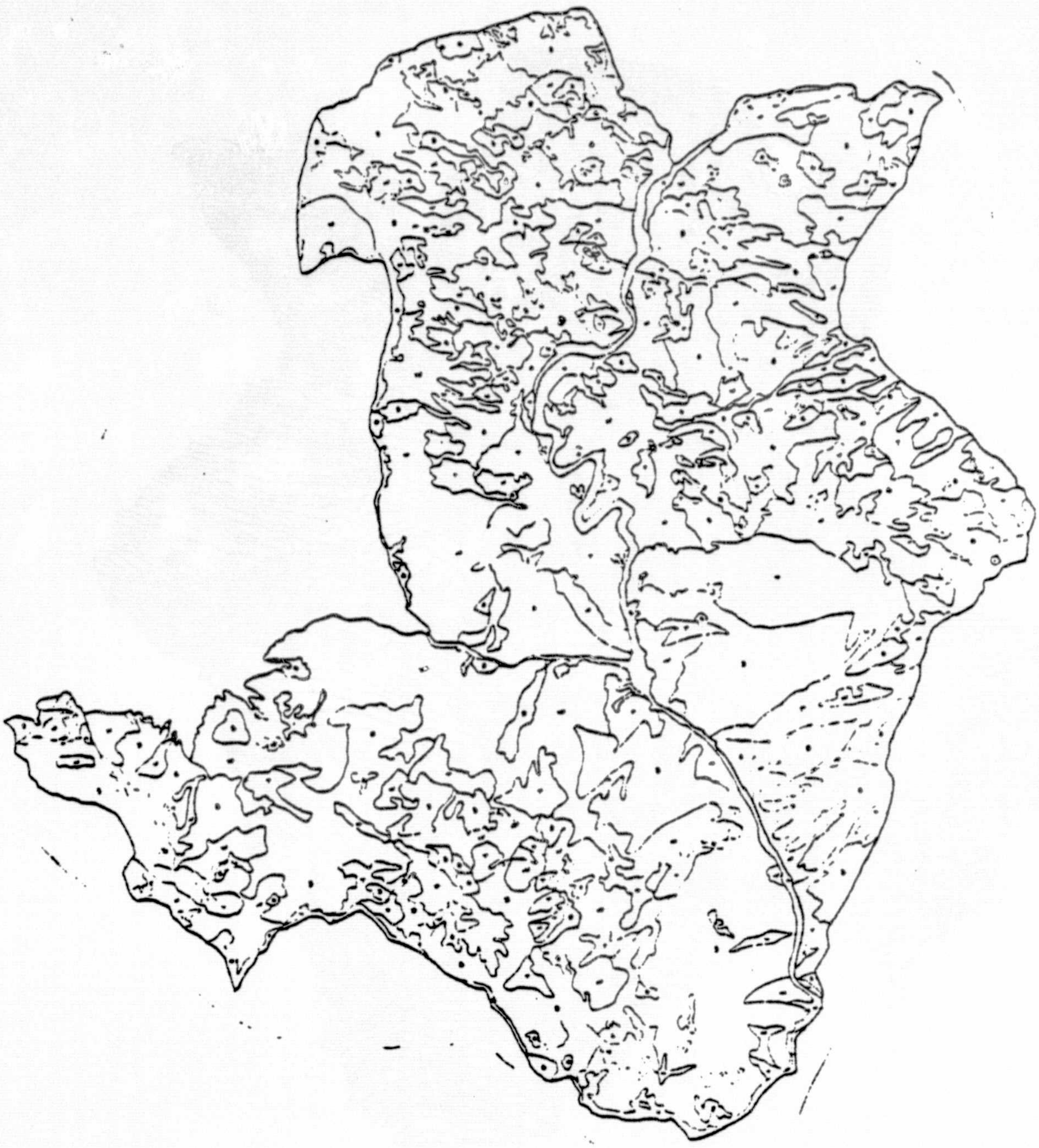
(ALL SCALES 1:100,000)

Figure 10 continued.



LAND FORM (Incline Plane Relief)

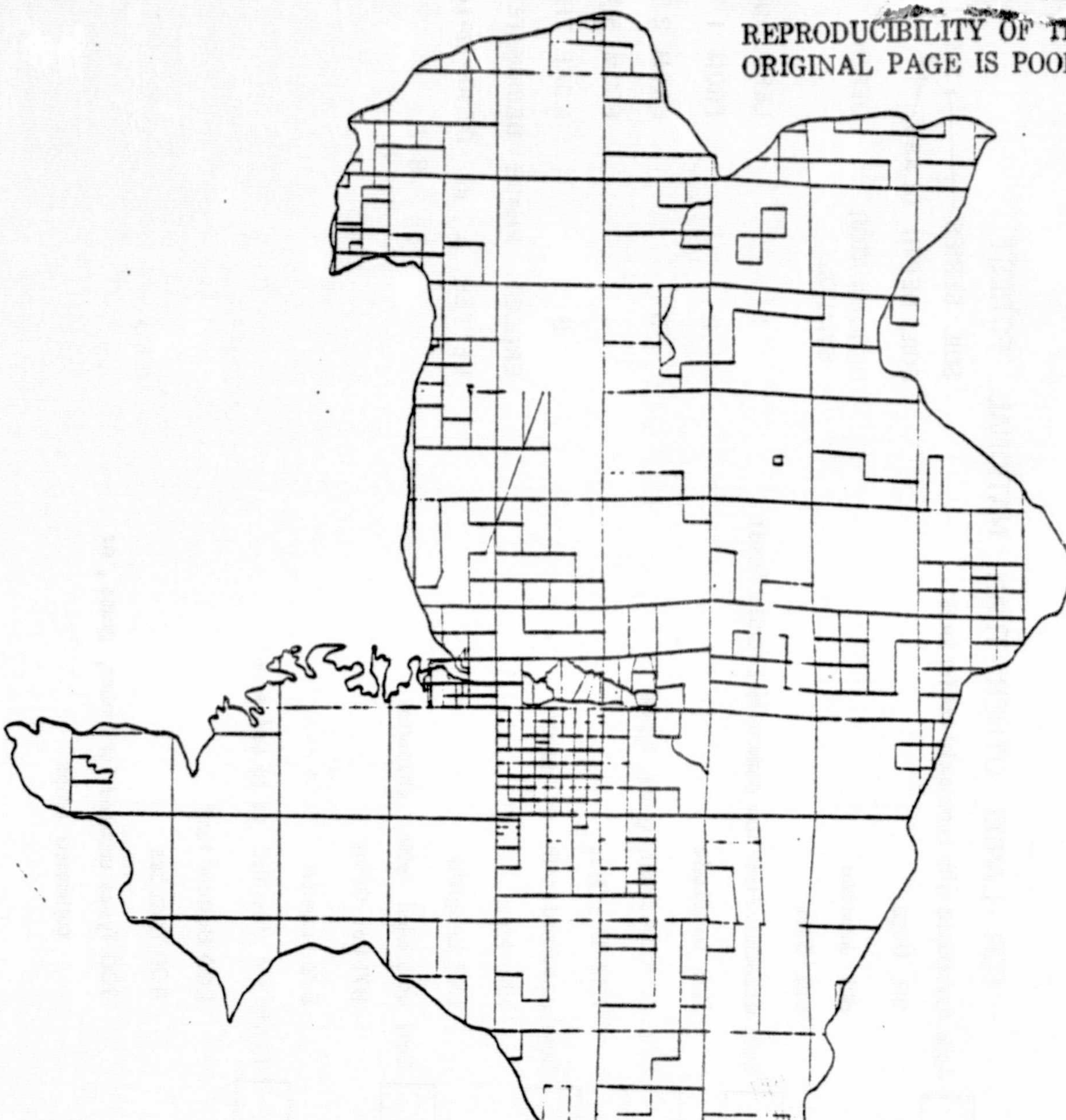
Figure 10 continued.



PRELIMINARY VEGETATION STRATIFICATION

(T=Timber, W= Mixed Woodlands, B= Brush, G= Grass, rock, barren)

Figure 10 continued.



PROPERTY OWNERSHIP (with section lines)

Figure 10 continued.

Figure 10 continued.

SOIL TYPES LEGEND

FOR LANDS OTHER THAN NATIONAL FOREST

☐ **Soils associated with commercial conifer forest**

- 812 Hugo
- 815 Josephine
- 816 Sites

☐ **Soils associated with non commercial conifer forest**

- 726 Dubakella

☐ **Soils associated with grass types**

- 832 Los Osos

☐ **Soils associated with oak-grass**

- 834 Hulls
- 847 Laughlin

☐ **Soils associated with chaparral**

- 871 Los Gatos
- 872 Maymen

☐ **Lands not classified as to soil series**

- 200 Bottom land
- 400 Terraces
- 700 Types unsuited for timber, grass, or cultivated crops

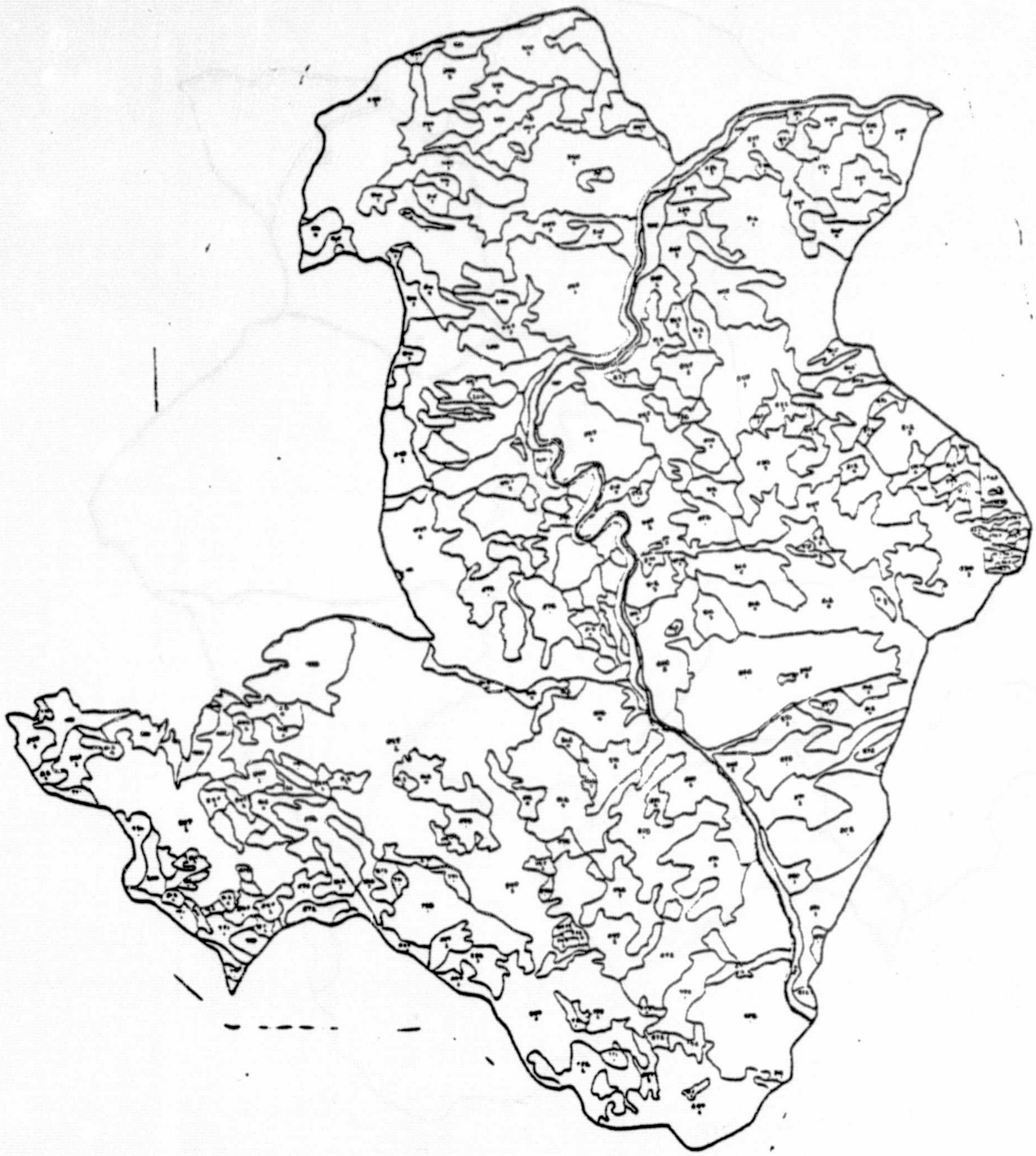
SOIL SERIES → 816

SOIL DEPTH CLASS → 2

DENOMINATOR SYMBOL	DEPTH, FEET
1	LESS THAN 1
2	FROM 1 TO 2
3	FROM 2 TO 3
4	FROM 3 TO 4
5	MORE THAN 5

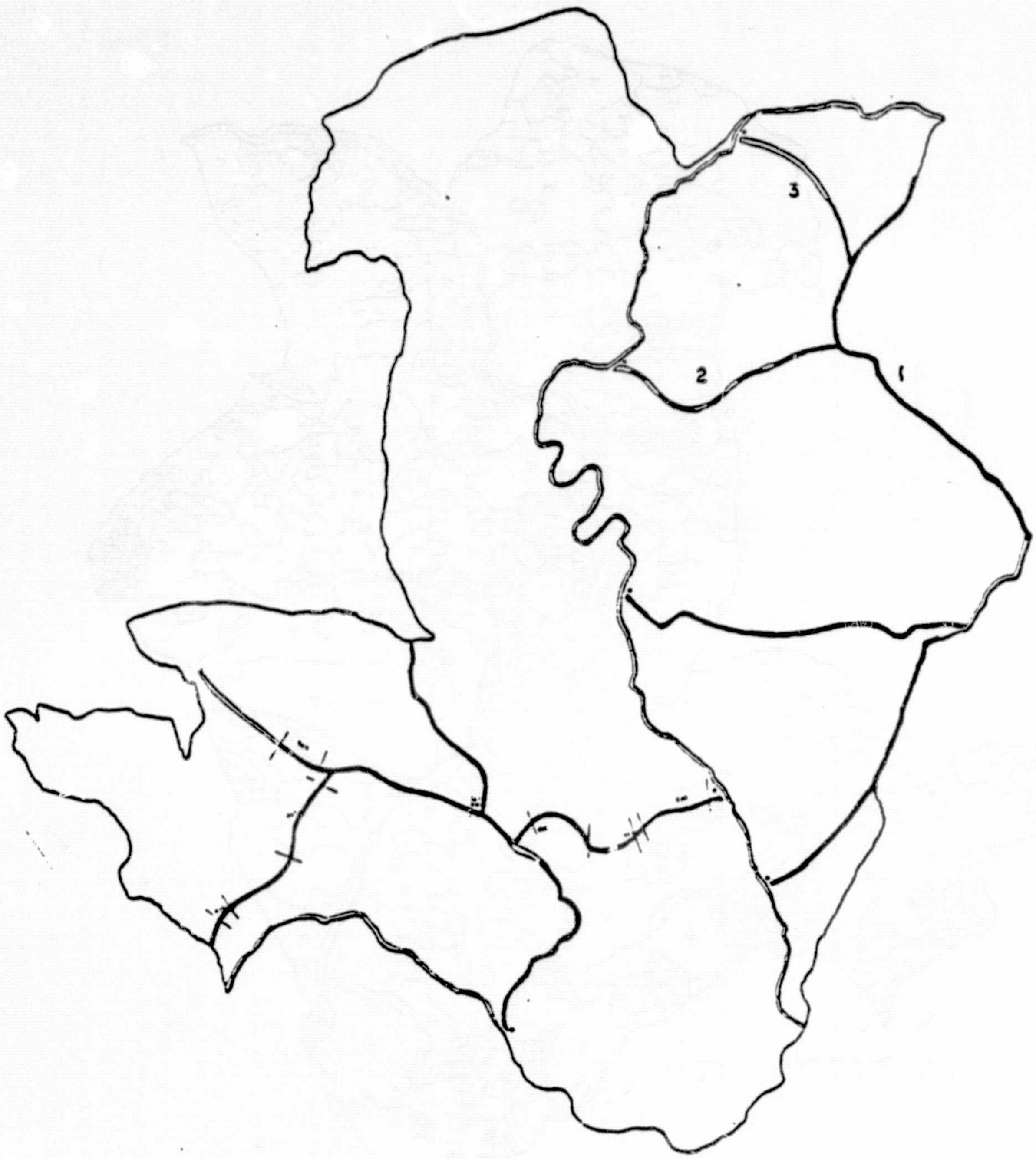
ERODED PHASE DESIGNATED BY LETTER e IN DENOMINATOR

847
1e



SOILS (Legend on following page)

Figure 10 continued.



NATURAL BREAK (CLEARING, EEL RIVER, ECT.)

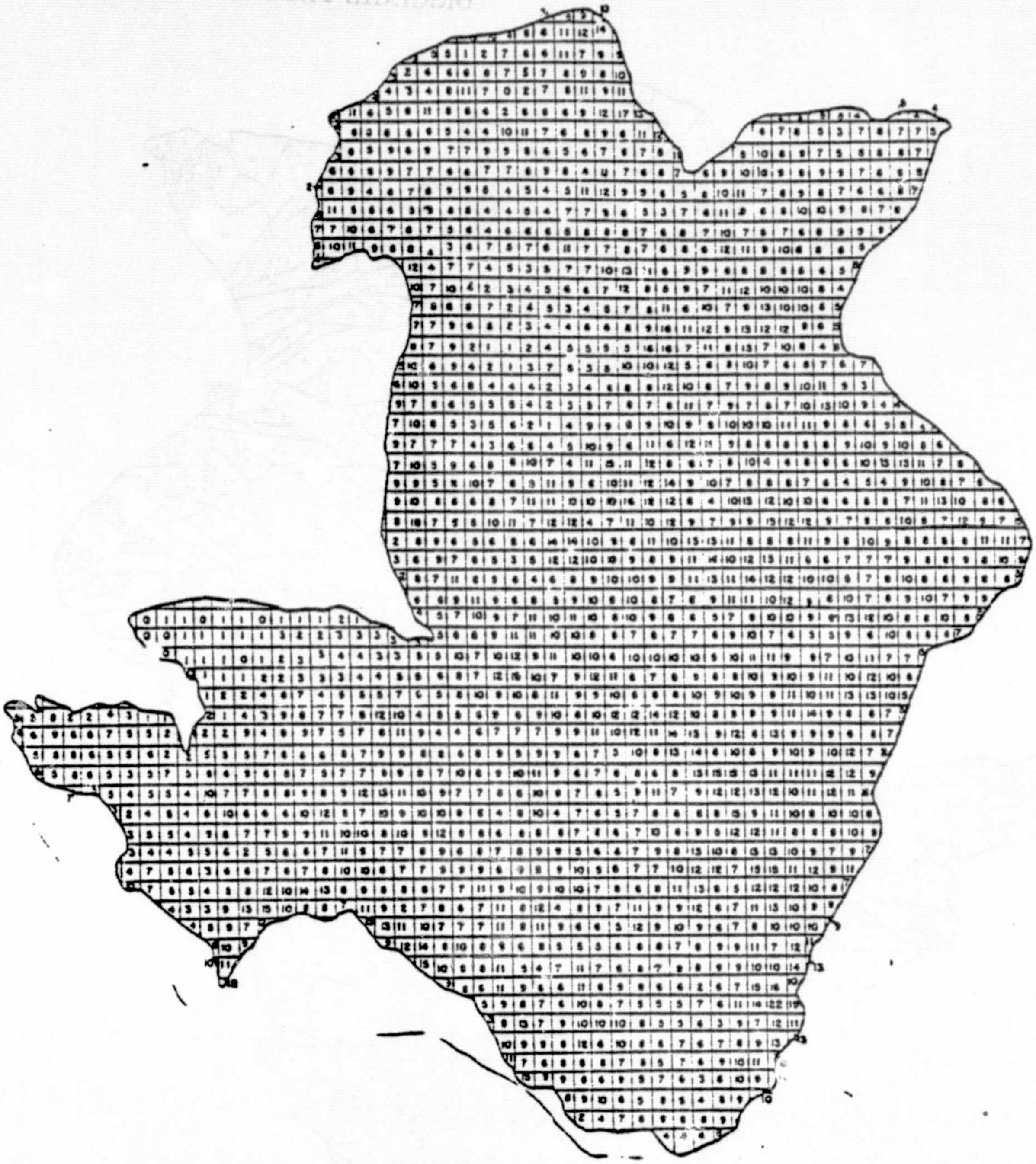
PROPOSED BREAK (Rx indicates prescription burn)

PROPOSED MANAGEMENT ACTION

Figure 10 continued.

ASPECT MAP (Numbers 1 thru 12 indicate slope direction as on a clock face. 12 = a north-facing aspect, 6 = a south-facing aspect, 3 = an east-facing aspect, etc.)

Figure 10 continued.



SLOPE MAP (Lowest numbers indicate flattest terrain, highest numbers indicate steepest slopes)

Figure 10 concluded

WORKSHOP IN UKIAH

To bring the aerial photo interpretation capabilities of the Watershed Mapping Team members to a level equal to the task of preliminary vegetation classification within the study area, a two day workshop was conducted by members of the RSRP. The workshop included coverage of basic interpretation principles, atmospheric attenuation, ground reflection variables, photographic emulsions, scale, stereo parallax, ground mensuration, orthophoto quads and an intensive lab session using color infrared photography (9' by 18"), in conjunction with orthophoto quads for the quick and efficient mapping of fuel and vegetation types. Also attending the workshop were representatives from the Lake and Mendocino County Soil Conservation Service, Ukiah District Bureau of Land Management, Jackson State Forest and the Colusa County Fuel Management effort. In all 18 people participated. Evaluations on the usefulness of the workshop showed good to excellent responses. Since the workshop, several county-based agencies have ordered copies of the May 1978 U-2 color infrared flight and orthophoto quads, where available (see enclosed letters and evaluation summation).

80

CONCLUSION

The Watershed Mapping Team has proved to be an effective tool for the correlation of various resource parameters in support of remote sensing product utilization. Resource Managers have found that mapping of resources at identical scale allows immediate and meaningful utilization of Landsat and aerial photo products and makes their own documentation and public relations effort easier and effective. It has further been shown that individuals with little or no drafting experience can quickly master the drafting skills required by such an effort and in a short time acquire aerial photo interpretation capability that is also meaningful to resource management needs.

STATE OF CALIFORNIA — RESOURCES AGENCY EDMUND G. BROWN JR., Governor

DEPARTMENT OF FORESTRY
JACKSON STATE FOREST
802 N. Main Street
P. O. Box 1185
Fort Bragg, California 95437
(707) 964-5674

February 23, 1979

Mr. Chuck Henderson
University of California
Watershed Mapping Unit
Courthouse
Ukiah, California 95482

Dear Chuck:

This is to express our appreciation of the training course offered by you early this month. All three of the fellows attending from Jackson State Forest were complimentary of the course, its content and presentation.

I am sure that having attended the course our employees will be much better versed in the source and use of available imagery.

Thanks once again.

Sincerely,

DEPARTMENT OF FORESTRY
JACKSON STATE FOREST

Forest B. Tilley

Forest B. Tilley
State Forest Manager

FBT:jgt

88

UNITED STATES DEPARTMENT OF AGRICULTURE

SOIL CONSERVATION SERVICE

405 Orchard Avenue, Ukiah, CA 95482 Telephone: 468-9223

March 13, 1979

Charles Henderson
Space Sciences Laboratory
University of California, Berkeley
Berkeley, CA 94708

Dear Chuck:

Subject; Aerial Photo Interpretation Workshop - February 7 and 8, 1979

I received your letter of February 22, 1979 and thank you for including members of the Ukiah Field Office and Soil Survey Office and the Lakeport Soil Survey Office of the Soil Conservation Service in your Workshop Program.

I was particularly intrigued by the use of the filtered projections that high lighted different vegetation types and regret the missed opportunity to discuss how to set that system up. Could that system be set up using the infra-red photography this office currently has? As you demonstrated at the Covelo meeting and in the Workshop it's a very useful tool.

Again, thank you for the opportunity, information and instruction provided for the eight soil scientists and conservationists.

Those in attendance, either full or part time:

Roy Bowman, Soil Scientist, Party Leader, Ukiah SSO
John Weatherford, Soil Scientist, Ukiah SSO
Steve Borchard, Soil Scientist, Ukiah SSO
Terry Bowerman, Soil Scientist, Ukiah SSO
Harold Burlingame, Soil Scientist, Lakeport SSO
Don Berry, Forester, Ukiah Field Office
Frank Archuleta, Range Conservationist, Ukiah Field Office
Bryan Furman, District Conservationist, Ukiah Field Office

Sincerely,

Bryan D. Furman

Bryan D. Furman
District Conservationist

BDF:rc

Ukiah -- February 7-8, 1979

AERIAL PHOTO INTERPRETATION WORKSHOP

OVERALL EVALUATION

4 Excellent   13 Good   0 Ho-hum

Do you currently use orthophotoquad material? 11 Yes 6 No

If NO, do you anticipate using orthophoto products as a result of the workshop? ___ No 2 Yes 4 Maybe

Do you feel the use of 1:32,500 CIR aerial photography could increase your confidence in vegetation classification?

18 Yes ___ No

Do you anticipate using orthophotoquads in conjunction with CIR small scale photography?

6 Sure thing 9 Perhaps 3 No

What aspect(s) of this workshop had the most value for you?

How could this workshop have been of greater value to you?

Any other comments, remarks, ideas?

YOUR NAME ______________________ Agency ______________________

90

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Katibah, Edwin F. and W. C. Graves. "Remote sensing-aided assessment of wild turkey habitat." Paper presented at Pecora IV, the Application of Remote Sensing Data to Wildlife Management, Sioux Falls, South Dakota; 1978.

CHAPTER 2

PART II

Remote Sensing-Aided Assessment of Wild Turkey Habitat in Mendocino County, California

Authors: Edwin F. Katibah
Assistant Specialist
Remote Sensing Research Program
University of California, Berkeley

and

W. C. Graves
Wildlife Biologist
California Department of Fish and Game
Chico, California

PART II

REMOTE SENSING-AIDED ASSESSMENT OF WILD TURKEY HABITAT IN MENDOCINO COUNTY, CALIFORNIA

INTRODUCTION

One of the most prized game birds in California is the wild turkey (Meleagris gallopavo). Although not native to California, they were first introduced in 1877 to Santa Cruz Island (an island off the Southern California coast) by ranchers. The first public releases of these birds were made by the California Fish and Game Commission (now the California Department of Fish and Game) in 1908 and were continued through 1951. Although during that period over 3,000 pen reared turkeys were released throughout the state, only three sustaining populations became established (Burger, 1954). A turkey release program using only wild trapped birds from existing California flocks (Figures 1, 2, and 3) or from established populations in other states gained new support following the release in 1959 of 62 wild trapped Rio Grande (M.g.gallopavo) turkeys from Texas. This new program was highly successful with several populations established and several counties later opened to turkey hunting (Harper, 1977). Turkey populations are continuing to increase from natural dispersion of established flocks and through continued trapping and stocking programs.

93

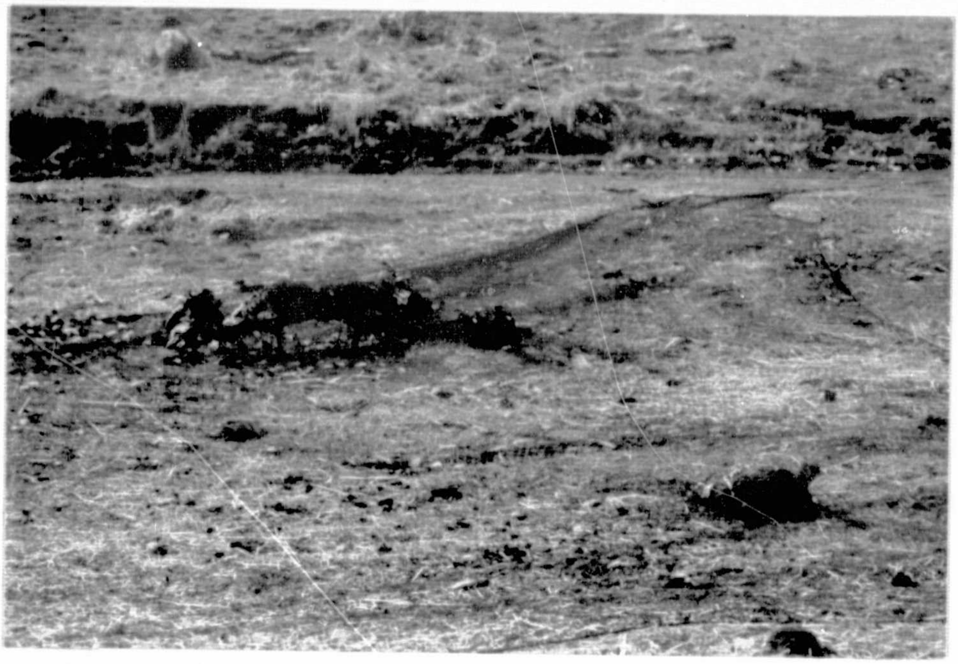

Figure 1. A cannon net, fired over wild turkeys feeding at bait stations, is a commonly used method of capture. This group of hen turkeys was captured on February 1, 1979 near Booneville, Mendocino County, California.

Figure 2. Wild turkeys must be transported to the release site in a manner which disturbs the birds the least. Special carboard boxes are used here to provide suitable containers for transporting the big birds.

Figure 3. Prior to release, the wild turkeys are tagged to provide the California State Department of Fish and Game information on individual birds at some future date. This information will help the Department determine whether the turkeys utilized the release site or moved on to other areas.

95

METHODOLOGY

Mendocino County (located on the north coast of California) was selected for testing remote sensing and ancillary data analysis techniques for mapping turkey habitat (see Figure 4).

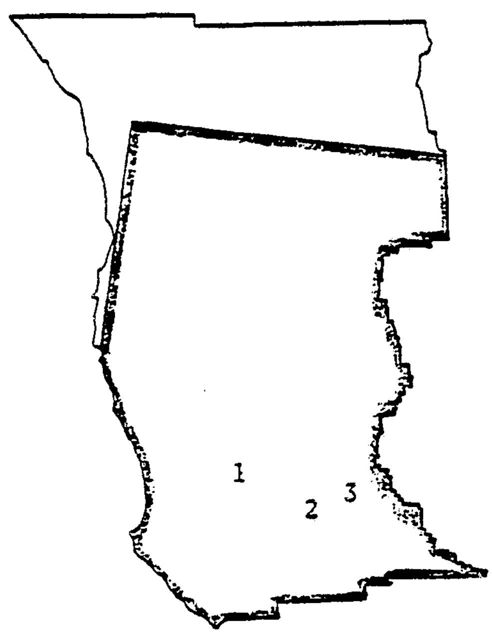

Figure 4--Map of Mendocino County showing the study area (dark shading) and the training and testing sites (1. Bonneville; 2. Yorkville; 3. Hopland).

In order to aid in the establishment of the wild turkey as a key game species in California, the California Department of Fish and Game developed a document titled "The Wild Turkey Management Plan" (Harper et al. 1973). This plan attempted to determine the location and extent of potential turkey habitat throughout the state of California and to identify future release sites. Using conventional mapping methods 5,800,000 hectares (14,500,000 acres), or 14.5 percent of the land area of California, was identified as potential turkey habitat (prior to this study, release sites were selected subjectively following field inspection of sites within areas previously identified as potential habitats). Following this procedure 45 sites were stocked with wild turkeys prior to 1975. Sustaining populations were established in 66 percent of these areas. Because of the time and expense involved in capturing and moving turkeys, and because only a few sites are available for stocking each year, it soon became obvious that a more objective procedure was needed to identify suitable habitat and release sites. The ongoing research which is briefly documented in this paper, has been designed to (1) provide site specific habitat information that is needed to determine the exact locations where wild turkeys might be successfully introduced, and (2) to delineate the extent of that potential habitat.

Using conventional mapping techniques, 42,241 hectares (104,300 acres) or 4.5 percent of the county, were identified as potential turkey habitat. Eight sites within this habitat have been stocked with turkeys: four areas have sustaining turkey populations with an estimated total population exceeding 1,000 turkeys; two areas were considered unsuccessful releases; and the stocking level in two areas is unknown.

Due to the large land area involved it was evident that remote sensing analysis techniques could provide the necessary data for assessing potential turkey habitat. To minimize the cost and amount of time needed to analyze an area as large as this study area a multi-information package was needed. The basis for this remote sensing-aided assessment of wild turkey habitat was the integral use of Landsat 2 digital data, high altitude (1:33,500) 9x18" conventional color and color infrared aerial photography, supplemental map data, and ground sampling.

Prior constraints dictated the development of a procedure for Landsat data analysis that could be implemented quickly and inexpensively. Towards this end only one Landsat date was used for analysis. The date chosen, June 27, 1976, was considered to be the best date to separate spectrally the principle vegetation associations.

The data anslysis was performed in three distinct steps: preprocessing, in which a sample area was selected to generate spectral training data; processing, in which the sample area was clustered to produce training statistics which were submitted to the maximum likelihood classifier that classified the entire study area; and post processing, in which the classified output was analyzed by wildlife experts to determine potential turkey habitat locations.

Preprocessing. The primary goal of this step was to select training and testing areas of all vegetation features that would be present in good wild turkey habitat. Only those areas in which wild turkey population had been introduced and established were selected as the training and testing sites.

Three good turkey sites were present within the study area: Booneville, Yorkville, and Hopland. The Booneville site was selected as a training site because it has had a sustaining turkey population since 1970, and it presently serves as a trapping area to supply stock for releases in new areas. The Yorkville and Hopland sites were selected as testing sites.

These three areas were located on USGS topographic maps and then transferred to aerial photos (1:33,500), color and color infrared) which were acquired in May 1978. Then, through the use of an interactive color display system, the Landsat coordinates of these areas were determined with the aid of the aerial photos, and the spectral data from the areas were extracted from the Landsat scene.

Processing. The spectral data from the Booneville site were submitted to the algorithm ISOCLAS which automatically generated 23 spectral clusters about the band means. After the clustering of the

C-2

training site had been completed, and prior to submitting the training statistics to the classification algorithm, each of the 23 clusters had to be labeled as one of the five major vegetation associations present in the site (Table 1). To facilitate this labeling procedure,

Table 1.--Definitions of the major vegetation associations for the Booneville test site

Vegetation Association	Definition
Bare soil	Urban, rock, bare ground, etc.
Grassland	Complex of annual grasses and forbes
Oak/Grassland	Grassland with scattered oaks (primarily _Quercus Douglasii_)
Oak	Predominately oak stands composed of _Quercus Carryana_, _Q. agrifolia_, _Q. Kelloggii_, with some _Lithocarpus densiflora_
Conifer	Stands composed large of _Sequoia sempervirens_, _Pseudotsuga Menziesii_ with some _Lithocarpus densiflora_
Other	Various brush types, water, etc.

the clusters were ranked on the basis of the ratio of two times the mean cluster value in the infrared band (Band 7) to the mean cluster value in the red band (Band 5) as shown in Table 2.

Table 2.--ISOCLAS cluster ordering by 7/5 ratioing of Landsat band means with major vegetation associations

Order	Cluster number	7/5 ratio	Major vegetation association
1	6	1.20	Bare soil
2	1	1.29	Bare soil
3	5	1.39	Grassland
4	9	1.43	Grassland
5	2	1.58	Oak/Grassland
6	14	1.58	Oak/Grassland
7	10	1.63	Oak
8	15	1.73	Oak
9	11	1.75	Oak
10	13	1.76	Oak
11	3	1.77	Oak
12	21	1.94	Oak
13	16	2.11	Oak
14	17	2.12	Oak
15	20	2.20	Oak
16	12	2.22	Oak
17	8	2.54	Oak
18	4	2.62	Oak
19	23	2.75	Conifer
20	18	2.84	Oak
21	19	3.09	Oak
22	7	3.13	Conifer
23	22	3.36	Conifer

The ordered ratios used in conjunction with annotated aerial photos of ground conditions and with the display of the clusters on the interactive monitor were used by wildlife and remote sensing specialists to label the clusters. The labeled ISOCLAS clusters were then grouped into five major vegetation associations for the Booneville area.

The ISOCLAS clusters were then used to provide the statistical data necessary to classify the remaining study area on the Landsat digital data. The program CALSCAN (the maximum likelihood classific developed by the Purdue University Laboratory for the Application of Remote Sensing modified to run on the University of California's CDC 7600 computer) was given the ISOCLAS data relating to the major vegetation associations. Each Landsat pixel was assigned to one of the ISOCLAS clusters. To eliminate pixels which did not closely fit any of the ISOCLAS clusters, a decision model was introduced to "threshold" out these areas. The remaining classification therefore, showed only those areas which were similar to the original ISOCLAS clusters spectrally and therefore in vegetation association information.

To make the final classified output more interpretable to wildlife specialists, each vegetation association was assigned a specific color (see Figure 5). In addition, major urban/agricultural areas within the county which are not appropriate turkey habitat were masked out of the display.

Postprocessing. Two criteria have been established for the interpretation of the vegetation association map for turkey habitat: (1) the proper mix of vegetation associations; and (2) a sufficient aerial extent of these mixes to support wild turkey populations. Experience of past releases in California and other states indicates that a minimum area of 2,000 hectares (5,000 acres) of contiguous

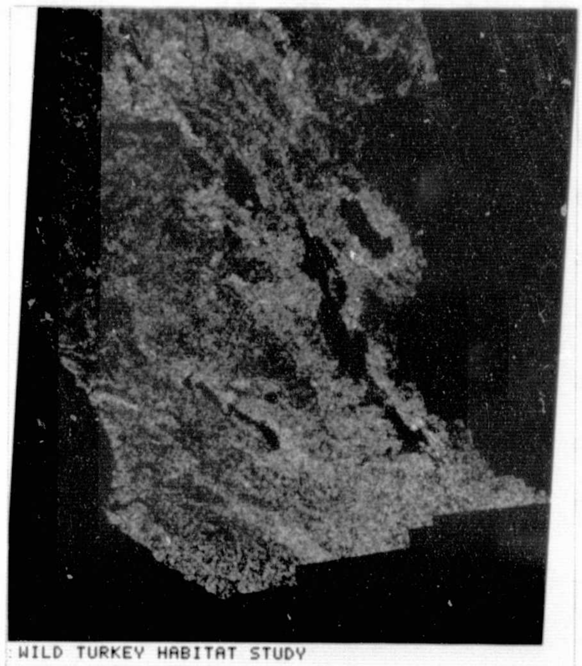

Figure 5. The aerial extent of the major vegetation associations within the Mendocino study area. Key:

White	- Bare Soil
Green	- Grassland
Yellow	- Oak/Grass
Red	- Oak
Light Blue	- Conifer
Black	- Mask

suitable habitat is needed. Good turkey habitat in Mendocino County is represented primarily by the oak and oak/grassland associations. Turkeys are also known to use the edges of the conifer and grassland associations when these areas adjoin the oak and oak/grassland areas.

To identify potential turkey habitat throughout the study area, use was made of the vegetation association map and two potential habitat criteria of proper vegetation mix and aerial extent of habitat. Figure 6 was compiled using the above criteria. Areas known to be currently supporting wild turkey populations were identified as well as those that are apparently suitable but presently unoccupied.

RESULTS AND DISCUSSION

Three major results of this study are (1) the generalized definition of proper vegetation mix, (2) the generation of a vegetation association map, and (3) the generation of a map of occupied and unoccupied potential turkey habitat for the study area located in Mendocino County.

The Booneville training site encompassed 2,300 hectares (5,760 acres) (Figure 7). Grassland, oak/grassland and oak (the primary components of turkey habitat) comprised 70 percent of the

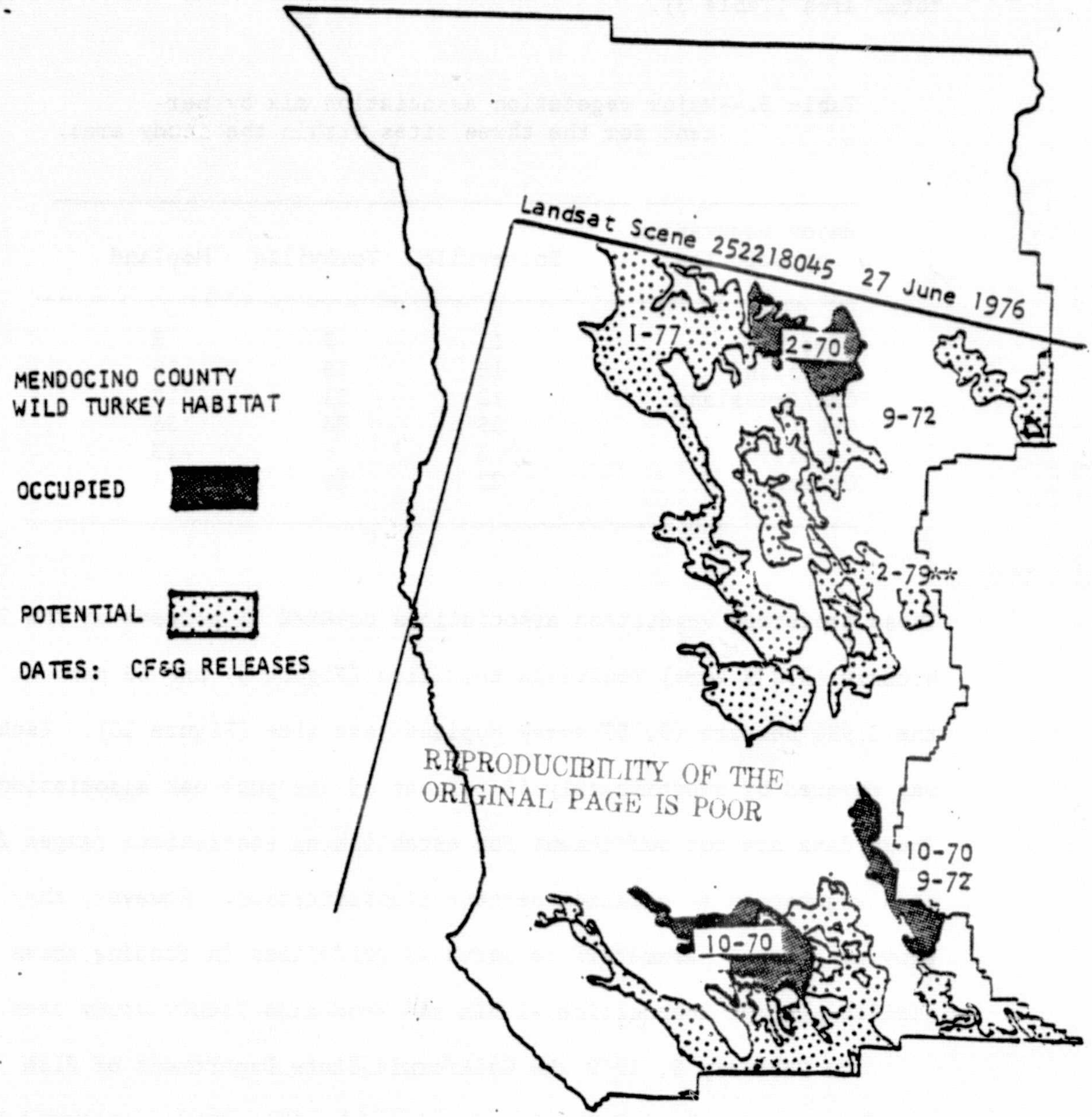

Figure 6. This map illustrates the release dates for wild turkey introduction within the study area. Occupied and potential turkey habitat were derived from the display of the computer classification of major vegetation associations (Figure 5).

105

total area (Table 3).

Table 3.--Major vegetation association mix by percent for the three sites within the study area.

Major vegetation association	Booneville	Yorkville	Hopland
Bare soil	11	3	3
Grassland	16	18	16
Oak/Grassland	12	21	18
Oak	35	34	36
Conifer	3	6	13
Other	22	19	14

These preferred vegetation associations covered 73 percent of the 2,040 hectare (5,039 acre) Yorkville test site (Figure 8) and 63 percent of the 3,950 hectare (9,757 acre) Hopland test site (Figure 10). Each area was covered by approximately 35 percent of the pure oak association. These data are not sufficient for establishing statistical ranges for each vegetation association percent classification. However, they do provide general parameters to serve as guidelines in finding areas of similar habitat composition within the Mendocino County study area.

On February 9, 1979 the California State Department of Fish and Game, using the information developed by this study, released 19 Rio Grande Turkeys (4 Toms and 15 hens) (See Figure 10). The release site (Potter Valley) was identified using the data contained in Figure 6. The release site will be evaluated based on sighting of

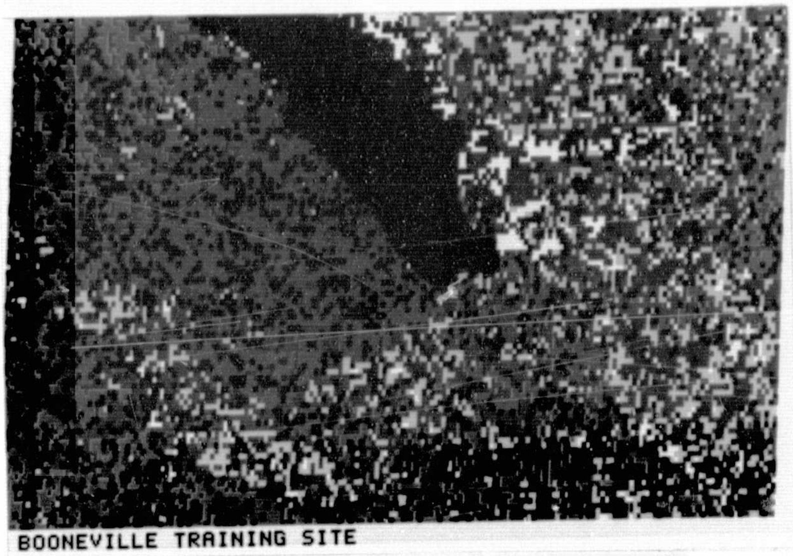

Figure 7. This computer display of the Booneville training site provides a close-up look at the detail contained in Figure 5. The key to color vs. plant association is the same as in Figure 5.

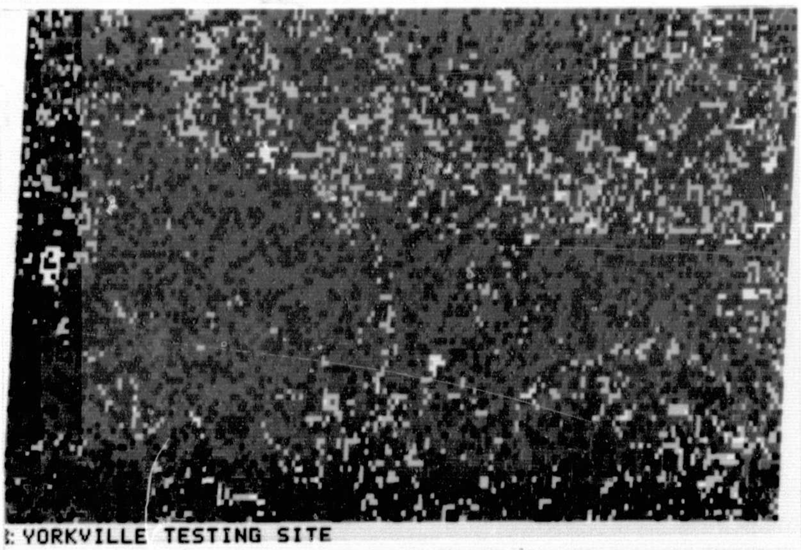

Figure 8. The Yorkville testing site, used to determine the suitability of the computer classification, is shown on a computer display. The color vs. plant association key is consistent with Figures 5 and 7.

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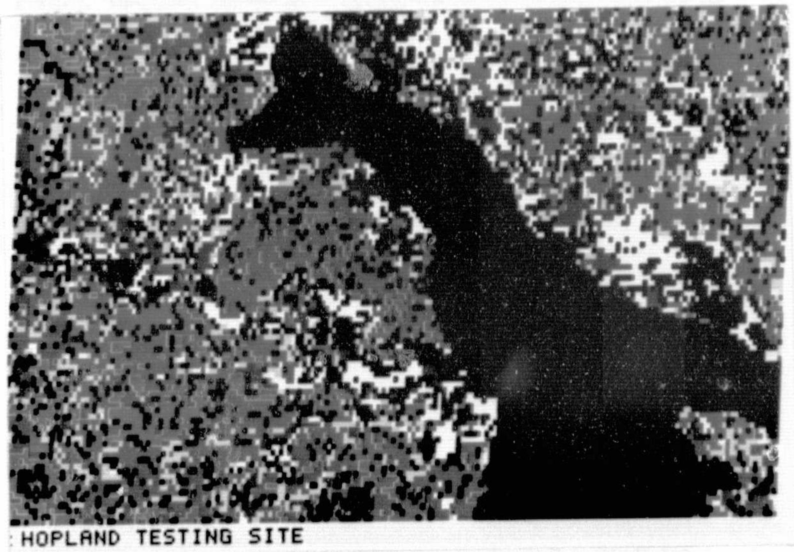

Figure 9. As in Figure 8, the Hopland testing site was used as a verification site to test the computer classification. Again the color-plant association key remains consistent.

Figure 10. One of nineteen wild turkeys released at the Potter Valley Site on February 9, 1979 by the California Department of Fish and Game.

turkeys to determine the success of the birds in occupying this area. If all goes as expected, other areas identified by this study will be used as a basis for further releases of wild turkeys into previously unoccupied habitat.

SUMMARY

Potential wild turkey habitats comprised of known vegetation associations were identified throughout Mendocino County, California from a computer-assisted analysis of Landsat 2 digital data. Areas in which wild turkey populations had previously been successfully established were used as training sites to identify comparable vegetation associations elsewhere throughout the study area. By this means an area known as "Potter Valley" clearly appeared to be best suited, even though its suitability had not been recognized from any previously-acquired information. A total of 19 Rio Grande turkeys (4 Toms and 15 hens) were successfully transplanted to the Potter Valley area on February 9, 1979 and their adaptability to this environment is now being evaluated by personnel of the California Department of Fish and Game.

PROPOSED FUTURE WORK

The release site at Potter Valley will continue to be evaluated based, in part, on sightings made from time to time of the transplanted birds and their offspring. Concurrently, and with substantially increased involvement by personnel of the California Department of Fish and Game, additional sites considered optimum for the transplanting of wild turkeys will be selected in Mendocino County and elsewhere in northern California from computer-assisted analyses of Landsat digital data. As such sites are identified wild turkeys will be transported to them and released as part of the on-going program of the California Department of Fish and Game to introduce wild turkeys in suitable sites wherever possible throughout the state.

There is good prospect that matching funds for this future work will be provided by at least 2 counties (Shasta and Tehama). With the steadily increasing interest in this program by the U.S. Fish and Wildlife Service, (through its office in Portland, Oregon) that agency may wish to employ our Landsat-based techniques in other states also.

111

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CHAPTER 3

CENTRAL CALIFORNIA STUDIES

Co-Principal Investigator: John E. Estes

INTRODUCTION

PART I

Cotton Mapping From Landsat Imagery

Authors: Tara L. Torburn, Larry R. Tinney

PART II

Green Fuel Moisture Estimation Using Landsat

Authors: Susan G. Atwater, Michael J. Cosentino

PART III

Remote Sensing of Perched Water and Soil Salinity

Authors: C. Elaine Ezra, Larry R. Tinney

PART IV

Watershed Runoff Predictions Using Landsat Digital Data

Author: Fredrick C. Mertz

PART V

The Ventura County Program

Authors: Douglas A. Stow, Michael J. Cosentino

Geography Remote Sensing Unit
University of California
Santa Barbara

GRADUATE RESEARCH RELATED TO NASA GRANT NSG 7220

A large number of students, both graduate and undergraduate, have participated in the research projects reported herein. The impact of this participation has been mutually beneficial to the students and the projects. In addition to financial support during their education, the students have been involved in applied remote sensing research and experienced the very real issues and problems associated with the demonstration and transfer of a new technology. In many instances the student's involvements have led to Master's Thesis topics directly related and of substantial value to the projects. Some of these completed and ongoing Master's Theses are briefly summarized here.

Analysis of Landsat and Digital Terrain Tape Data in a Geobase Information Systems Context: Ventura County Study Area By Douglas A. Stow

Originally a "spin-off" of another NASA grant effort, this masters research has been strongly influenced by the Ventura County Public Works Agency (VCPWA) projects of this current NASA grant. The thesis documents the accuracy attributes of digital Landsat classification and terrain data sets that are processed in the context of a geobase information system. It also provides background material for county-level resource managers to better understand the attributes of these particular data sets, as well as for geobase information systems. This study, in conjunction with an assessment of their information needs, may more effectively enable county-level resource managers to determine the utility of Landsat data in the context of a geobase information system. VCPWA has in fact initiated the development of a digital Landsat data base and intends to incorporate it with other digital data for environmental review information needs.

Green Fuel Moisture Estimation Using Landsat
By Susan G. Atwater

The Landsat green fuel moisture estimation project to be discussed in this chapter, is directly serving as the research base for a Master's Thesis to be completed by June, 1979. The major effort in this project is to determine the feasibility of using Landsat data in an operational mode to estimate the moisture content of live vegetation in the chaparral dominated Los Padres National Forest. If successful, Landsat derived band ratios will be used to estimate the green fuel (live vegetation) moisture content variable required for Fuel Model B of the National Fire-Danger Rating system in predicting fire danger indexes.

Cotton Mapping from Landsat Imagery
By Tara Lee Torburn

Research being conducted for the cotton project is being undertaken as a Master's Thesis topic to be completed by June, 1979. This project arose from an interest by the California Department of Food and Agriculture (CDFA) to incorporate remote sensing techniques into their cotton mapping surveys for the Pink Bollworm Project. If a procedure for mapping cotton fields from Landsat imagery under the project time constraints can be developed which can produce results commensurate with CDFA needs, the methodologies will be transferred to CDFA personnel for implementation.

Watershed Runoff Predictions Using Landsat Digital Data
By Frederick C. Mertz

The vegetation data generated by the watershed project will supply the research data base for a Master's Thesis to be completed by June, 1979. The purpose of the thesis is to analyze the remote sensing derived vegetation data as input to existing watershed runoff models, specifically, the Soil Conservation Service (SCS) model. The model will be calibrated using remote sensing input on "training" watersheds, then the transferability of the input data will be tested by determination of runoff coefficients for neighboring watersheds. If the technique is transferable, then counties using the SCS model and having similar watersheds can accept Landsat data as input to their models.

CHAPTER 3

PART I

Cotton Mapping From Landsat Imagery

Authors: Tara L. Torburn
Larry R. Tinney

COTTON MAPPING FROM LANDSAT IMAGERY

INTRODUCTION

During the past two years our group has been involved in research related to the mapping of San Joaquin Valley cotton fields in support of the joint state and federal pink bollworm control program. The initial development and preliminary portion of this effort was funded as part of this grant. Subsequent funding was provided through the NASA-Ames Consortium Agreement (NASA - Ames OR680-801) to incorporate historical Landsat data into the analyses and assess temporal reliability of the procedures. These demonstrations led to matching California Department of Food and Agriculture (CDFA) funds for a larger scale demonstration during the 1978 crop season (CDFA-7073). As part of our effort under this grant we have continued to coordinate and document these additional research efforts. We are presently summarizing the results for all of these research projects and developing a proposal for a semi-operational demonstration during 1979 that will parallel the present field mapping program. We are proposing that the major portion of funds for this new project be provided by the California Cotton Pest Control Board. This Board functions on self-imposed cotton bale assessments and is therefore directly responsive to cotton grower needs.

Objectives

The purpose of this research is to demonstrate and document the

118

feasibility and the operational utility of a Landsat methodology for early season mapping of cotton. To be practical this methodology must be suitable for implementation by Department of Food and Agriculture personnel. Satellite remote sensing systems, such as NASA's Landsat series, offer a means of acquiring multidate and spatially extensive information that is potentially both more timely and economical than conventional ground based sources. The temporal aspect of Landsat coverage makes it particularly suitable for crop identification studies where a series of "looks" throughout a growing season, or portion thereof, may yield more information than a one-time "look" on the ground, as is done in automotive "windshield surveys."

Specific objectives during this reporting period included the development of a detailed cotton crop calendar, comparative analysis of the multiple year classification results, and documentation of the 1978 demonstration. The 1978 demonstration project was delayed by poor image availability (the Landsat-3 launch disrupted normal MSS image acquisitions) but will be reported in the November Semi-Annual Report.

Background

Cotton is California's most valuable field crop. Within California the principal cotton growing regions are the San Joaquin Valley (producing 92% of the State's cotton) and the Imperial Valley, with Kern and Fresno counties alone accounting for more than half the State's 1974, 1975, and 1976 production (Figure 3-1).

Because of cotton's role in both the state and national economy (fifth most valuable U.S. crop) the control of pests and infestations

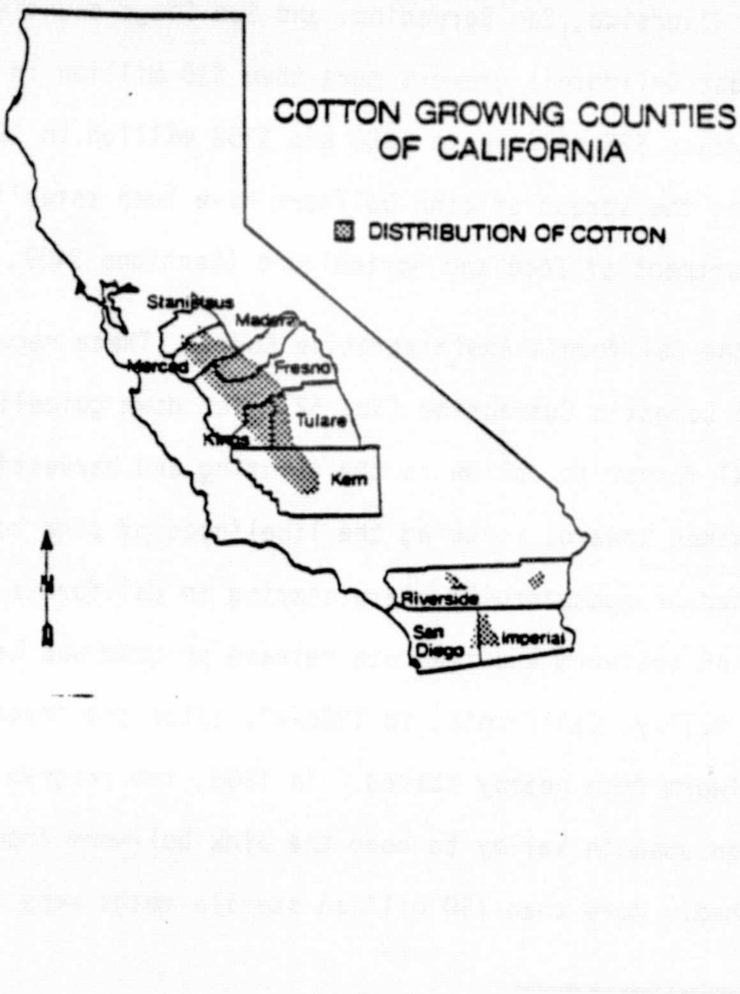

FIGURE 3-1. Location of cotton growing regions in California. (from Durrenberger and Johnson, 1975)

that affect cotton yield is a major agricultural concern. Unfortunately, cotton is very susceptible to attact by pests, with approximately one half of all insecticides used in agriculture in the U.S. applied to cotton, which represents less than 5% of total cropped acreage. The biggest threat to cotton in California is the pink bollwork, *Pectinophora gossypiella*, considered one of the world's most destructive cotton pests. First collected in California in October 1965, it has caused extensive damage to cotton in Imperial, Riverside, San Bernadino, and San Diego counties. Yeild loss and control cost California growers more than $19 million in 1974, and are estimated to reach $78 million in 1980 and $152 million in 1981. Regulations for controlling the spread of pink bollworm have been established by the State Department of Food and Agriculture (Sections 3409, 3590, and 3595 of the California Administrative Code). These regulations and a Federal Domestic Quarantine (No. 52), set down guidelines for the individual farmer to follow in the planting and harvesting of cotton and are aimed towards reducing the likelihood of pink bollworm being transported or successfully overwintering in California.*

A pink bollworm sterile moth release program was begun in the Imperial Valley, California, in 1966-67, after the invasion of the pink bollworm from nearby states. In 1968, the program was expanded to the San Joaquin Valley to keep the pink bollworm from becoming established. More than 150 million sterile moths were released by

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*A news release by the California Department of Food and Agriculture in late October, 1977, changed the "plowdown" date for the San Joaquin Valley, California, from February 1, 1978 to January 1, 1978. It was changed on recommendations from the Cotton Pest Control Advisory Board "to help San Joaquin Valley growers beat down what could be the beginning of an infestation of pink bollworms in the major cotton growing counties of the state."

USDA's Animal and Plant Health Inspection Service (USDA-APHIS) in the Valley in 1975, with more than 2,000,000 being released daily in 1977.

To monitor the effectiveness of the sterile-release program and native pink bollworm population levels, the California Department of Food and Agriculture (CDFA) and the U.S. Department of Agriculture (USDA) engage in trapping programs. Baited traps are set between July and October/November to catch the moth stage of the pink bollworm; presently one trap is set for each 40 acres of cotton. To assure optimum distribution of traps, maps are generated during April and May showing all cotton fields in the San Joaquin Valley. Mapping procedures involve automotive "windshield surveys" which presently cost approximately $100,000 per year. After the location of the cotton fields has been determined, trapping districts are established, and the appropriate number of traps (about 29,000 per year for the last 4 years) are set and monitored throughout the growing and harvesting seasons.

Study Area

As already mentioned, the San Joaquin Valley is California's principle cotton growing region, and it is here that the CDFA and USDA have concentrated their efforts for the Pink Bollworm Program. The pink bollworm has already become established in the three major agricultural areas in southern California - Imperial, Coachella, and Palo Verde Valleys. Strict regulations were set down in 1972 to help control the population increase and geographic expansion of the pink bollworm from these heavily infested areas to the San Joaquin Valley.*

*Presently, control measures keep the pink bollworm population levels in check. The only chance for eradicating this pest from southern California would also require eradication in Arizona and Mexico.

Within the San Joaquin Valley, selected areas were chosen as test sites for exploring the feasiblity and operational utility of cotton mapping techniques based on multidate Landsat imagery. The first of these is an area of approximately 45 mi^2 within the Wheeler Ridge-Maricopa Water Storage District, located in Kern County at the southern end of the San Joaquin Valley (see Figure 3-2.)This area was chosen because of previous and ongoing research by our group in this region, which has resulted in an extensive collection of crop data for the years 1974-1978. Within this test site are found about 20 different crops, with cotton making up about 50% of the cropped fields.

Towards the middle and northern limits of cotton growing in the San Joaquin Valley, five test sites of 9 mi^2 each were chosen in cooperation with personnel of the CDFA Pest Control office in Fresno, California (see Figure 3-2).These sites were chosen so as to represent a variety of crops and field sizes. "Ground truth" maps were prepared of these sites by CDFA personnel. Cotton accounts for approximately 40% of the cropped fields in these five test sites.

APPROACH AND PROCEDURES

The multidate aspect of Landsat makes it particularly suitable for crop identification. Many crops have distinct growth or phenological cycles which, when observed throughout the year, can uniquely identify the crop. Cotton is a good example; given a full years Landsat coverage cotton can be easily identified from other crops. Figure 3-3 shows the cotton phenological cycle and its appearance as viewed by Landsat.

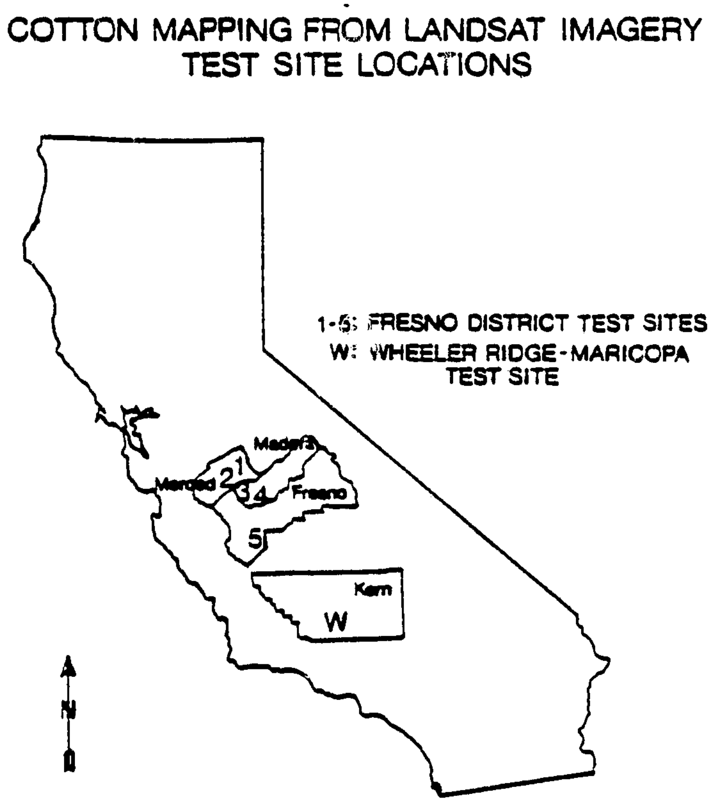

FIGURE 3-2. Location of test sites in California for cotton mapping from Landsat imagery.

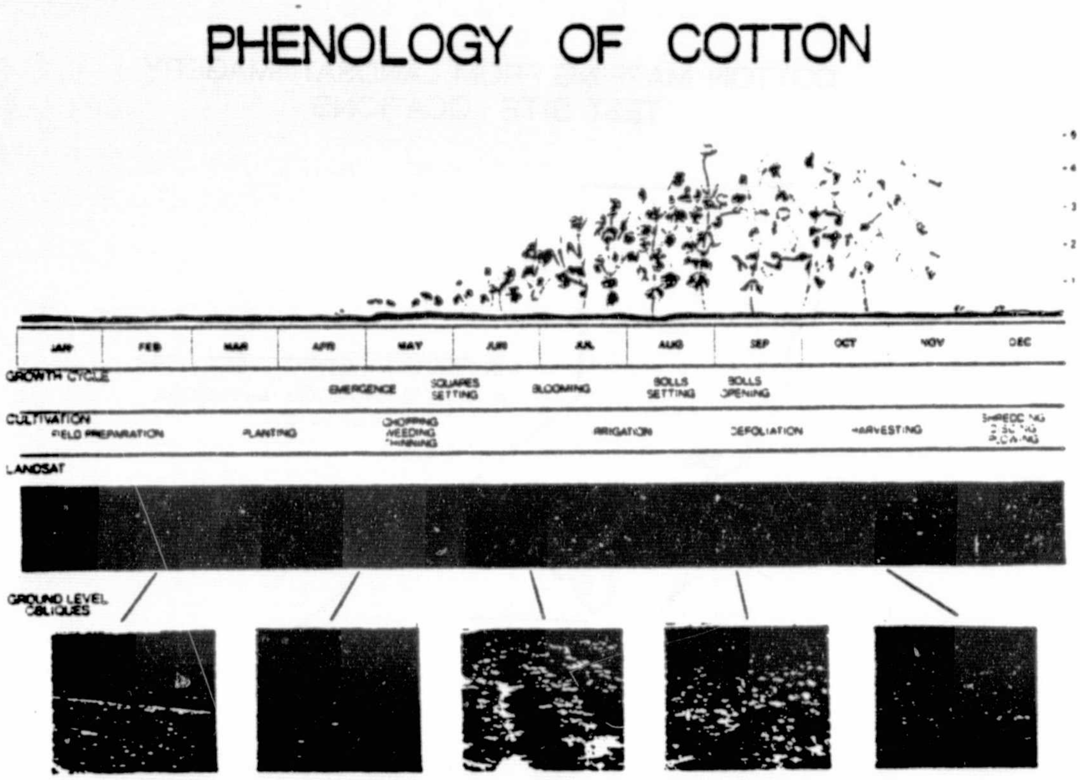

FIGURE 3-3. Phenological cycle of cotton. The Landsat "chips" are greatly enlarged false color composites of a cotton field as viewed by Landsat during the year. This diagram has been localized to the San Joaquin Valley, California.

The bright red color infrared signature indicative of full, healthy plant cover can be seen to correspond to the time of year when cotton is mature.

The major problem in identifying cotton for the Pink Bollworm Program is the time constraint of producing maps by early June. For this reason, only Landsat imagery taken through May of each year can be used. It can be seen in Figure 3-3 that in this time frame, cotton has just been planted and is at most only a few inches tall. Therefore, the mapping of cotton fields from Landsat imagery is largely accomplished through elimination of vegetated or fallow fields. Some confusion crops, such as melon and tomatoes, do cause interpretation problems during this early season period. Fortunately, these crops account for only a small percentage of the cropped fields in this region. Young orchards and vineyards may also cause interpretation problems, but it is possible to eliminate these areas from the interpretation by earlier aerial photographic surveys.

TASKS PERFORMED TO DATE

Black and white 9-1/2" positive Landsat images, MSS bands 4, 5, and 7 were acquired of the Wheeler Ridge-Maricopa Water Storage District study area for the years 1974, 1975, 1976, 1977, and of the Fresno test sites for 1977. Cloud free 70 mm chips encompassing the study areas were cut from the images, and then color combined on an additive color combiner. The end result of the process is a false color composite print of the study area at a scale of 1:167,000. This procedure was followed for each useable overpass for January-May of each year (see Figure 3-4). One set of prints for the Wheeler Ridge-Maricopa test site were used to make the interpretation keys for the various crops growing in the study area. Individual fields were cut out and grouped by crop and field number (for identification only) on index cards; where possible, five examples (fields) per crop were used.

When administering the interpretation tests, the interpreters were told they need only identify cotton, and that averaged over the four years cotton fields comprised 50% of the fields in the interpretation test. They were provided with field boundary overlays on which to note their interpretations. All of the interpreters are experienced photo-interpreters, familiar with the study area in the context of extensive ground data collection for other non-crop related projects.

RESULTS

Tables 3-1 through 3-4 show the results of interpretations for the years 1974, 1975, 1976, and 1977 for the Wheeler Ridge-Maricopa Water Storage District test site. There is significant variation from year to year in the overall accuracies: 1974, 88%; 1975, 78%, 1976, 91%; and 1977, 54%. One of the known sources of error is the Spring Crop Survey by the Wheeler Ridge-Maricopa Water Storage District, which is used as "ground truth," but is not, in fact, 100% correct. Table 3-5 shows the discrepancies within the test site for the four years between the different agencies which map the cotton fields. Each considers the other to be in the range of 90-96% accurate.

Landsat Overpasses for the Wheeler Ridge - Maricopa Test Site
January - May 1974 - 1977

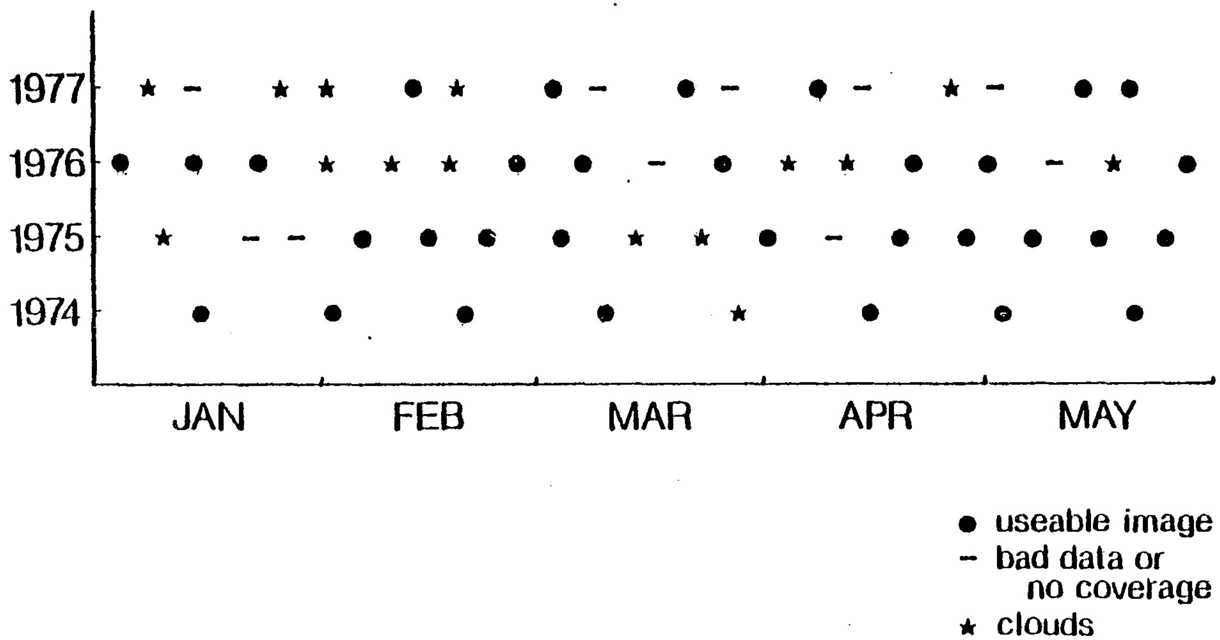

FIGURE 3-4

TABLE 3-1

MULTIDATE COLOR COMPOSITE MANUAL INTERPRETATION ACCURACIES OF COTTON VERSUS NON-COTTON, WHEELER RIDGE-MARICOPA TEST SITE, 1974

GROUND TRUTH	TOTAL FIELDS	PERCENT CORRECT	INTERPRETATION	
			COTTON	NON-COTTON
COTTON	432	92	398.5	33.5
NON-COTTON	276	80	55	221
TOTAL	708	88	453.5	254.5

TABLE 3-2

MULTIDATE COLOR COMPOSITE MANUAL INTERPRETATION ACCURACIES OF COTTON VERSUS NON-COTTON, WHEELER RIDGE-MARICOPA TEST SITE, 1975

GROUND TRUTH	TOTAL FIELDS	PERCENT CORRECT	INTERPRETATION	
			COTTON	NON-COTTON
COTTON	280	91	253.5	26.5
NON-COTTON	388	69	122	266
TOTAL	668	78	375.5	292.5

TABLE 3-3

MULTIDATE COLOR COMPOSITE MANUAL INTERPRETATION ACCURACIES OF COTTON VERSUS NON-COTTON, WHEELER RIDGE-MARICOPA TEST SITE, 1976

GROUND TRUTH	TOTAL FIELDS	PERCENT CORRECT	INTERPRETATION COTTON	INTERPRETATION NON-COTTON
COTTON	394	93	366.5	27.5
NON-COTTON	306	89	34.5	271.5
TOTAL	700	91	401	299

TABLE 3-4

MULTIDATE COLOR COMPOSITE MANUAL INTERPRETATION ACCURACIES OF COTTON VERSUS NON-COTTON, WHEELER RIDGE-MARICOPA TEST SITE, 1977

GROUND TRUTH	TOTAL FIELDS	PERCENT CORRECT	INTERPRETATION COTTON	INTERPRETATION NON-COTTON
COTTON	286	67	193	93
NON-COTTON	416	45	227	189
TOTAL	702	54	420	282

TABLE 3-5

DISCREPANCIES IN MAPPING OF COTTON BY DIFFERENT AGENCIES IN THE WHEELER RIDGE-MARICOPA TEST SITE

1974

WR-M WSD CROP SURVEY	TOTAL # FIELDS	PERCENT CORRECT	USDA FIELD CHECK COTTON	NON-COTTON
COTTON	216	95	205	11
NON-COTTON	138	91	12	126
TOTAL	354	94	217	137

1975

WR-M WSD CROP SURVEY	TOTAL # FIELDS	PERCENT CORRECT	USDA FIELD CHECK COTTON	NON-COTTON
COTTON	140	94	131	9
NON-COTTON	194	97	5.5	188.5
TOTAL	334	96	136.5	197.5

1976

WR-M WSD CROP SURVEY	TOTAL # FIELDS	PERCENT CORRECT	USDA FIELD CHECK COTTON	NON-COTTON
COTTON	197	93	183	14
NON-COTTON	153	93	11	142
TOTAL	350	93	194	156

TABLE 3-5continued

1977

WR-M WSD CROP SURVEY	TOTAL # FIELDS	PERCENT CORRECT	USDA FIELD CHECK COTTON	NON-COTTON
COTTON	143	83	119	24
NON-COTTON	208	94	11.5	196.5
TOTAL	351	90	130.5	220.5

1977

WR-M WSD CROP SURVEY	TOTAL # FIELDS	PERCENT CORRECT	DWR LAND USE SURVEY COTTON	NON-COTTON
COTTON	143	88	126	17
NON-COTTON	208	93	15	193
TOTAL	351	91	141	210

1977

USDA FIELD CHECK	TOTAL FIELDS	PERCENT CORRECT	DWR LAND USE SURVEY COTTON	NON-COTTON
COTTON	143	97	138.5	4.5
NON-COTTON	208	93	15	193
TOTAL	351	94	153.5	197.5

The test results have been computed on a field rather than acreage basis. This was done on request by CDFA; their concern is mainly in locating the cotton fields since once that has been accomplished determining the acreage of the fields is a relatively minor task.

In 1977, a special problem arose. In mid-April, MSS band 4 on Landsat I became inoperable. This band is normally used in conjunction with MSS bands 5 and 7 to create color infrared composites. It was therefore necessary to create color composites using only two MSS bands. The latest May image used in the interpretation test, May 20, was the only date affected. However, this data is of critical significance to the interpretation test. Because of the poor interpretation test results, it was decided to add the June 1 image (the next Landsat 2 overpass) to the interpretation test. At this point in the season, most cotton was about 6" tall. Table 3-6 shows the results of the interpretation using the June 1 image; by comparing Tables 3-4 and 3-6 it can be seen that the interpretation accuracy greatly increased by adding the single date.

A more complete analysis of the interpretation results will be undertaken to determine why the other variations in accuracy for the different years have occurred, and also where improvements in the procedure can be made in order to increase the overall accuracies. The tests will then be expanded to the Fresno district test sites to assess signature extension problems and operational feasibility.

TABLE 3-6

MULDIDATE COLOR COMPOSITE MANUAL INTERPRETATION ACCURACIES
OF COTTON VERSUS NON-COTTON, WHEELER RIDGE-MARICOPA TEST SITE, 1977
WITH ADDITION OF EARLY JUNE IMAGE

1977

GROUND TRUTH	TOTAL FIELDS	PERCENT CORRECT	INTERPRETATION COTTON	NON-COTTON
COTTON	286	82	234.5	51.5
NON-COTTON	416	78	90	326
TOTAL	702	80	324.5	377.5

SUMMARY

The results of this project to date suggest that Landsat techniques may be suitable for assisting the pink bollworm control program. Although the temporal constraint of providing maps by early June significantly impacts the Landsat approach, it is of similar significance to field based techniques because of the large area that must be mapped.

A major concern at this point is that the techniques be demonstrated as reliable, accurate and repeatable from year to year. Based upon the critical importance of a late May date to accuracy performance it will be necessary to pursue probable cloud cover impacts and the frequency of satellite coverage. Operational data flow characteristics (from overflow to delivery of final map) will also need to be realistically addressed.

PROPOSED FUTURE WORK

Historical accuracy results indicate that Landsat-based classification performance is comparable to existing procedures. An operational demonstration is being developed for the 1979 crop year. This effort is proposed to be jointly sponsored by the California Cotton Pest Control Board and this NASA grant.

The test region for this demonstration will include the cotton growing regions of the San Joaquin Valley, California. Because of the unique time constraints associated with the Pink Bollworm Project, that is, the necessity of generating a map of all cotton fields by early June, almost immediate turn-around of late May Landsat data will be required. Following this operational demonstration, the methodologies developed for mapping of cotton fields from Landsat imagery will be transferred to the California Department of Food and Agriculture for implementation.

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CHAPTER 3

PART II.

Green Fuel Moisture Estimation Using Landsat

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Michael J. Cosentino

BACKGROUND .

Southern California Fire Control Problem

Historically, Southern California has exhibited a high potential for catastrophic fires. The losses that result from these fires include not only the immediate devastation of structures and vegetation resources, but also long-lasting effects such as potential mud slides, debilitation of the soil, decreased land values, and ill-timed release of inferior quality water. The fire control problem in Southern California is the product of highly flammable fuels and steep topography which combine with warm, dry Santa Ana winds to produce severe burning conditions. The containment of a potentially catastrophic fire hinges upon the assessment of the expected behavior of the fire in order to efficiently allocate the available fire control resources.

Daily Predictions of Fire Danger

In order to have sufficient fire control resources on call, it is necessary for the fire control officer to be able to predict the potential fire danger. The National Fire-Danger Rating System is a means for deriving these predictions and is based upon the relative effects of weather on the following aspects of fire behavior; (1) fire spread, (2) fire intensity and (3) fire ignition. The effects of weather on fire spread and fire intensity are combined and rated on a scale of 0-100 to give the Burning Index or relative measure of how difficult any particular fire will be to control. The effects of weather on fuel ignitability is then rated on a scale of 0 to 100 to give a relative measure of fire probability or the Ignition Index. Combining the Burning Index and the Ignition Index into a Fire Load Index, again on a 0 to 100 scale, produces a relative measure of the potential job load per day. This Fire Load Index is then used to determine the necessary level of staffing and deployment.

Structure of the National Fire-Danger Rating (NFDR) System*

The basic structure of the NFDR system (Fig. 3-5) provides three indexes designed to aid in planning and supervising fire control activities on a fire protection unit. The indexes are defined as follows:

- Occurrence Index (OI) - A number related to the potential fire incidence within a rating area.
- Burning Index (BI) - A number related to the contribution that fire behavior makes to the potential amount of effort needed to contain a fire in a particular fuel type within a rating area.
- Fire Load Index (FLI) - A number related to the total amount of effort required to contain all probable fires occurring within a rating area during a specific period.

These indexes are derived from the three fire behavior components -- Spread Component (SC), Energy Release Component (ERC), and Ignition Component (IC).

Spread Component (SC) - The SC is derived from a mathematical model developed at the Northern Forest Fire Laboratory. This model integrates the effects of wind and slope, together with fuel bed and fuel particle properties to compute the fire spread rate (Rothermel, 1972).

Since the characteristics of the fuels through which the fire is burning are so basic in determining the rate at which the fire front moves, a unique

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* Deeming, Lancaster, Fosberg, Furman, and Schroeder. The National Fire Danger Rating System. USDA Forest Service Research Paper RM-84, Rocky Mountain Forest and Ranger Experiment Station, Fort Collins, Colorado, August, 1974.

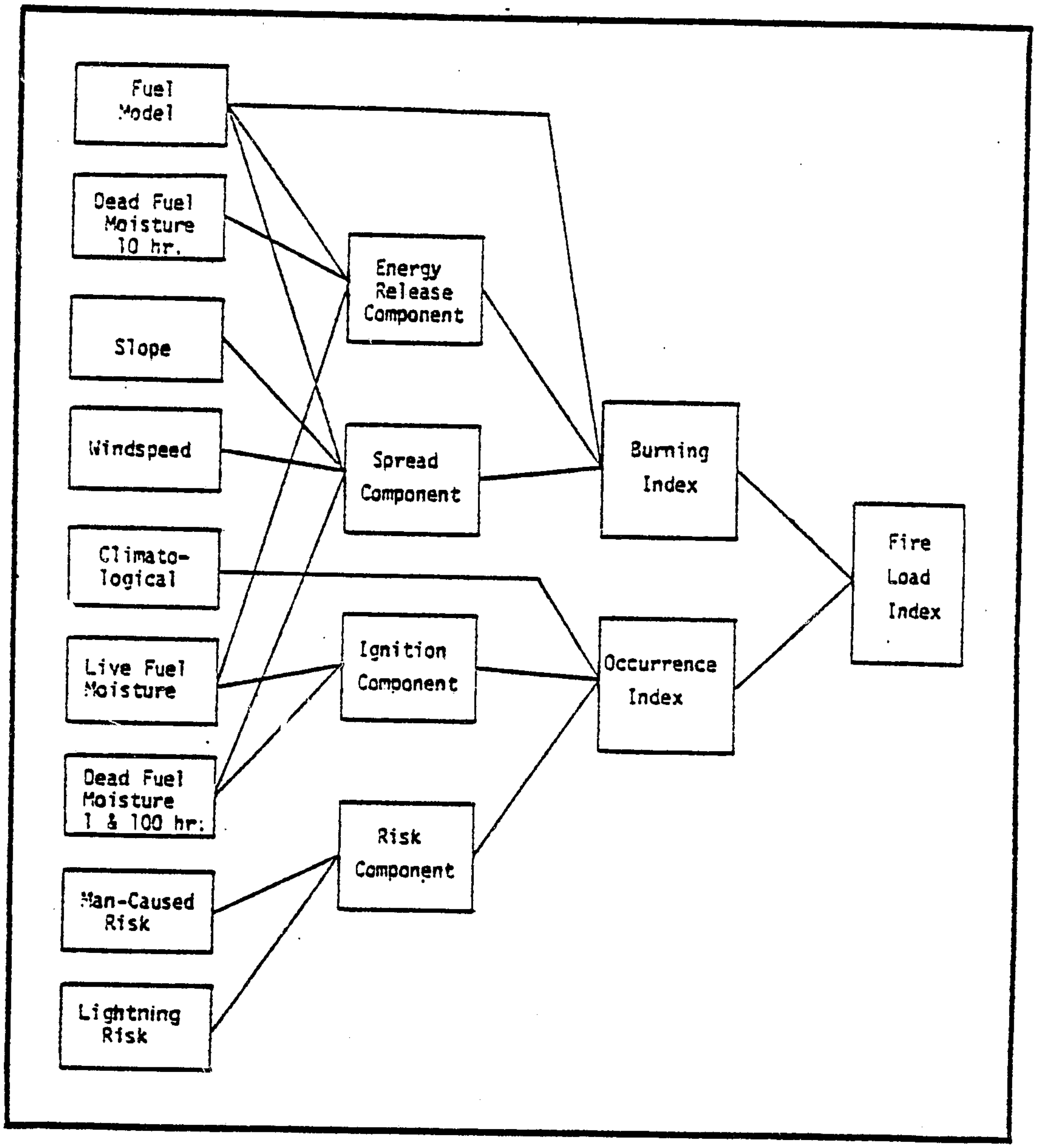

FIGURE 3-5. Structure of the National Fire-Danger Rating System.

SC table is necessary for each of the nine fuel models recognized by the system.

In the calculation of the SC the inputs used are: windspeed, slope, fine fuel moisture (includes the effect of green herbaceous plant material), and the moisture content of the foliage and twigs of living woody plants (woody vegetation condition).

The SC, since it indicates the rate of forward spread of the fire, will give an indication of the time within which a fire must be contained to prevent it from exceeding an acceptable size. It can also be a guide to the positioning of units to keep travel time within necessary limits. Travel time and the rate of line construction by the various mixes of personnel and machines are key factors.

Energy Release Component (ERC). - Like the SC, the ERC is calculated using a table unique to each fuel model. The combustion rate is almost wholly dependent on the same fuel properties as are considered in the equations which calculate the SC. A principal difference is that, whereas the SC is determined primarily by the finer fuels, the ERC calculation also requires moisture content inputs for the 10-Hr. and 100-Hr. time-lag fuels.

The ERC is used as a guide to the kind of attack forces that will be most effective. For low values, direct attack methods are practical. If the fuel, soil, and topographic conditions allow, hand crews may be adequate. On the other hand, when the ERC is high, it is likely that heavy equipment may be needed for direct attack. If the ERC is very high, direct attack by any means will frequently be impossible and indirect attack methods should be used. With experience, the effectiveness and practicability of using chemicals, ground or air delivered, may be indicated by the ERC. It may

142

also be used as a general indicator of the potential for certain types of fire damage.

Ignition Component (IC). - The IC represents the ease with which fine fuels are ignited. Ignition normally takes place in the dead component of the fine fuels. The three distinct steps that must be considered are (1) the firebrand must come in contact with the dead fuel, (2) the fuel particle must be dried, and (3) the temperature of the fuel particle must be raised to the kindling point, about 380°C. (716°F).

Living material in the fine fuel complex shields the dead fuel from the firebrand or otherwise reduces its efficiency. Therefore an adjustment dependent on the percent of the fine fuel which is living (herbaceous vegetation condition) is made.

The IC is an indicator of potential for spotting, i.e., the likelihood that a spreading fire will result when a wind blown firebrand is introduced signficantly ahead of the spreading front of a fire.

Applications of the NFDR System

As stated previously, the three major indexes (occurrence, burning, and fire load) derived from the fire behavior components are designed to aid in planning and supervising fire control activities on a fire protection unit. The operational applications of these indexes are as follows:

The Occurrence Index (OI) is an indicator of the potential fire incidence on a protection unit during a rating period. A high OI would indicate that the detection system should be brought to a high level of readiness. Then looking at Risk the fire control manager will know whether to concentrate detection efforts in the lightning belts of the protection unit or in the areas frequented by people. If the probability of people-caused fires is high, some additional resources of the unit probably should be diverted to patrol and prevention work.

The Burning Index (BI) integrates the effects of weather, fuels, and topography on fire behavior. It will indicate the level of personnel staffing and the amount and kind of equipment which should be directed to a single fire. However, since the BI is made up of the Spread Component (SC) and the Energy Release Component (ERC), a more precise estimate of the requirements for the prompt containment of a particular fire can be made by examining both of these values.

The Fire Load Index (FLI) is the number to which readiness plans will be keyed. It will indicate the level of readiness at which supression forces on a protection unit should be maintained to handle the potential fire situation.

When the daily, weekly, and monthly FLI's are added, the sum is the Seasonal Severity Index (SSI). The SSI will provide a yardstick for comparing the potential fire problem of one protection unit against another, or for evaluating accomplishments. When considered with actual fire occurrence, the SSI will provide decision aids for such administrative tasks as allocating monies, changing authorized staffing levels, and so forth.

Fuel Moisture and Fuel Models in the NFDR System

The rating of fire danger, in its simplest form, is the prediction of the behavior of a potential fire. Principal determinants of fire behavior can be classified as being variable or constant in time. Variable determinants are weather dependent; they are wind, fuel moisture, and fuel temperature. The more constant determinants are topography and fuel type.

Five classes of fuels, three dead and two living are considered by the NFDR system. Since the system is designed to measure the job of containment (not extinguishment) of the fire, only those fuels involved in combustion within the immediate flaming front need be considered. Because moisture content, to a large extent, determines the flammability of fuels, the separation of dead fuels into classes was based on the rapidity of the moisture content response of individual fuel particles to changes in relative humidity (Lancaster, 1970). Living fuels are classified according to whether they are herbaceous (grass and other herbaceous) or woody (twigs less than one-fourth inch in diameter and the foliage of woody plants). One-fourth inch is considered to be the upper size limit of living woody material which can be desiccated and consumed within the flaming front of an initiating fire.

Living herbaceous material is considered only as it changes the effective moisture content of the fine fuels. The living woody material is treated both as a heat sink (it takes a considerable amount of energy to desiccate this material) and as a heat source (after it has been desiccated, it burns and contributes energy just as dead fuel does) (Fosberg and Schroeder, 1971).

In the formulation of the NFDR fuel models, typical values for the loadings (tons/acre) by fuel classes, surface area to volume ratios, and bed depths were determined for the fuel situations to be represented by the fuel model. Fuel particle properties such as density, heat content, and mineral content are assigned constant values. The remaining inputs, the moisture content by fuel classes, are variables determined by physiological and climatological processes. Hence, they must be evaluated daily. Fuel moisture contents, wind, and fuel temperature account for the short-term variation of fire danger.

Fuel Model B classically represents the Southern California dense brush and chaparral. It is characterized by heavy loadings of dead woody material and/or litter layers 3" deep and over. The primary cover plants must average 6 feet or more in height. Foliage of brush plants typically becomes easily involved in the fire. Individual plants in these associations almost always form a dense, continuous fuel bed occupying two-thirds or more of the area.

Fuel Model B of National Fire-Danger Rating System

The U.S. Forest Service (USFS) uses Fuel Model B of the NFDR system to derive the various fire potential indexes for the Los Padres National Forest located in south central California. The indexes are derived by the model for 10 fire danger rating areas that encompass the Los Padres National Forest. Fire danger ratings are used on the Los Padres National Forest to make a number of critical management decisions such as, closure of an area to recreation, deployment of personnel during fire situation, and location of fuel breaks.

Fuel Model B is designed for use in the chaparral community most commonly found in the Los Padres National Forest. Fire potential indexes of occurrence, burning and fire load are derived from the fire behavior components of spread, energy release, ignition and risk (lightening risk and man-caused risk).

The dynamic variables that drive this model include weather data, dead versus live herbaceous vegetation ratio, and "woody vegetation condition" which refers to the moisture content of the green foliage and small twigs of woody perennial plants. At present, data for the first two variables, weather and dead vs. live ratio, are collected with recording instruments and field volume transects respectively. The woody vegetation condition or green fuel moisture is calculated from samples collected in the field by USFS personnel.

The samples consist of new growth from chamise (Adenostoma fasciculatum) and are cleaned of all dead material. Chamise is a representative plant species for woody vegetation since it is a common and aggressive shrub which has a wide range and produces more volume of growth than any other shrub in Southern California. It is also one of the most hazardous wildland fuels in Southern California. Sampling is done between the hours of 12 and 3 p.m. at which time any surface moisture has evaporated leaving only the internal plant moisture to be measured. Three samples of 75 grams are taken from each collection site in the field and weighed, dried and reweighed until all contained moisture is removed and then reweighed to obtain the moisture content by weight. This method is both time consuming and expensive since the collection stations are remote and widely spaced.

USER REQUIREMENTS

Forest Service personnel of the Los Padres National Forest expressed an initial interest in this research project and have cooperated throughout the project. Initially this work was proposed as a feasibility study using Landsat image data to estimate given fuel moisture content but excluded the study of digital Landsat data due to the level of funding. The L.P.N.F. fire control and planning personnel were sufficiently interested in including the digital aspect to the study that they purchased for the project five dates of Landsat computer compatible tapes (CCT's). In addition they have been most supportive in terms of providing ground truth data for green fuel moisture and weather from the ten different collection stations in the study area. We have worked closely with the L.P.N.F. personnel in defining the problem and establishing their data requirement needs.

Fuel Model B presently requires that three general levels of moisture in green fuel be estimated for each of the ten fire danger rating areas. The three levels are:

1) high moisture content (> 120%) which occurs in the early part of the growing season and produces rapid growth of new leaves, needles, and twigs.

2) low moisture content (70-120%) when growth continues at a much reduced rate, this stage normally persists until fall when deciduous species lose their leaves.

3) severe drought (< 70%) which is hard to detect during any season in its beginning stages, especially in evergreen species.

An important requirement of the model that critically effects its utility is the timeliness of the field data. The maximum time lag between the measurements of green fuel moisture and its input to the model and output of fire potential indexes is approximately one week. This time requirement

148

will vary with changing temperature, relative humidity and moisture conditions. The most critical time for frequent moisture measurements is in the late summer and fall before winter rains begin when temperatures are high.

In terms of utilizing Landsat data for estimation of green fuel moisture content on an operational basis, the turn-around time will of necessity need to be much shorter than the present four week average for receiving processed data from the satellite.

STUDY AREA

The area for which this study is being undertaken includes the contiguous southern portion of the Los Padres National Forest that falls primarily in Santa Barbara, Ventura and Kern Counties (see Figure 3-6). This sub-section of the larger Los Padres National Forest, which includes portions of San Luis Obispo and Monterrey Counties, was chosen to accomodate the area encompassed in one Landsat image scene. Both Landsat and green fuel moisture ground truth data are available for the entire forest area, thus at a future date this technique could be evaluated for the entire Los Padres National Forest. However, the scope of this study permits the acquisition and analysis of only one Landsat scene per date.

Results obtained in the sub-section under study should be relevant to the remainder of the forest area excluded from this study. This is due to the fact that fuel moisture data is collected in a similar manner from chamise plants throughout the entire Los Padres National Forest. Thus the fuel moisture estimation technique using Landsat data for chamise stands in the southern portion of the forest should be valid for chamise stands in the northern portion of the forest.

Figure 3-6 delineates in addition to the Los Padres National Forest, Fire Danger Rating Area boundaries and fuel moisture sampling stations. Fire Danger Rating Areas are units of land on which weather is measured and, insofar as practical, represent a distinct climatic type. Each Rating Area is further classified according to the fuel type (grass, brush, or timber) that predominates in the principal risk zones.

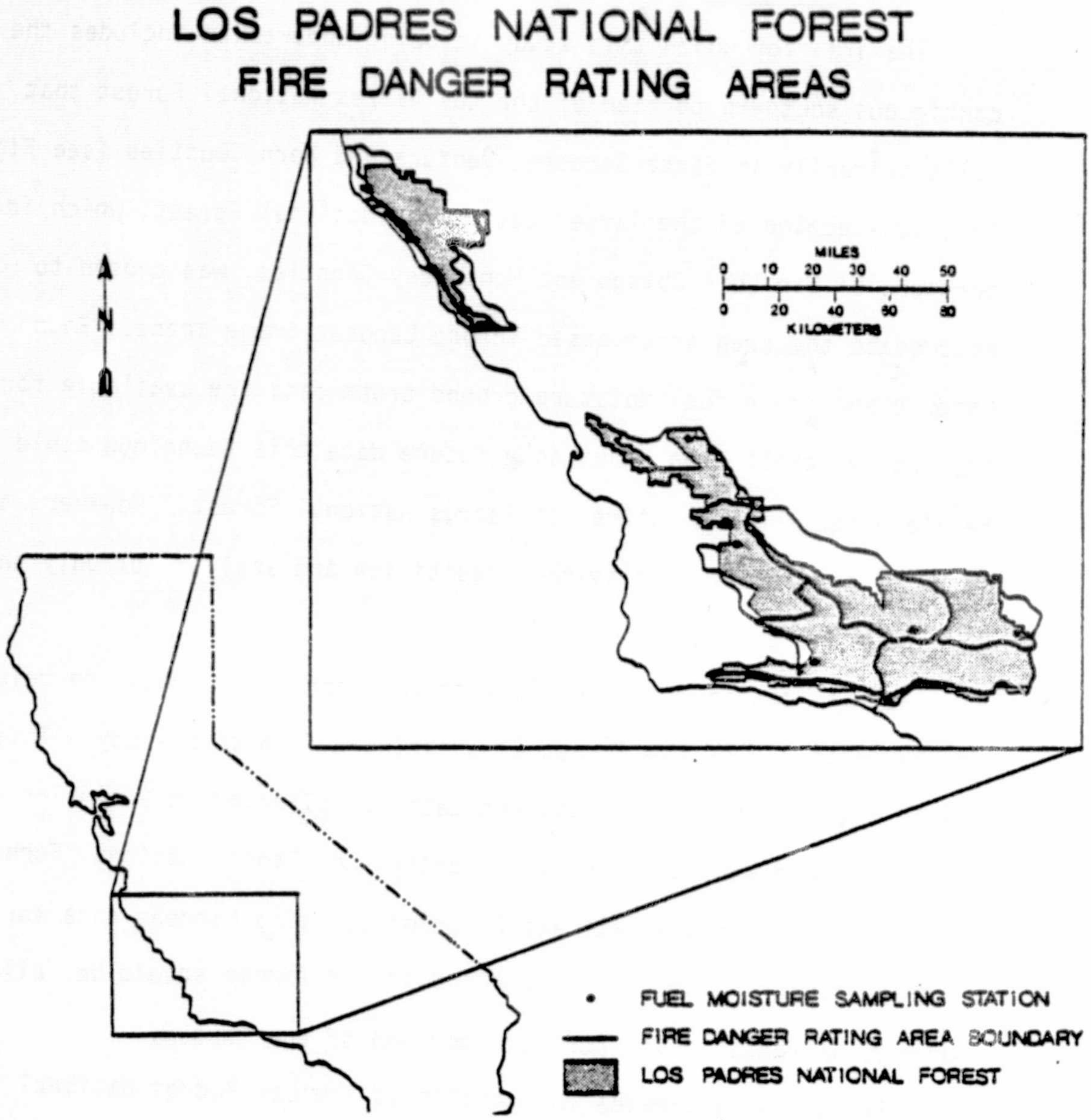

FIGURE 3-6. Los Padres National Forest Fire-Danger Rating Areas.

All Rating Areas in this study are classified as brush and are listed in Table 3-7 by number with their associated name and fuel moisture collection station(s).

Table 3-7

Fire Danger Rating Areas Under Study and Associated Fuel Moisture Collection Station(s).

Number	Name	Fuel Moisture Collection Station(s)
582	Santa Margarita-La Panza	Black Mountain
585	Upper Santa Maria Drainage	Shell Peak Buckhorn
586	Upper Santa Ynez Drainage	Upper Oso San Marcos Pass
588	Cuyama Valley	Ozena
600	Southern Ventura County	Laguna Ridge Stewart Canyon
650	Ojai Inland	Nordhoff Ridge
651	Chuchupate	Hardluck

The fuel moisture collection stations are locations within each Fire Danger Rating Area where large continuous stands of chamise are found. As previously stated, the chamise plant is sampled for fuel moisture content due to its status as the most potentially dangerous or hottest fuel in the Los Padres National Forest vegetation configuration.

152

APPROACH AND PROCEDURES

Justification for Approach

The Landsat satellite carries onboard a multi-spectral scanner (MSS) collecting information in four discrete spectral regions: .5-.6 μm green visible (band 4); .6-.7 μm red visible (band 5); .7-.8 μm near infrared (band 6); and .8-1.1 μm infrared (band 7). Each band collects different information about the landscape. Band 4 is a region where little chlorophyll absorption (absorption of the radiation by chlorophyll pigments) occurs, thus is called the green band. The chlorophyll absorption is maximized in Band 5 thus resulting in the red band nomenclature. The Band 6 signal is related to green leaf biomass and the associated high soil-green vegetation reflectance contrast. Band 7 is more highly related to green leaf density although a water absorption band at .92-.98 μm creates signal degradation due to atmospheric effects (Tucker, 1978). Satellite imagery, such as that provided by the Landsat series, has shown significant correlation with leaf water content and vegetative biomass in previous research. Rouse et al. (1973 and 1974) analyzed Landsat MSS data and found that it could be used to monitor biomass, leaf area indexes and other phenological phenomena for certain crop and range types. C.J. Tucker (1977) has found that the photographic IR/red ratio, the difference between IR and red, and the (IR-red)/(IR-red) values are sensitive to photosynthetically active or green biomass and leaf water content.

Tasks Performed to Date

- Selection of optimum study period

The initial step was to determine from past field data records the time period that would provide a wide range of fuel moisture conditions for study. Additionally it was important that the study period coincide temporally with a number of high quality cloud free Landsat overpass dates.

A calendar matrix was developed with 1)green fuel moisture data from each collection station, 2) rainfall data from each U.S. Forest Service weather station, and 3) Landsat overpasses and their quality in terms of cloud cover and atmospherics. From the matrix it was determined that the spring, summer, and fall of 1975 and 1976 provided a good set of coincident ground and satellite data.

- Acquisition of ground truth data

All ground truth data was obtained from historical records gathered in the field by U.S. Forest Service personnel and maintained at the regional office of the Los Padres National Forest in Goleta, California. Green fuel moisture data is available for ten sites in the forest, for varying periods of time. Local rainfall data are not usually taken from the same locations, however, local ranger stations record daily amounts of precipitation. Table 3-8 shows the green fuel moisture collection stations, their corresponding rainfall station and the period for which data was obtained for this project.

- Acquisition of Landsat data

Landsat imagery was acquired in both image and computer tape (CCT) formats. The Geography Remote Sensing Unit had previously acquired much of the Landsat image data for the study region during the 1975 and 1976 seasons when ground truth data was available. The U.S. Forest Service, interested in pursuing the digital data approach, has purchased five Landsat CCT's of the study area. These include the dates 5/10/76, 6/6/76, 7/21/76, 8/8/76, and 10/10/76. This data set provides a sufficient amount of coincident ground and satellite data to study a wide range of fuel moisture conditions

Table 3-8

Fuel Moisture Station	Rainfall Station	Data Collection Period
Black Mountain	Salinas Dam	July 1975 - September 1975
Buckhorn	Pine Canyon	May 1975 - Present
Hardluck	Chuchupate	August 1976 - November 1976
Laguna Ridge	Casitas	February 1975 - Present
Nordhoff Ridge	Ojai	July 1976 - Present
Ozena	Ozena	August 1976 - November 1976
San Marcos Pass	San Marcos Pass	May 1976 - Present
Shell Peak	Pine Canyon	April 1976 - August 1976
Stewart Canyon	Ojai	February 1975 - Present
Upper Oso	Los Prietos	May 1976 - Present

- Determine image density values

  Image density values were measured from Landsat transparancies of the four MSS bands for each of the ten field sampling stations with a Macbeth Quantalog densitometer. Density values were measured for the 15 step grey scale on each image and used to normalize the density range between dates.

  In order to normalize density values between dates, a multiple regression was run between the density values of the 15 step grey scale for each date and those of a base date. The resulting equations were then used to correct the density values for each collection station on an image to the base date grey scale. In this way all collection station density values were normalized to the same base date grey scale.

- Correlation of Landsat image data to ground truth data

  The normalized image density values were correlated to ground truth values of percent green fuel moisture using band ratioing. These data sets were also graphically compared in scatter plots. Several ratios of the Landsat bands were used to rank their sensitivity to fuel moisture. This inital correlation is expected to be somewhat lowered due to the fact that ground fuel moisture measurements were not taken coincidentally with the Landsat overpasses. Other factors that could affect the correlation are limited only to the image format data and do not affect the digitial CCT data correlation. The first factor is the spatial resolution obtainable by observing the Landsat images with the densitometer. Although data is recorded on the image in approximately 80 meter square resolution elements or "pixels" which are observable through magnification, they cannot be individually separated or resolved by the densitometer. Using the smallest aperture of .5 mm on the 1:1,000,000 scale image gives a field of view equal to 46 pixels or 50.6 acres on the ground. Thus each density reading is a composite of the radiance values of all 49 pixels in the area viewed by the densitometer. Each density reading was taken for the group of pixels in close proximity to the point on the image where a fuel moisture collection station was located.

The second factor that can affect the correlation of image format data with ground data is reduced radiometric resolution. Landsat originally records digital data on 128 radiance levels. This number is reduced when producing imagery from the CCT's thus the sensitivity and range of image density values is reduced.

The band ratios make use of the four discrete spectral bands of information available on Landsat. The four different sensors onboard Landsat collect data in the green, red, near infrared, and infrared spectral regions. The ratios used in the correlations are:

1) band 7 + band 5

2) band 7 - band 5

3) band 5/band 7

4) (band 7 - band 5)/(band 7 + band 5)

5) square root of [(band 7 - band 5)/(band 7 + band 5) + .5]

Table 3-9 gives the results of the correlation of the bands ratio to percent green fuel moisture. These results indicate no correlation between the Landsat and ground truth data for green fuel moisture. Owing to the factors that influence this correlation of Landsat image data, as described below, these results are not unexpected. One further manipulation of this data will be attempted during the next reporting period. The image density values will be used with the Kauth tasselled-cap linear transform which isolates green

156

development and soil brightness. This may provide a more diagnostic tool to observe vegetative changes due to moisture stress throughout the growth cycle.

TABLE 3-9

Band Ratio	Correlation Coefficient	Significance Probability
7 + 5	-.22	.08
7 - 5	-.43	.0004
5/7	.50	.0001
VI	-.50	.0001
TVI	.50	.0001

Processing Landsat Digital Data

Landsat digital data has been extracted from the CCT's and band ratios are being calculated for correlation with ground truth measurements of green fuel moisture. The extraction of digital numbers (DN's) from the tapes was done using the Video Image Communication and Retrieval (VICAR) software package. This involves reformatting the tape to VICAR format, locating the ground data collection sites to within several pixels and extracting the appropriate DN values.

Correlation of Landsat Digital Data to Ground Truth

The same procedure used to correlate Landsat image data with ground truth data will be used. The Landsat digitally derived band ratios will be correlated to ground truth measurements of percent green fuel moisture. These data sets will be graphically plotted to aid in the evaluation of the correlation. Additionally, a correlation will be made between Landsat band ratios and fuel moisture values ranked according to low, medium, and high moisture contents. At this point green fuel moisture input to Fuel Model B is required in a ranked variable format with 0-70% as low, 70-120% as medium and greater than 120% as high.

Evaluation of the Accuracy and Utility of this Procedure for Operational Use

Both the image and digital format approach will be evaluated for accuracy and utility in an operational setting. Accuracy will be assessed in deriving both integer and ranked values of green fuel moisture. Accuracy in deriving the ranked values of low, medium, and high, as defined in a previous section, is imperative for operational use in the present Fire-Danger Rating System. Although the application of integer values for fuel moisture is not feasible now, future refinements in the fuel models may require this type of data.

Another important assessment of the utility of this procedure involves the turn-around time from Landsat data acquisition to the availability of fuel moisture estimates for input to the fuel models. The user requirements of the USFS in this regard will have to be determined on a seasonal or even monthly basis. It is expected that the turn-around time requirement will change as the fuel moisture levels reach a critical point, although this will be affected by the existing climatological conditions.

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CHAPTER 3

PART III

Remote Sensing of Perched Water and Soil Salinity

Authors: C. Elaine Ezra
Larry R. Tinney

INTRODUCTION

Remote Sensing of Perched Water and Soil Salinity

Many arid agricultural regions are experiencing crop yield losses and deteriorating soil conditions due to the excessive build-up of shallow or "perched" water tables and salts in the soil root zone. Problems associated with the presence of shallow water tables are significant at the global and national, as well as local levels. In the United States alone, more than 20 million acres of potentially arable land have high water tables in the rooting zone of the soil horizon. In many arid environments where irrigation is practiced the total acreage affected by soil drainage problems continues to increase.

Various remote sensing systems offer potential means for timely and cost-effective collection of perched water and soil salinity related data. As part of our research effort we are directing attention towards the operational use of remote sensing techniques to collect this type of data.

It is extremely unlikely that any remote sensing technique or combination of techniques will ever completely replace conventional monitoring of test wells in drainage control programs. There do appear, however, three potentially significant ways in which remote sensing may aid the collection of perched water data. These include: 1) general reconnaissance of an area to aid in optimum siting of test well locations; 2) interpolation and extrapolation between point samples provided by test well data based on environmental factors interpreted from remote sensing data, including possible use of such data in hydrologic models; and 3) direct collection and interpretation of perched water table conditions or some surrogate indicator of perched water table conditions.

OBJECTIVES

Previous research efforts have demonstrated the technical feasibilities of various remote sensing systems for providing useful drainage related data. The major goal of this project is to document, through highly visible demonstrations, those remote sensing techniques presently not used but considered well suited for operational implementation by major user groups in Kern County. Where appropriate we will also continue, at lower priority, to provide assistance to those users implementing more conventional remote sensing techniques (e.g. interpretation of aerial photography). Although Kern County agricultural land will be emphasized in this project, the techniques demonstrated and experience derived should also benefit the large number of users present in similar arid environments.

Specific research objectives to meet the general goals of this project include:

- The identification of the major user groups information requirements (i.e., individual farmers, local water districts, Kern County Water Agency, and State Department of Water Resources) specifically as they pertain to remote sensor system resolution in the spatial, temporal, and quantitative dimensions.
- A systematic assessment of the utility of remote sensing systems for operationally providing needed drainage related data.
- An evaluation of the usefulness of image processing and enhancement techniques, such as digital ratioing and photographic color compositing, for extracting more information from Landsat imagery.
- The development and implementation of a cooperative field data collection program to provide better depth to perched water table and soil thermal data, the dynamics of which are presently inadequately defined.

Subsequent sections of this portion of our report discuss the nature of drainage problems in Kern County, the approach and results we have obtained, and both scheduled and proposed research on this topic.

Kern County Test Site

Typical of an arid region where drainage problems are extensive and growing is the southern end of the San Joaquin Valley, which includes western Kern County, California. Kern County has nearly one million acres of irrigated cropland and is the second most productive agricultural county in the United States (Figure 3-7). Approximately one million acre-feet of water is presently imported via the California Aqueduct and Friant-Kern Canal systems to supplement an annual groundwater extraction estimated in excess of two million acre-feet. With the growth of agriculture, there has been a continuous decline in groundwater levels over most of the county.

In a number of areas within Kern County, however, the nature of the groundwater problem is just the reverse; buildups of perched water tables, related to applied irrigation water, are rapidly increasing soil drainage problems. Factors leading to the development of perched water tables include geology, topography, soil type and stratigraphy, and water use management.

Perched water tables normally develop when layers within the soil profile of low permeability retard or prevent deep percolation of applied water. A perched water table is created when water is added in excess of the natural percolation rate (see Figure 3-8). Shallow, fine textured layers impede vertical flow of groundwater in the unconsolidated alluvial sediments of the San Joaquin Valley. In Kern County, the uppermost clay, designated the "A" (Hanford) clay, is for the most part the major perching layer and it

165

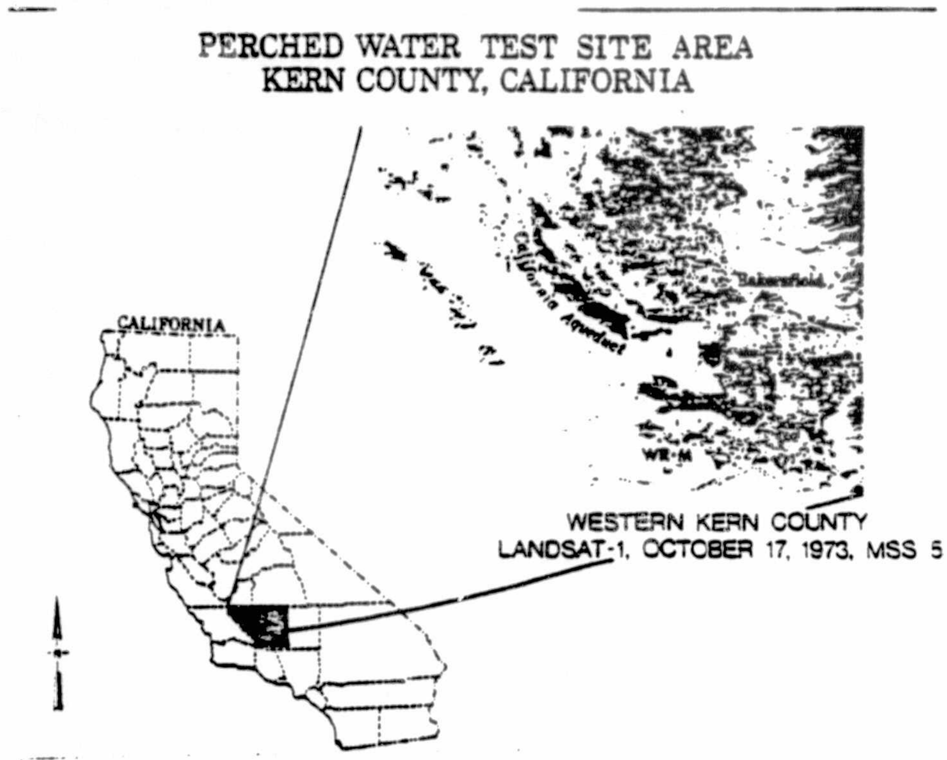


Figure 3-7. Location Map and Landsat Insert of Perched Water Test Site in Kern County, California.

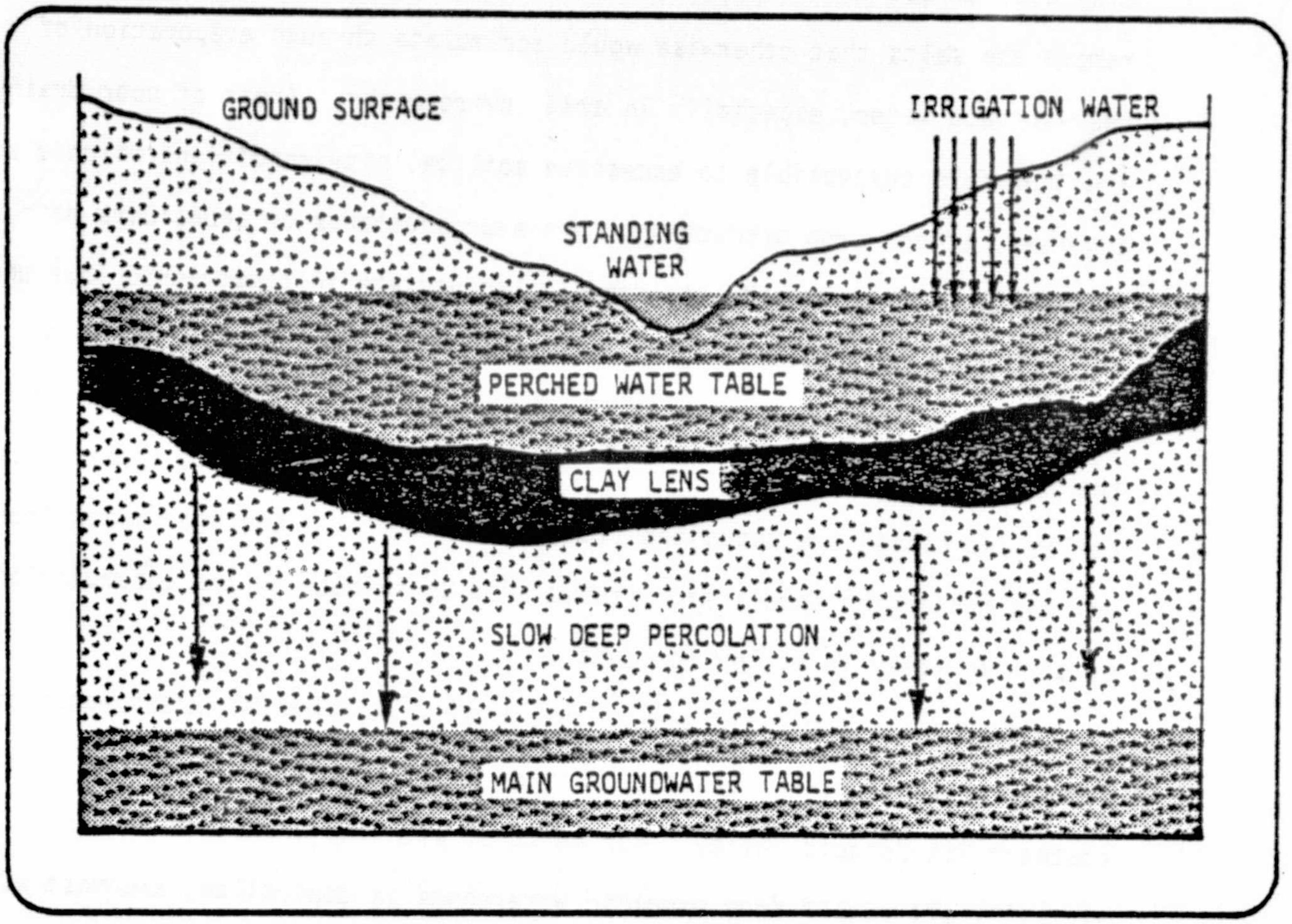


Figure 3-8. Perched Water Table Formation. Perched water tables are formed when an impermeable or semi-impermeable layer, such as a clay lens, is present above the main groundwater table. Normal deep percolation is impeded, forming a shallow or "perched" water table above the main groundwater table.

167

ranges in depth from about 40' to 100' (KCWA, 1976 b). By intercepting the normal deep percolation of applied irrigation water these layers of clay also affect the movement of salts. Deep percolation is necessary to remove the salts that otherwise would accumulate through evaporation of near-surface water, especially in arid environments. Areas of poor drainage are therefore susceptible to excessive soil salinity conditions which also adversely affect crop production. Whenever aquatards or aquacludes have a slope component, groundwater tends to accumulate in topographic lows under the influence of gravity. Thus, areas most prone to the development of drainage problems usually lie in the topographically lower regions, where the finer soil constituents more responsible for drainage characteristics (silts and clays) are deposited (see Figure 3-9). Seepage losses from unlined irrigation canals and ditches also contribute to the accumulation of perched water in valley lowlands.

In arid and semi-arid areas, only a minor portion of excess water comes from precipitation. Precipitation averages an annual 5 to 6 inches in the southern San Juaquin Valley. Furthermore, with the exception of flood flows, virtually all runoff from mountain watersheds in controlled, and most water reaching the valley floor is used for irrigation (Department of Water Resources, 1970). As a consequence, natural sources of water inputs appear to have little effect on perched water table fluctuations.

Figure 3-10 shows seasonal changes in the extent of perched water table conditions under the old Kern Lake bed, and demonstrates the direct relationship of irrigation water to perched water levels. The high point in the cycle (April-July) is related to the application of irrigation water. The low point (December) reflects the cumulative effects of reduction in irrigation

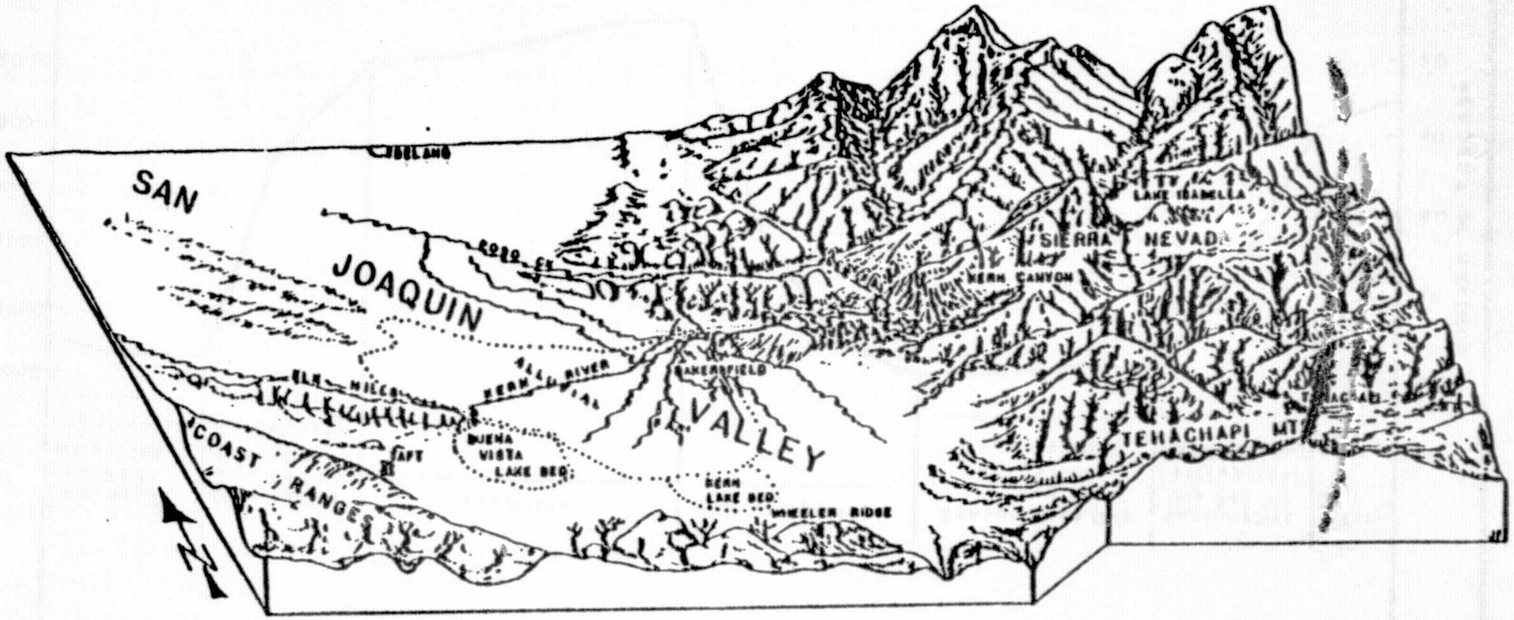


Figure 3-9. Kern River Alluvial Fan and Surrounding Area (From United States Geological Survey, 1966).

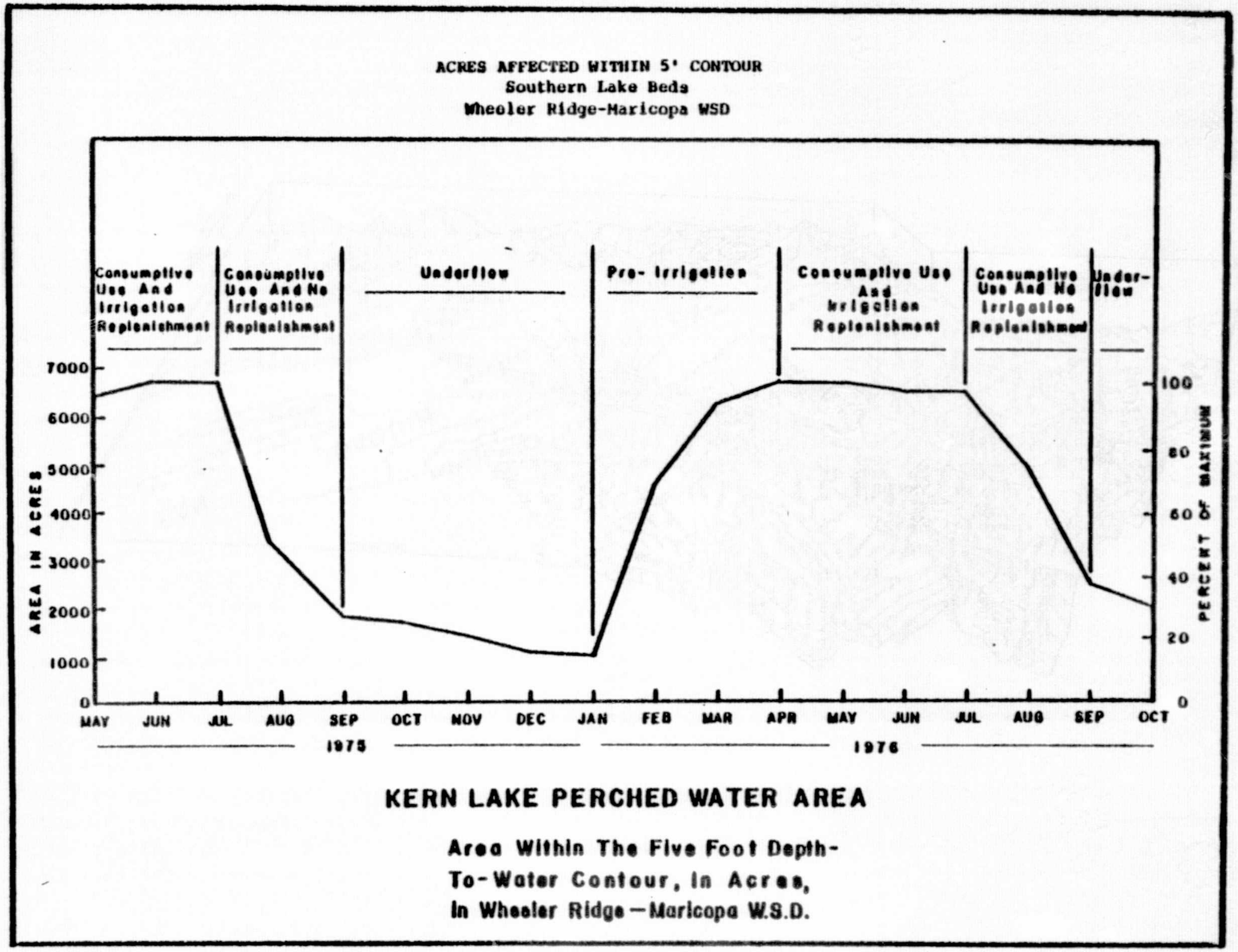


Figure 3-10. Kern Lake Perched Water Area Cycle (Kern County Water Agency, 1976).

applications, consumptive use, and underflow out of the problem area (Wheeler Ridge-Maricopa, 1976).

The effects of poor drainage on agricultural production can be extensive. Saturated upper profiles create tillage problems as well as an unsuitable environment for seedling germination. High water tables can affect actual crop growth in two principal ways: 1) through reduction of available root zone which causes root drowning; and 2) by the resultant increase in soil salinity. Soil salinization is the more widespread and serious consequence of perched water tables (Department of Water Resources, 1970). Taking into consideration that the salinity tolerance of crops depends on several factors, it is evident that growth inhibition and yield losses increase as salinity concentration increases. High salinity levels must be minimized to reduce growth inhibitation and yield losses; this often requires drainage programs to eliminate the major source of salt accumulations.

The total acreage in Kern County affected by perched water has increased significantly in recent years. An indication of the magnitude of this increase is shown by the comparison of data gathered by the California Department of Water Resources (1958-1963) and the Kern County Water Agency (1974-1976). During the thirteen years between surveys, the area with perched water within 5 feet of the surface increased from less than 180 acres (1963) to over 16,400 acres (1976). The total probably exceeds 22,000 acres today (Kern County Water Agency, 1976a). Crop yield reductions due to drainage problems will result in a substantial income loss to farmers, with some properties being removed from agricultural use as production becomes uneconomical. Annual damages in Kern County are estimated to increase from $2,655,000 in 1965 to $19,735,000 in 1985 and to $45,215,000 in 2005, assuming no type of project is initiated to control the problem (Kern County Water Agency, 1976a).

Shallow water tables need to be continuously monitored to detect expansions of the problem area. Historically, state and local agencies have laboriously gathered information concerning the extent and depth of perched water tables. During 1975 and 1976, the Kern County Water Agency in conjunction with Kern Delta Water District, Wheeler Ridge-Maricopa Water Storage District, and Arvin Edison Water Storage District, drilled and installed 140 piezometers in the Southern Lake bed area. This intensive grid of piezometers provide measurements of depth to water and electrical conductivity of water (KCWA, 1976b). From these measurements rough "depth to perched water" contours were constructed.

Within Kern County, jurisdiction for water resource management lies with the Kern County Water Agency (KCWA). It is responsible for the forecasting of water supply and demand on both a long and short-term basis, as well as being involved in the allocation and pricing of water to water districts within the county. KCWA needs timely and accurate perched water information to make groundwater basin management decisions. Their requirements are for both district wide and more localized information. One major management decision affected by perched water information in the location and extent of future drainage network systems. In addition, perched water information would also benefit the assessment of crop dollar damage. These economic impact assessments are necessary for cost/benefit evaluations of corrective measures.

Tile drainage is one method of water management which can be undertaken by the individual farmer, but proves more effective when utilized on a regional scale. This is the most commonly used method for correcting perched water table problems in California. Tile drains are advantageous in that they waste no land, do not interfere with farm operations, and require little care once installed. Although initially expensive they are economically feasible on a long-term basis (see Figure 3-11). Farm tile drainage systems have been effective in putting abandoned land in Kern County back into production. However, the current problem is of a magnitude and complexity which calls for a larger, regional collection and transmission system.

Both KCWA and the California Department of Water Resources are involved in a task force effort to develop a San Joaquin Valley Master Drain. These agencies are concerned that without a concerted effort at improving the quality of agricultural lands and water supplies in the San Joaquin Valley, agricultural productivity will be severely affected.

173

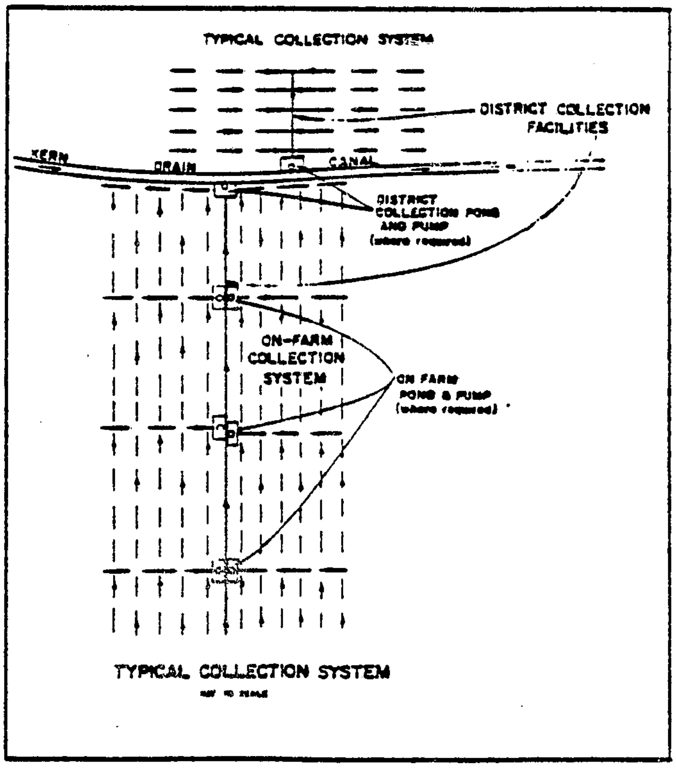


Figure 3-11. Typical Tile Drain Collection System (From Kern County Water Agency, 1976).

APPROACH AND RESULTS

Define User Information Requirements and Capabilities

A user information survey was developed to define requirements of perched water and salinity data for the folowing user groups:

1. Individual farmers
2. Local water districts
3. Kern County Water Agency
4. California Department of Water Resources

These groups encompass a wide range of user capabilities and information requirements. This diversity should enable the results of this project to be applicable to locations and user groups other than those in the Kern County study area.

Specific data requirements assessed include:

- type of data currently collected for the detection and monitoring of drainage problem areas.
- Area specificity, which will govern the spatial resolution and area coverage requirements of the system.
- Timeliness of the data, which will govern the temporal resolution requirements of the system.
- Quantitative or qualitative data characteristics, which will affect the accuracy requirements of the system.

We have developed a user needs survey designed for all levels of users (farmers, local water districts, KCWA, and California Department of Water Resources). The user is provided with a description of the remote sensing systems available for the detection of drainage problems (low altitude aerial photography, high altitude aerial photography, Landsat, thermal infrared, micrad and radar) and are given examples

175

of each type of imagery for a Kern County test site. Information concerning costs, availability, turn-around times, etc. is also provided. The survey questions are designed to provide us with a better understanding of the specific user information needs as well as user familiarity with the techniques of remote sensing.

Previous contacts with various user groups in Kern County facilitated cooperation. For the past five years, Kern County Water Agency has been the primary user of crop information derived from high altitude and satellite remote sensing imagery. A major use of this data has been as input to a groundbasin hydrologic model. Additionally, KCWA funded a thermal infrared flight in April 1978 for analysis of flooding conditions and cooperated in much of the supporting field data collection. Several Kern County water districts have benefited from our cropland mapping and have contributed in the collection of ground truth information for many of our projects. Local farmers have been made aware of research efforts in the Kern County area through contacts in the Kern County Water Agency and local water districts. Individual farmers in the Wheeler Ridge-Maricopa Water Storage district recently cooperated in the collection of ground truth data in conjunction with a microwave flight which was analyzed for its potential in soil moisture detection. These established contacts and existing working relationships with additional user groups provided an excellent base for accomplishing a complete assessment of drainage related information requirements and the potential of remote sensor systems to provide data relative to them.

Results from the user needs survey compiled thus far are summarized in Tables 3-10 and 3-11. Survey results from the California Department of Water Resources as well as individual farmers have not been received In general, it appears that remote sensing is viewed by the potential users as a useful and viable resource for monitoring perched water tables at different levels. However, actual implementation of remote sensing techniques has not significantly occurred to date. Lou Beck, director of the San Joaquin Valley Interagency Drainage Program has given support to on-going and future research in perched water studies using remote sensing. The potential exists for data to be obtained as input to the California Master Drain Plan decision making process.

TABLE 3-10

	ARVIN EDISON	WHEELER-RIDGE MARICOPA	KCWA	IDP
Types of data currently collected for detection and monitoring of drainage and salinity problem areas.	Piezometer wells measuring depth to water table.	Piezometer test wells for depth to water table and E. C. levels.	Field measurements & some Landsat imagery with 300M-transfer scope analysis.	Data collection by DWR and US Bureau of Reclamation.
Approximately how much is spent annually to detect/monitor perched water tables/salinity problem areas.	$5,000/year.	$2,500/year.	Two weeks field work Two weeks evaluation	DWR program.
How might you use remote sensing imagery in perched water table monitoring.	---	Dependent upon costs, availability and accuracy.	Crop damage and soil moisture determination.	Better definition of perched water table areas.
If you had imagery in house, would you make it available.	Possibly, district has limited staff.	Yes, to farmers in the district.	Yes.	Yes.
What type of training have you had in remote sensing.	None.	Landsat-C conference.	Photo interpretation; several seminars and "schools" on using remote sensing in this field.	None.
Would you attend training courses for application of remote sensing to perched water/salinity problem areas.	Possibly.	Yes.	Yes.	Yes.

TABLE 3-11

Question	Low Altitude Photography	High Altitude Photography	Thermal IR Imagery	Landsat Imagery	Micrad Imagery	Radar Imagery
Have you ever seen this type of imagery before?	1) No 2) Yes 3) Yes 4) No	1) No 2) Yes 3) Yes 4) No	1) No 2) Yes 3) Yes 4) No	1) No 2) Yes 3) Yes 4) No	1) No 2) No 3) No	1) No 2) No 3) No
Do you ever use this type of imagery? (Never, infrequently, frequently)	1) Never 2) Infrequently 3) Infrequently 4) Never	1) Never 2) Never 3) Infrequently 4) Never	1) Never 2) Never 3) Infrequently 4) Never	1) Never 2) Never 3) Frequently 4) Never	1) Never 2) Never 3) Never 4) Never	1) Never 2) Never 3) Never 4) Never
If there was economical, timely, imagery available would you use it? (Yes, no)	1) Possibly 3) Yes 4) Yes	1) Possibly 3) Yes	1) Possibly	1) Possibly 3) Yes	1) Possibly	1) Possibly
How specific an area would you need coverage of (per field, local, regional)	1) District wide 3) Local 4) Would like to identify changes within each section	1) District wide 3) Local	1) District wide	1) District wide 3) Local	1) District wide	1) District wide
How often would you need imagery coverage? (Daily, weekly, monthly, annually)	1) Annually 4) 3 times a year - pregrowing season, mid-growing season, and after harvest.	1) Annually	1) Annually	1) Annually 3) Annually	1) Annually	1) Annually

1) Arvin-Edison Water Storage District
2) Wheeler Ridge-Maricopa Water Storage District
3) Kern County Water Agency
4) Interagency Drainage Program

179

SAN JOAQUIN VALLEY
INTERAGENCY DRAINAGE PROGRAM
1490 W. SHAW AVENUE
SUITE F
FRESNO, CALIFORNIA 93711

TELEPHONE (209) 488-5681

April 20, 1979

FIGURE 3-12

Ms. Elaine Ezra
Geography Remote Sensing Unit
University of California
Santa Barbara, CA 93106

Dear Ms. Ezra:

Enclosed is your questionnaire on users needs for remote sensing of perched water tables.

You can see that I've never used remote sensing, but from your report I can see a lot of potential and promise. I think that remote sensing could provide an accurate definition of the drainage problem areas in the San Joaquin Valley. In addition, seasonal variations and annual changes could be determined.

I would like to be informed of your further efforts in remote sensing of perched water tables.

Sincerely yours,

L A Beck

L. A. Beck
Director

LAB:lv

Enclosure

Figure 3-12

SPONSORS
CALIFORNIA STATE DEPARTMENT OF WATER RESOURCES
UNITED STATES BUREAU OF RECLAMATION
CALIFORNIA STATE WATER RESOURCES CONTROL BOARD

WASTE WATER MANAGEMENT

Assessing Remote Sensing Systems

Information obtained from previous research was used to assess the operational utility of various remote sensing systems to specific perched water and salinity information requirements. Specific system characteristics being considered include:

- Availability of the data in terms of:
    1. turn around time from flight to user image acquisition
    2. costs associated with obtaining imagery
    3. present development and future availability.
- Applicability of the data in terms of:
    1. spatial resolution
    2. relationship of spectral qualities to perched water
    3. use of surrogates such as crop damage in detecting perched drainage problems.

The sensors evaluated are:

1. Aerial photography
2. Landsat
3. Thermal infrared
4. Passive microwave (micrad)
5. Active microwave (radar)

The compilation of a table illustrating the availability and applicability of the data for the following sensors: aerial photography, Landsat, thermal infrared, passive microwave, active microwave has been designed (see Table 3-12 and 3-13). Information concerning the individual systems capabilities and constrains will aid in identifying feasible techniques for the individual user. Many of the sensor systems

181

TABLE 3-12

TYPICAL REMOTE SENSING SYSTEM CHARACTERISTICS

CHARACTERISTICS \ SYSTEMS	LOW ALTITUDE PHOTOGRAPHY	HIGH ALTITUDE PHOTOGRAPHY	LANDSAT	THERMAL	MICRAD	RADAR
GENERAL USER AVAILABILITY	EXCELLENT	GOOD	EXCELLENT	GOOD CONTRACTUAL	LIMITED EXPERIMENTAL	VERY LIMITED CONTRACTUAL
PLATFORM	COMMERCIALLY AVAILABLE LIGHT AIRCRAFT	NASA U-2 AIRCRAFT	LANDSATS 2 and 3	AIRCRAFT/ EXPERIMENTAL SATELLITE	AIRCRAFT/ EXPERIMENTAL SATELLITE	AIRCRAFT/ EXPERIMENTAL SATELLITE
SOURCES OF IMAGERY	PRIVATE	NASA/EROS	NASA/EROS	PRIVATE/ CONTRACTUAL	NASA EXPERIMENT	NASA EXPERIMENT
COSTS ASSOCIATED WITH OBTAINING IMAGERY	$50-75 total	$15/frame	$10-15/ frame	CONTRACTUAL	CONTRACTUAL	CONTRACTUAL
FREQUENCY OF COVERAGE	EXCELLENT CONTRACTUAL	LIMITED CONTRACTUAL	GOOD EVERY 9 DAYS	LIMITED CONTRACTUAL	VERY LIMITED EXPERIMENTAL	VERY LIMITED EXPERIMENTAL
TURN AROUND TIME	1-4 days	1 week	30 days Rush: 5 days	1 week	1-3 months	1-3 months
SPATIAL RESOLUTION	0.1-3m	.6-20m	80m MSS 40 m RBV	1.0 mr	10 mr	2-10 mr real aperture 0.2-1 mr synthetic
DAY/NIGHT CAPABILITY	DAY ONLY	DAY ONLY	DAY ONLY	DAY/NIGHT	DAY/NIGHT	DAY/NIGHT
ATMOSPHERIC PENETRATION	HAZE	HAZE	HAZE SMOKE	HAZE SMOKE	HAZE SMOKE FOG	HAZE SMOKE FOG
REAL TIME CAPABILITY+	GENERALLY NO	GENERALLY NO	GENERALLY NO	YES	YES	POTENTIAL EXISTS

TABLE 3-13

SYSTEMS / CHARACTERISTICS	LOW ALTITUDE PHOTOGRAPHY	HIGH ALTITUDE PHOTOGRAPHY	LANDSAT	THERMAL	MICRAD	RADAR
GEOMETRIC RECTIFICATION *	EXCELLENT	EXCELLENT	EXCELLENT	GOOD	POOR/FAIR	FAIR
SPATIAL PERSPECTIVE	PER FIELD	PER FIELD-REGIONAL	REGIONAL	PER FIELD-REGIONAL	PER FIELD-REGIONAL	PER FIELD-REGIONAL
WAVELENGTH RANGE	0.4-0.7µm	0.4-0.7µm	.4-1.1µm	.78-1000µm	.1mm-3cm	.83-133 cm
PHYSICAL BASIS FOR DETECTION	REFLECTANCE OF VISIBLE WAVELENGTHS	REFLECTANCE OF VISIBLE WAVELENGTHS	REFLECTANCE OF NARROW SPECTRAL BANDS; GREEN, RED AND PHOTOGRAPHIC IR	TEMPERATURE EMISSIVITY	EMISSIVITY DIELECTRIC CONSTANT	REFLECTANCE DIELECTRIC CONSTANT
DEPTH OF PENETRATION	SURFACE (less than a micron)	SURFACE	SURFACE	SURFACE SUBSURFACE TEMPERATURE EFFECTS	1-5 cm	1-5 cm
FUTURE			LANDSAT D	HCMM LANDSAT D SHUTTLE	SHUTTLE	SHUTTLE SEASAT

+ real time capability- ability to evaluate a sensor system's output as the original information is acquired

* geometric rectification- the potential for planimetric mapping

mm = millimeters 1" = 25.4 mm
cm = centimeters 1" = 2.54 cm
m = meters 1" = .025 m
mr = milliradians

182

are currently at the experimental state, and are not practical for operational use at the present time; in some of these cases, however, the future looks very promising for operational implementation as satellite systems are improved.

Landsat Techniques

A recent study conducted by our group and entitled "Detection of Perched Water Tables Using Remote Sensing: A Pilot Study" (Estes, et al., 1978) examined a variety of remote sensing systems (aerial photography, Landsat, thermal infrared, micrad and radar) and their technical feasibility for detecting perched water tables. Electromagnetic radiation within the spectral regions of the remote sensing systems used in the study (0.4 μm to 23 cm) does not directly interact with soils to depths that are of significant concern to perched water table monitoring programs (5-10 feet). It is possible to sense reflected or emitted energy from only surface or extremely near surface (approximately 5 cm) soils. Therefore, if remote sensing techniques are to be used, indirect or surrogate measures indicative of the deeper (>5 cm) perched water tables must be relied upon. For bare soil conditions, soil salinity, moisture, and temperature anomolies associated with shallow water tables are potential indicators because the physical, chemical, and electromagnetic properties of water and salts are significantly different from those of dry soil.

For vegetated conditions the remote detection of perched water tables is based upon the conditions of the crop canopy. Plants are frequently good indicators of subsurface soil conditions. The root systems of plants explore a rather large soil volume and are therefore often more representative of site conditions than standard soil samples. Landsat multispectral analysis techniques have demonstrated an ability for detecting these bare soil and vegetated surrogate indicators of drainage problems, and warrant further research.

Two Landsat techniques investigated for this project include:

1. Multidate color compositing of Landsat imagery for enhancing drainage conditions.

2. Assessment of the reflectance differences in perched compared to non-perched cotton fields using biomass ratios and linear transformations.

Multidate Color Composites

An optical color combiner, such as the I^{2}S Addcol used by our group, utilizes black and white multiband imagery and functions by using the "additive color" theory. Multispectral photographs and images taken simultaneously, combined in registration, and colored via filters can provide a high resolution composite image. By varying color, density and hue, the observer can detect subtleties normally undetected by the human eye.

The procedure similar to that used to create standard single date color composites may also be used with a single band from 3 different dates of Landsat imagery to create a multidate color composite. By not constraining the input channels to multispectral images from one date, various changes between dates may be enhanced. By proper date and band selection, this procedure can enhance the contrast between drainage problem areas and dry soil conditions in general and accentuate any

185

apparent variations in soil moisture conditions between the dates; vegetation stress areas can also be enhanced in this manner. Three dates of Landsat imagery have been obtained from a flooding period in 1977-1978 affording an excellent opportunity for experiments to determine if differential drainage can be detected using this technique.

Perched water tables are known to fluctuate on a seasonal and annual basis. The multidate color composite concept allows examination of variations between monthly, seasonal, as well as different years of imagery. Dates from 1976-1978 Landsat overpasses have been selected, with a single band from each date registered and combined to form a multidate color composite. Minor problems are encountered in registering three bands of Landsat imagery from different dates, due to minute scale variations.

During late 1977 and early 1978, extremely heavy precipitation in the Southern San Joaquin Valley caused a severe flooding problem (see Figure 3-13). Multidate composites were created to assess the variable drainage of this flooding using December 16, 1977, February 8, 1978, and May 19, 1978. Within the seasonal perched water cycle, December has the lowest levels, February is a period of rapid buildup, and May has peak perched water levels. Using this combination of dates, comparative color composites were created using MSS bands 5 and 7. Indicators of perched water areas include: salinity accumulations, riparian vegetation, vegetation stress/damage and standing water.

Analysis of the MSS 5 composite shows enhancement of drainage patterns and saline accumulations. In contrast, the MSS 7 composite emphsizes areas of riparian vegetation and crop stress/damage.

Annual fluctuations of perched water tables facilitated the selection of a three year sequence (1976-1978) of Landsat overpasses for the months of February and May using MSS band 7.

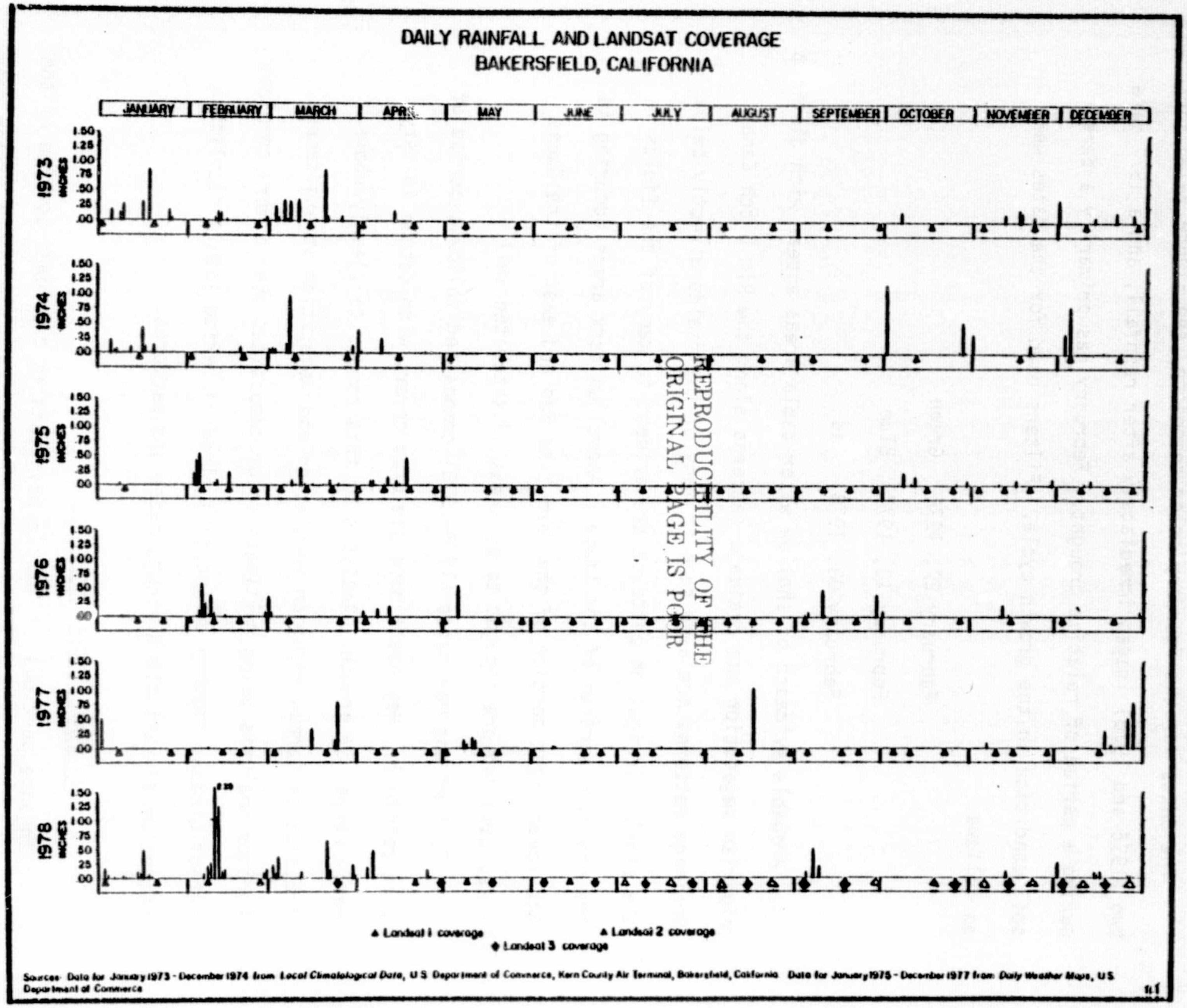


Figure 3-13. Daily Rainfall and Landsat Coverage, Bakersfield, California.

187

The dates for the February color composite (see Figure 3-14) included two (1976 and 1978) imaged immediately after rainfall, and a 1977 date during a period of relative drought. February has primarily a bare soil condition in the growth cycle. Filters used for the dates were as follows:

February 27, 1976	Green
February 13, 1977	Blue
February 08, 1978	Red

Probable evidence of shallow water table areas appear with distinct riparian vegetation and drainage patterns along the Rim Ditch Canal. Drainage patterns are also seen in many of the fields directly below the canal. Irrigation patterns are evident in many of the fields in the southern portion of the image. Anomalous dark areas occuring in the lower right portion of the Kern Lake Bed and east of the Buena Vista Lake Bed are thought to be areas of saturated soil.

Each of the May dates (1976-1978) composited follow a period of some rainfall. May has a moderate crop cover, with cotton in very early stages of growth. Analysis of this composite clearly shows drainage patterns, riparian vegetation and vegetation stress/damage. Further analysis using multidate color composites over a more complete set of Landsat imagery during this flooding period should facilitate detection of variable drainage rates and patterns.

Digital Transformations

In some portions of Kern County, such as the lower portion of the San Joaquin Valley floor, cotton is the predominant crop (greater than

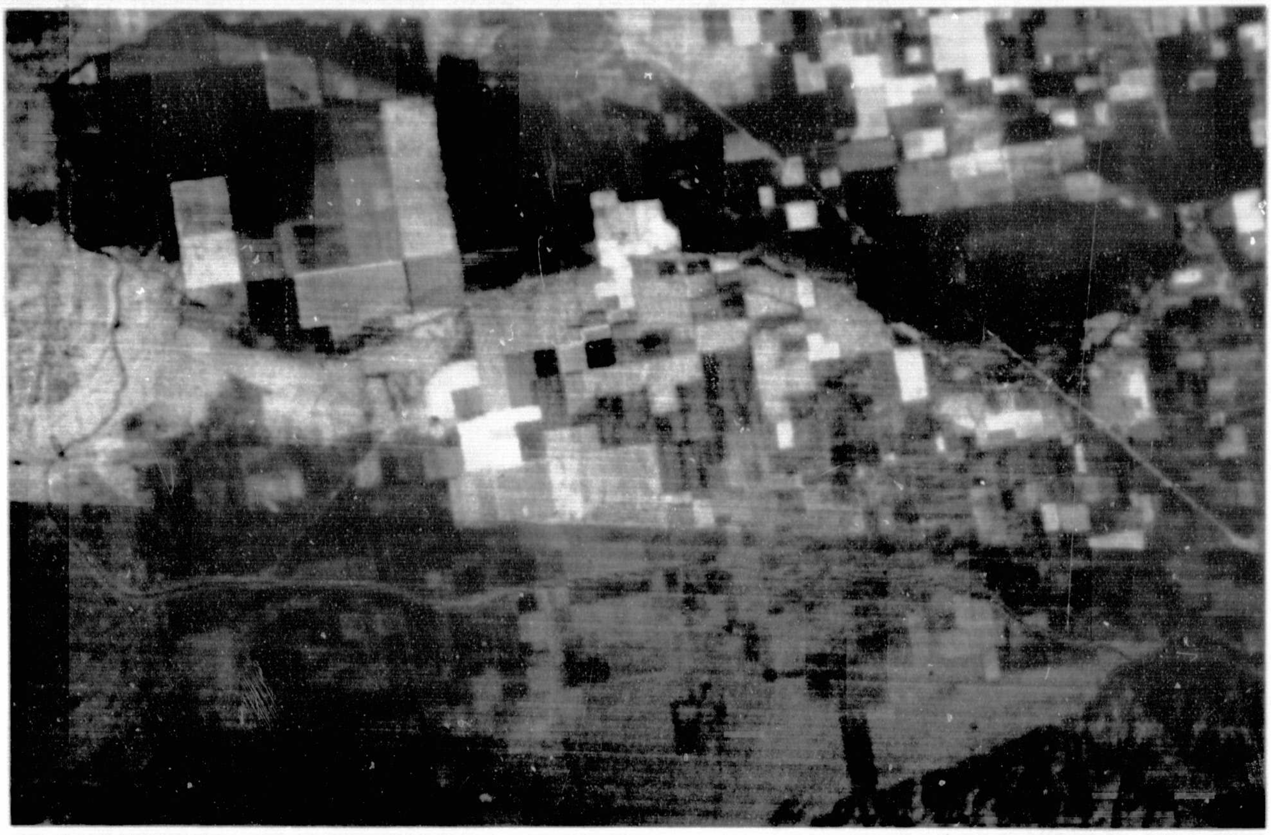


Figure 3-14. Multidate Landsat color composite of three dates; February 27, 1976, February 13, 1977, and February 08, 1978.

50% in Wheeler Ridge-Maricopa Water Storage District). Therefore, a crop specific monitoring program might be possible for assessing soil moisture and salinity impacts. Spectral reflectances are expected to differ between cotton fields grown in perched water table areas and cotton fields in non-perched areas. Vegetation stress/damage should reduce the spectal signature characteristics of the perched area cotton fields. Application of different biomass ratios and various transformations may enhance these reflectance differences. These manipulations are accomplished using an interactive minicomputer system implementing basic image processing programs.

To measure spectral reflectance differences between cotton fields in perched areas as compared to non-perched areas, we used the BASIC-Plus digital image processing system implemented at the University of California, Santa Barbara. Depth to water table measurements taken in July, 1976 by the Wheeler Ridge-Maricopa Water Storage District from test wells, and crop identification maps compiled by the Kern County Water Agency, enabled us to select cotton fields in perched water table areas (<5' depth to water table), and in non-perched areas (>20' depth to water tables). Each of the nineteen fields selected was of a uniform size (36 pixels on the July 1976 Landsat image). The BASIC-Plus program calculated a mean spectral reflectance value per field, as well as the standard deviation, and minimum and maximum pixel reflectance values for each channel. (Table 3-14).

TABLE 3-14

STATISTICS	FIELD NUMBER																		
CH 1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Mean	57.5	52.5	56	55.5	60	61	64.5	54.5	59.5	54.5	56	56	56	58	60.5	63	58.5	59	57.5
St. Dev.	4.5	3	1,5	3	4.5	3.5	3.5	3	2	1	4	2	1.5	3	4.5	5	3	6	3
Min.	52	47	52.5	51.5	52.5	56	58	50	54.5	51.5	50	52.5	53.5	53.5	55	57	53	54	53
Max.	72	64	60	64.5	71.5	73.5	73.5	60.5	63	57.5	67	60.5	59.5	67.5	72.5	78.5	68.5	73.5	65.5
CH 2																			
Mean	42.5	34.5	35	39.5	43.5	45	47.5	39.5	45.5	40	42.5	37.5	36	40.5	45.5	48.5	42.5	43	40
St. Dev.	7	4	3	4.5	6	4.5	6	5.5	3.5	2	6	3	2	4.5	7	8	4.5	9	3.5
Min.	34	31	32,5	32.5	34.5	38.5	39	30.5	37	35	34	32.5	32.5	34.5	37.5	36.5	35	36.5	35
Max.	44	52.5	47,5	53	54.5	56.5	65	51	50	44	62.5	47.5	42	53	65.5	71	53.5	69	50.5
CH 3																			
Mean	117	124	125	121.5	127	127.5	126.5	125.5	123	116	108.5	127.5	127.5	127	126	125	127	126.5	127
St. Dev.	4.5	4	3	4	.5	0	1.5	2	3	3.5	6	0	0	.2	3	3	.5	1.5	.5
Min.	108.5	108	110.5	109.5	124	127.5	121	117.5	115.5	110.5	95	127.5	127.5	126.5	113	115	125	121	124.5
Max.	125	127.5	127.5	126.5	127.5	127.5	127.5	127.5	127.5	125.5	122	127.5	127.5	127.5	127.5	127.5	127.5	127.5	127.5
CH 4																			
Mean	117	126	126	124.5	127	127.5	126	127	123	120.5	109.5	127.5	127.5	127	125.5	123.5	127	126	127.5
St. Dev.	7.5	2.5	3	3	1	0	3.5	1.5	4	3	8	0	0	.15	4.5	5	.2	4	0
Min.	100	116.5	115.5	117	123	127.5	112.5	119.5	112.5	115	86.5	127.5	127.5	127	106	109	126.5	113.5	127.5
Max.	127.5	127.5	127.5	127.5	127.5	127.5	127.5	127.5	127.5	125	123	127.5	127.5	127.5	127.5	127.5	127.5	127.5	127.5

191

It is expected that cotton fields in perched water table areas would have lower spectal reflectance values due to decreased leaf area index (LAI - the ratio of leaf area to soil area). A decrease in the LAI is expected with crop damage occurring in shallow water table areas with resultant root drowning and salinity effects. Healthy, leafy and densely spaced cotton fields will have a higher spectral reflectance than a less healthy, sparser cotton crop canopy. Studies have also shown that cotton crops in saline areas have decreased reflectance. Landsat imagery, which contains bands sensitive in the near infrared wavelengths, emphasizes the infrared reflectance of healthy green vegetation, which appears as bright red on standard color composite imagery. Cotton plants affected by salinity appear as darker shades of red, and, when seriously affected, very dark. White areas on the image are usually accumulations of salt on bare soil surface areas (see Figure 3-15). As illustrated in Table 3-15, for Channels 1 and 2, perched cotton fields have lower reflectance values than non-perched cotton fields. Channels 3 and 4 show some confusion between perched and probable perched fields with non-perched cotton fields. Both bare soil and vegetation are highly reflective in these two bands causing poor discrimination between vegetation condition and soil background noise.

In general, it appears that individual per channel reflectance values indicate trends of lower reflectance in perched fields, however, do not give complete enough information for confident discrimination between healthy and stressed or damaged vegetation.

Establishment of an apparent trend in distinguishing between perched

192

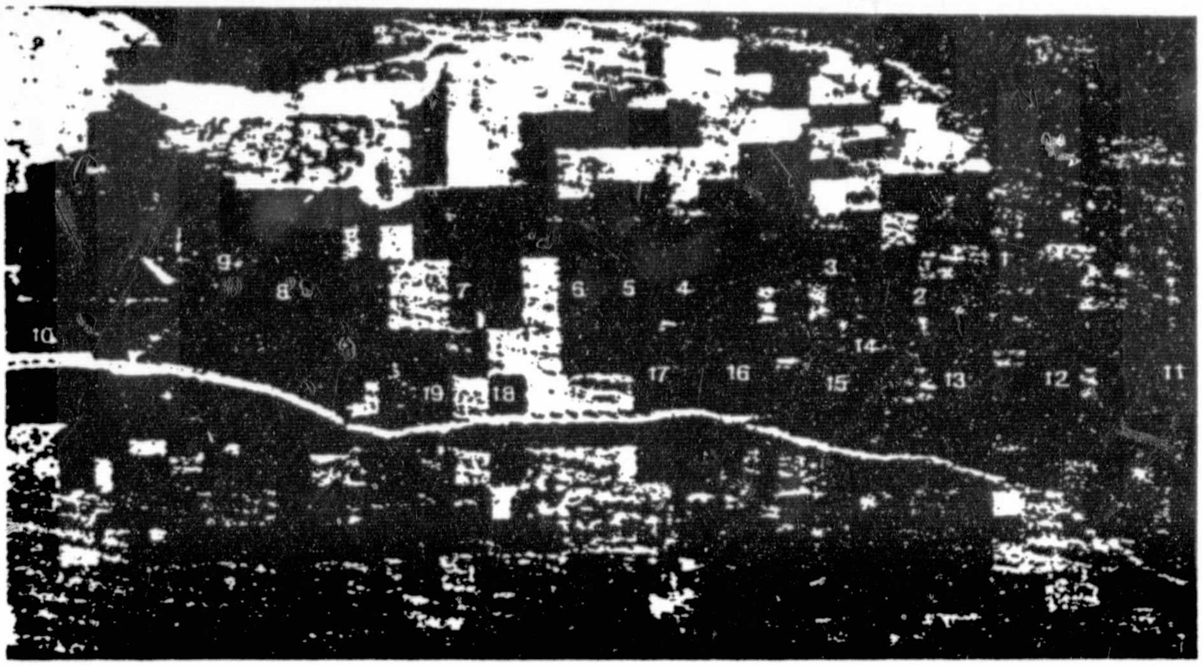
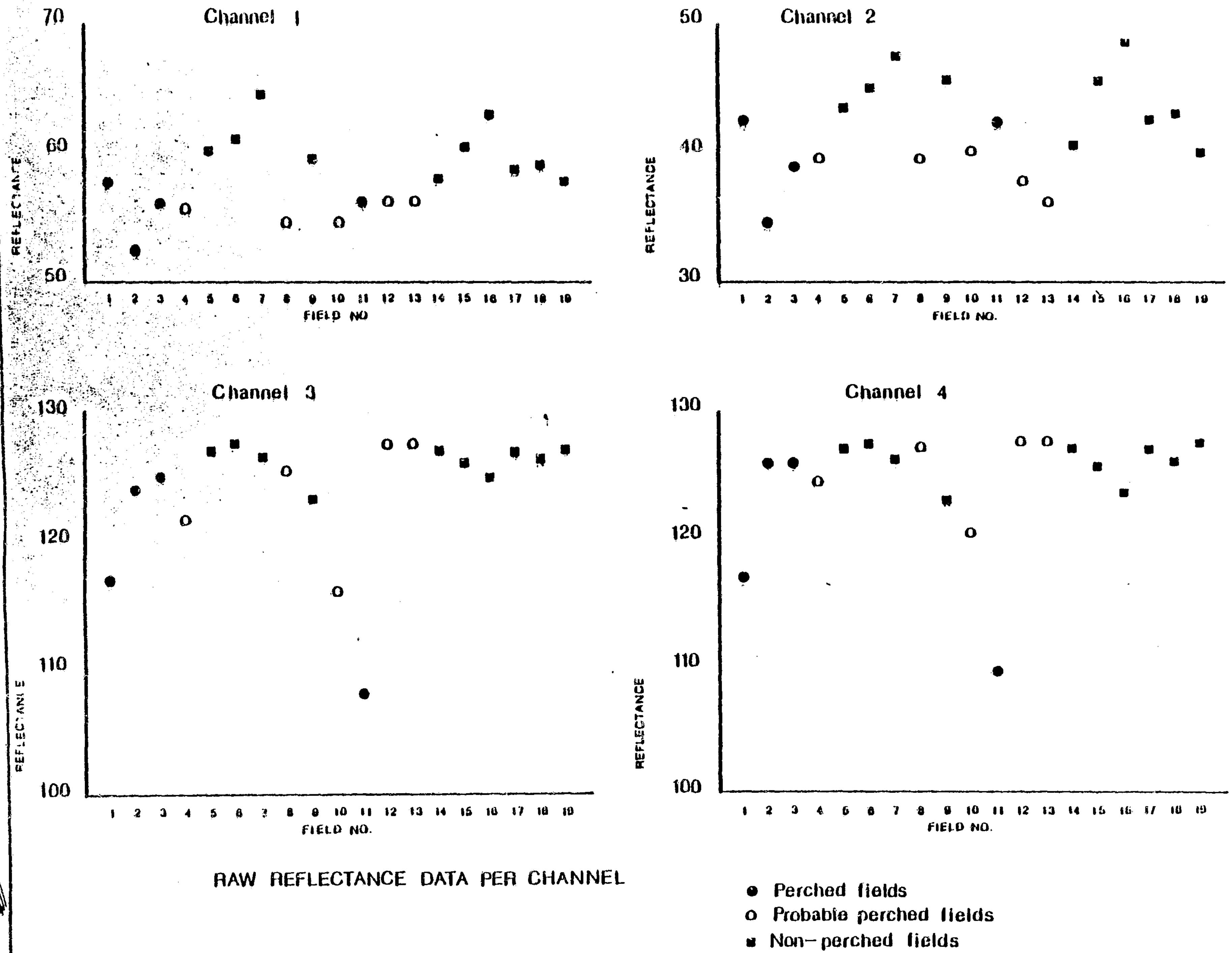


Figure 3-15. Color composite Landsat image, obtained June 1976; scale as shown approximately 1:320,000. Areas marked af fields 1 and 2 are cotton fields in perched water table areas; fields 3 and 4 are cotton fields in non-perched water table areas.



RAW REFLECTANCE DATA PER CHANNEL

TABLE 3-15

cotton field reflectances and non-perched cotton field reflectances facilitated efforts in further enhancement using ratioing techniques. The preprocessing BASIC-Plus program allows division of the reflectance value of a pixel in one channel by the reflectance value of another channel. The two ratios used were:

$$\frac{CH4 - CH2}{CH4 + CH2} \qquad \text{Vegetation Index (VI)}$$

$$\frac{CH4 - CH2}{CH4 + CH2} + .5 \quad 1/2 \qquad \text{(Transformed Vegetation Index (TVI)}$$

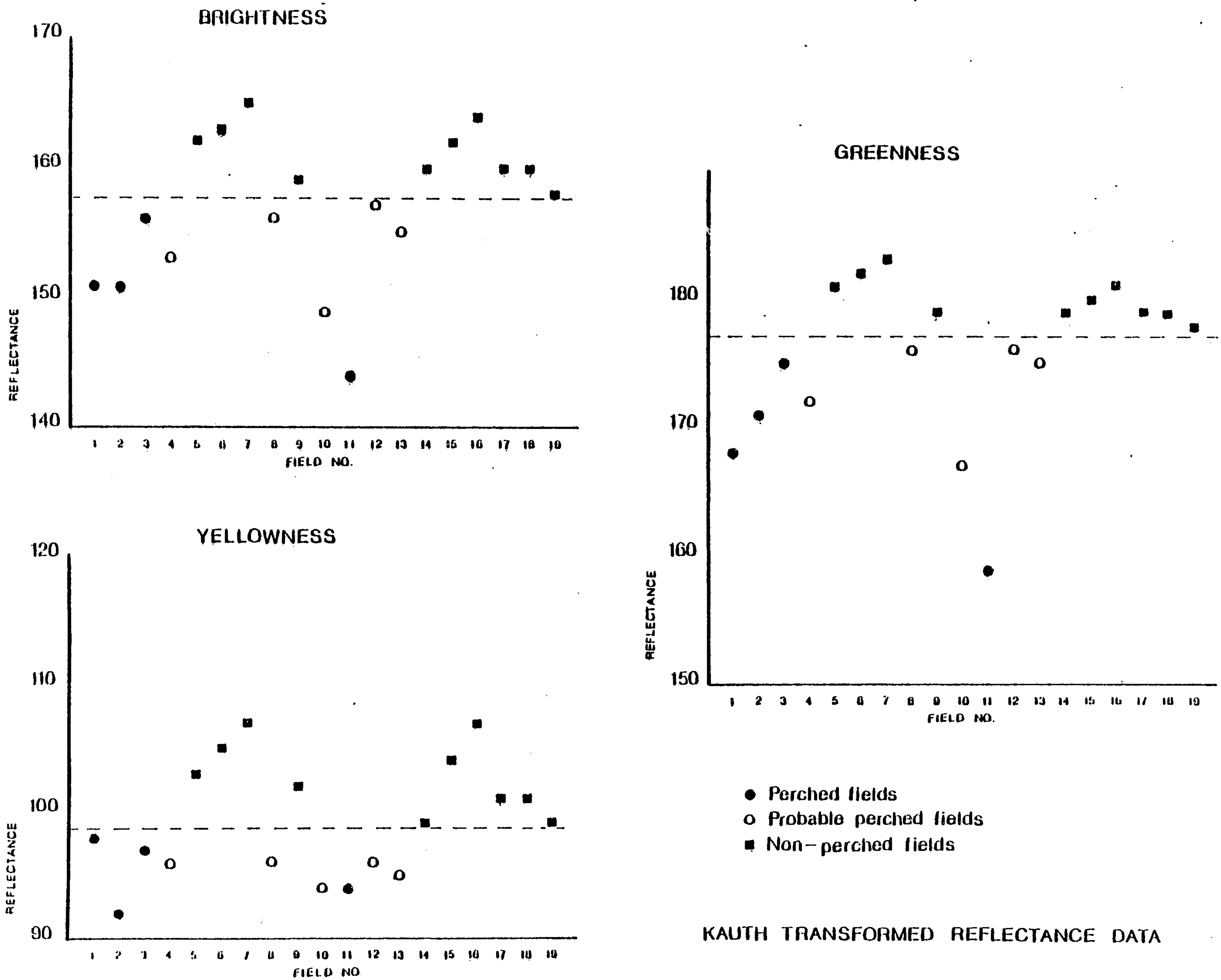
These two ratios are commonly used to enhance vegetation. As shown in Table 3-16 results did not show any discrimination between perched and non-perched cotton fields. The lack of rasults using these ratios may be due to the tandency of the CH4/CH2 ratio to normalize or compensate for variable amounts of bare soil for a given range of biomass, thereby negating the effects of differences in crop canopy cover experiencing damage or stress.

Further efforts to enhance Landsat reflectance differences between cotton fields in perched and non-perched areas utilized a linear pre-processing transformation relating Landsat variables to crop development and background variables (Kauth, 1976). The three background variables used for this study were "brightness," "greeness," and "yellowness." The brightness variable is related to soil color. Greeness is related to the vegetative development of a canopy, yellowness is related to yellow development. The implementation of the following "Kauth Landsat Agricultural Matrix" for the July 1976 Landsat image resulted in values shown in Table 3-16 , and is graphically shown in Table 3-17 .

C-3

	FIELD NUMBER																		
STATISTICS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Brightness																			
Mean	151	151	156	153	162	163	165	156	159	149	144	157	155	160	162	164	160	160	158
St. Dev.	5	4	2	4	6	4	4	5	2	3	4	3	2	4	5	5	4	6	3
Min.	143	139	152	145	153	157	159	149	155	142	137	152	152	154	156	156	154	154	154
Max.	167	163	159	164	173	176	175	166	163	154	151	165	160	171	175	181	172	176	168
Greenness																			
Mean	168	171	175	172	181	182	183	176	179	167	159	176	175	179	180	181	179	179	178
St. Dev.	5	4	2	3	4	4	3	4	3	3	5	2	2	3	4	3	3	4	3
Min.	159	159	169	162	174	177	178	168	174	159	153	173	173	174	173	176	174	174	174
Max.	181	180	178	180	189	192	188	184	188	174	169	183	179	188	189	192	189	189	185
Yellowness																			
Mean	98	92	97	96	103	105	107	96	102	94	94	96	95	99	104	107	101	101	99
St. Dev.	6	4	3	4	7	5	6	5	3	2	5	3	2	5	6	8	4	9	4
Min.	89	87	91	89	93	97	99	88	95	91	87	91	92	93	95	96	93	94	93
Max.	118	108	103	108	117	121	123	107	106	99	109	105	100	114	123	129	115	125	110
Vegetation Index																			
Mean	.465	.570	.525	.513	.493	.478	.435	.528	.478	.502	.450	.546	.560	.512	.469	.436	.503	.495	.522
St. Dev.	.084	.045	.034	.051	.053	.038	.062	.054	.043	.027	.087	.027	.021	.393	.069	.088	.042	.089	.034
Min.	.219	.387	.434	.389	.391	.386	.291	.425	.385	.455	.161	.457	.504	.411	.277	.226	.409	.244	.433
Max.	.573	.609	.534	.594	.574	.536	.531	.614	.550	.556	.563	.594	.594	.569	.545	.555	.569	.555	.569
Transformed Vegetation Index																			
Mean	.982	1.033	1.012	1.008	.996	.989	.956	1.013	.978	1.001	.973	1.022	1.029	1.006	.984	.966	1.001	.996	1.011
St. Dev.	.046	.022	.017	.025	.027	.019	.032	.026	.021	.013	.049	.013	.010	.019	.036	.046	.021	.048	.017
Min.	.848	.942	.967	.943	.944	.941	.889	.962	.940	.977	.813	.978	1.002	.954	.881	.852	.953	.862	.966
Max	1.036	1.053	1.046	1.045	1.036	1.018	1.016	1.055	1.025	1.027	1.066	1.045	1.046	1.034	1.022	1.027	1.034	1.027	1.034

TABLE 3-16



KAUTH TRANSFORMED REFLECTANCE DATA

Kauth Landsat Agricultural Matrix

		MSS 4	MSS 5	MSS 6	MSS 7	
Brightness	=	0.43258	0.63248	0.58572	0.26414	CH1
Greeness	=	-.28972	.56199	.59953	.49070	CH2
Yellowness	=	-.82418	.53290	-.05018	.18502	CH3

Brightness = Sum of channels

Greeness = IR minus green

Yellowness = Red minus green

Results of this transformation indicate a trend of differences in reflectance between perched and non-perched cotton fields. As expected, the brightness, greeness, and yellowness reflectance values are lower in the perched cotton fields as compared to non-perched fields.

Many ratio techniques use only two of the Landsat spectral channels. Due to the high correlation between channels 1 and 2 and channels 3 and 4, the assumption is that little information would be lost by throwing out channel 1 and 3. However, there appears to be significant information contained in the combination of the four channels, as demonstrated by the Kauth transform.

<u>Thermal</u>

Whereas visible and near infrared reflectance is essentially a surface property, the amount of thermal infrared radiation emitted from a soil is influenced by subsurface conditions to significant depths. Therefore, thermal infrared imagery provides a unique opportunity for the remote sensing of soil moisture and subsurface water table conditions. In our previous research, we noted two approaches indicative of subsurface conditions: surface temperature anomalies and vegetative condition.

Dynamic thermal changes within soil profiles greatly strengthen the opportunity for thermal infrared remote sensing of shallow water tables. As soil water content increases, the amplitude of the surface temperatures wave becomes smaller (the difference between maximum and minimum temperatures decreases). This can result in a diurnal surface anomaly whereby shallow water table areas appear warmer at night and cooler during the day than surrounding non-perched areas on thermal imagery.

In addition to diurnal cycles, heat fluxes also include seasonal and annual opportunities for detecting variation. In our analysis of temperature profile data acquired in conjunction with an April thermal infrared overflight, we estimated the diurnal damping depth at 75 cm (≈3.5 ft.) for our test site, thus necessitating use of seasonal or annual fluctuations. Other research estimates that in temperate latitudes the diurnal amplitude becomes zero at about 75 cm and that of the annual variation at about 12 meters (National Academy of Sciences, 1970).

Thermal infrared imagery has been shown to have some utility in assessing crop stress conditions. The presence of vegetative cover is a factor that significantly affects soil temperature. A crop canopy acts as an attenuator of soil emission and adds its own emission component as well. The parameters of this relationship are crop type and crop stage dependent, thus making it more difficult to evaluate than bare soil techniques.

Kern County Water Agency, in conjunction with the Geography Remote Sensing Unit (GRSU), provided for a thermal overflight of the Kern County Study area on April 13, 1978 at altitudes of 1,000 feet and 6,000 feet above terrain.

Concurrent with the aircraft thermal image acquisition, both field data and lower altitude oblique photography was obtained. Soil moisture and soil temperature profile data was collected prior and simultaneous to the overflight. A soil temperature profile recorder was also monitored to examine the diurnal temperature wave and allow an estimate of damping depth. Personnel of the Wheeler Ridge-Maricopa Water Storage District sampled several of their shallow water table monitoring wells to document subsurface perched water conditions.

Analysis of the thermal imagery yielded a general concurrence between a known shallow water table area and a large thermal anomaly that appears warmer than surrounding areas. However, difficulty arose with further analysis due to the limited number of test wells to verify depths to water table. Additionally, effects from seasonal or annual fluctuations could not be accounted for because of the short time span of our soil moisture and temperature profile data collections.

Kern County Water Agency is prepared to drill and monitor test wells at locations of our specification. From analysis of both Landsat and the thermal infrared imagery we plan to establish test wells in probable problem areas. This will serve two-fold purpose: 1) to verify our predictive capabilities for identifying perched water problem areas, and; 2) give us more complete depth to water table data.

Additional research to quantify the diurnal, seasonal, and annual cycles of subsurface thermal characteristics in this region and integrate this with optimal crop stage conditions will be facilitated by the insertion and monitoring of thermistor probes at different depths within the soil profile (6 inches, 1 foot, 3 foot depths), over an annual cropping cycle within perched and non-perched areas. Cooperation with KCWA and/or Wheeler Ridge-Maricopa Water Storage District personnel is anticipated.

The acquisition of depth to water table and temperature profile data will allow a more complete understanding of perched water table fluctuations and dynamics as compared to non-perched areas. Analyses that are more quantitatively oriented will incorporate these data and eventually improve the utility of thermal imagery.

261

SUMMARY

Kern County, California is a prime example of an area affected by high water tables and excessive soil salinity. Detection and monitoring of perched water tables is of considerable interest to several user groups in the southern San Joaquin Valley; conventional techniques for gathering perched water table data, however, involve costly and time consuming ground sampling procedures. By combining surface sampling procedures with the results derived from analysis of remotely sensed data, more cost-effective, timely and accurate methodologies are possible. In order to devise practical methodologies applicable to specific users, it is necessary to determine the user's information requirements. We have developed a user needs survey to define the cost, accuracy, frequency, timeliness, and other requirements of the individual farmers in the area, local water districts, Kern County Water Agency, and the California State Department of Water Resources.

Specific research and results of this study are as follows:

- Remote sensing system parameters for aerial photography, Landsat, thermal infrared, micrad and radar were compiled for a convenient assessment of system availability, costs, accuracy, turn around time, and application to the detection of perched water tables. Presently, the most feasible system for most users appears to be aerial photography and Landsat imagery because of their excellent availability. Present techniques using thermal infrared, micrad and radar are primarily in the experimental stage, or are prohibitive due to excessive costs. However, they do appear to be the most diagnostic techniques in the detection of perched water tables and may become feasible as image availability increases.
- Landsat multidate color composites using 1976-1978 dates were created to assess seasonal and annual perched water indicators.

Excessive precipitation in late 1977 and early 1978 caused tremendous flooding problems in the Kern County area. Combinations of December 1977, February 1978, and May 1978 using bands 5 and 7 enhanced indicators of perched water tables (riparian vegetation, salinity accumulations, crop stress/damage). Annual fluctuations were assessed for February 1976-1978 and May 1976-1978 using band 7. Additional multidate composite analysis using Landsat images throughout the flooding period should provide ideal conditions for assessing variable drainage between perched and non-perched water table areas.

- Spectral reflectance differences between cotton fields grown in perched water table areas as compared to non-perched cotton fields were assessed. Average reflectances values for each of the four Landsat CCT channels were digitally computed, and were found to correspond with expected results. Perched cotton fields generally had lower reflectances in all channels. Two separate biomass ratios (CH4 - CH2/CH4 + CH2) and $((CH4^2 - CH2^2)/CH4^2 + CH2^2) + .5)1/2$ were calculated but did not allow perched/non-perched discrimination. A linear transformation using Kauth Landsat Agricultural Matrix values was computed for values of brightness (soil color) and greeness (vegetation color) and yellowness (vegetative color). Each of these variables resulted in lower reflectance values for the perched cotton fields. Preliminary results indicate the potential for discrimination of crops grown in perched water table areas based upon differences in reflectance from healthy crop cover.

- Thermal infrared imagery has been found to have unique potential in detection of perched water tables. Perched water tables fluctuate diurnally, seasonally, and annually with resultant changes in the thermal profiles. In order to more accurately assess and analyze thermal infrared imagery, a better understanding of the thermal dynamics of perched compared to non-perched water table is necessary. Kern County Water Agency is prepared to drill depth to water table test wells in suspected perched areas where there is no current data available. Additionally, thermal thermistor probes will be implanted and monitored over an annual cropping cycle. Depth to water tables and thermal profile data over an annual cycle will provide necessary information for determining actual perched water table fluctuations and dynamics.

FUTURE WORK

Future areas of interest in perched water table studies include:

- Documentation of operational remote sensing techniques for perched water management.
- Further refinement of thermal infrared techniques for detection of perched water tables.

Operational Demonstration and Implementation of Remote Sensing Techniques

Research conducted by our group (Estes, et al., 1978) analyzed the limits and comparative applications of available remote sensing systems to the detection of perched water tables. From this information we were able to design a user needs survey covering a wide range of potential user groups to determine actual information requirements related to perched water table monitoring efforts. Using information obtained from this study as well as our previous research, we hope to be able to document cost effective, statistically reliable remote sensing assisted methodologies for operationally detecting and monitoring perched water table/salinity conditions in conjunction with standard field sampling techniques for major user groups. In addition to evaluating the application of various remote sensing systems for detecting and monitoring of perched water tables, we would also consider the factors of cost and availability of imagery and user group inhouse capabilities for operational implementation, and how each of these considerations can meet the user's information requirements.

By evaluating remote sensing approaches and applying them to the development of transferable methodologies to user groups, it should be possible to more effectively control perched water tables and associated problems. The primary contribution of this research would be a remote sensing assisted methodology that is more cost-effective, timely, and accurate than present techniques in general use.

Further Refinement of Thermal Infrared Techniques

Results of previous research indicates that thermal infrared imagery has unique potential monitoring capabilities in perched water table regions because of unique soil and water thermal characteristics. The acquisition of depth to water table fluctuations and thermal profile data over an annual cycle should allow a more accurate assessment of the fluctuations in thermal characteristics of perched water tables, facilitating a more precise definition of optimal timing for thermal overflights. We are interested in obtaining additional thermal infrared imagery that, ideally, would be flown both day and night to assess diurnal thermal variations and anomalies, as well as during minimum and maximum perched water table conditions to assess seasonal cycle patterns.

Our previous thermal imagery was flown at altitudes of 1,000 and 6,000 feet. Results indicated that although lower altitude imagery allowed localized mapping of moisture conditions, it did not provide the regional perspective necessary for a shallow water table monitoring program. We are consequently interested in a NASA U-2 flight to obtain high altitude thermal imagery.

205

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207

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CHAPTER 3

PART IV

Watershed Runoff Predictions Using Landsat Digital Data

Author: Frederick C. Mertz

KERN COUNTY WATER AGENCY WATERSHED RUNOFF STUDY

During this reporting period the Geography Remote Sensing Unit (GRSU) was notified by the Kern County Water Agency (KCWA) that there could be no match funding as previously agreed. The $10,000. originally allocated by KCWA to GRSU for computer processing costs is unavailable due to the passage of Proposition 13. KCWA's primary source of support is county property taxes. Due to Proposition 13, property tax rates have been drastically cut throughout the state, thereby substantially reducing KCWA's available capital, and restricting future and ongoing projects. Since the funds used for the KCWA/GRSU remote sensing vegetation study could infringe upon basic resident services supplied by KCWA, the funding priority is low. However, recent communications indicate 10 man days of field work, and approximately $500. for processing costs will be supplied by KCWA.

The initial NASA funds supplied for this project have been and are being used for staff salaries directed towards the development of a user oriented product via digital image rectification and classification of vegetation categories necessary for input to a watershed runoff model. KCWA's intent was to fund the "production" portion of the study by covering computing/processing costs for the original 89 quadrangle study area (See Figure 3-16).

210

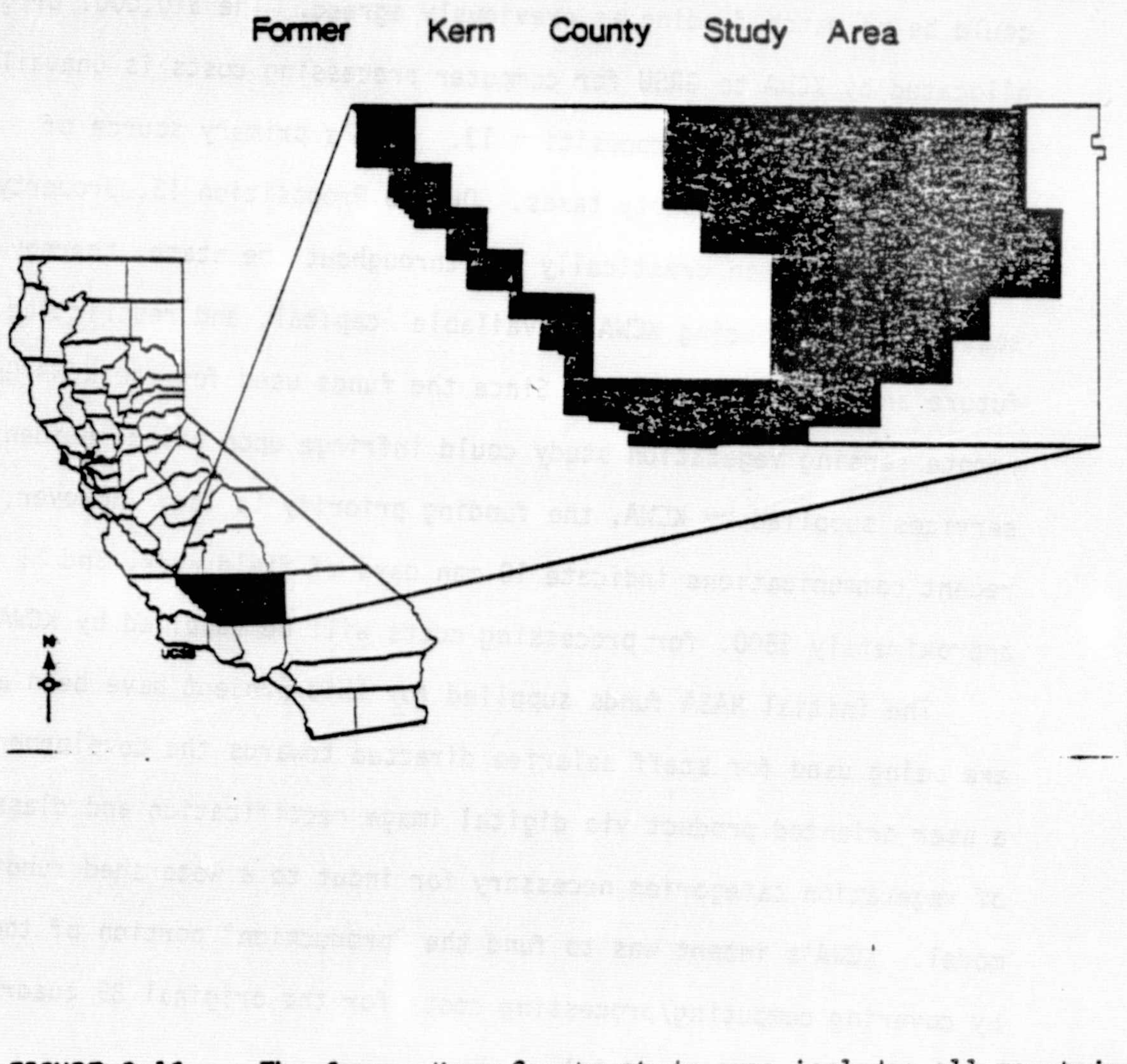

FIGURE 3-16 The former Kern County study area includes all mountainous watersheds within Kern County, California and encompasses approximately 10,000 square kilometers.

INTRODUCTION

Background

The introduction of intensive mechanized agriculture to the San Joaquin Valley floor region of Kern County has established it as the second leading agricultural county in the United States. However, only about one-half of the possible arable land is cropped as sufficient water is not yet available for full agricultural development. The Kern River, with a discharge of approximately 615,000 acre feet per year, is the only major stream in the county. Water importation through the California Aqueduct and Friant-Kern Canal and tapping of groundwater sources is extensive. At present, Kern County agricultural interests use about two million acre feet of groundwater annually bringing about an overdraft of approximately 700,000 to 800,000 acre feet per year. If this overdraft continues, the economics of pumping groundwater for agriculture usage will become critical. Even with increasing amounts of imported water, the Kern River surface flow (i.e., runoff) remains an important parameter in the water supply/demand models in Kern County and reinforces the importance of maximizing its potential.

KCWA is mandated by the Kern County Board of Supervisors, under the authority of the California State Legislature, to provide storm runoff predictions for approximately 10,000 km^2 of mountainous watershed within the county (Figure 3-16). KCWA must develop storm runoff predictions for all watersheds in Kern County in order to:

- delineate flood plain boundaries which affect building standards for commercial and residential structures;

- establish building standards for specialized flood control facilities such as dams, debris basins, spreading ponds. etc.; and
- provide base-line data for flood insurance.

KCWA currently uses the runoff prediction procedure developed by the United States Department of Agriculture's Soil Conservation Service (SCS). In this procedure runoff Curve Numbers (CN) are based on the soil-cover complex present in an area, and are the major drivers of the SCS runoff equation. Appendix A contains an example of the type and level of detail (especially vegetation) required for the southern California coastal plains and mountains in order to successfully implement the model. The SCS runoff equation is:

$$Q = \frac{(P - 0.2S)}{(P + 0.8S)}$$

where: Q = runoff in inches

P = rainfall per storm

S = water storage factor equal to (1000/CN - 10)

CN = function of soil type, soil moisture, vegetation cover and density

KCWA uses the data contained in Table 3-18 to determine the runoff Curve Numbers (CN) for input to the SCS equation. The conventional method of obtaining vegetation cover data (items 2, 3, and 4 in Table 3-18) is by field survey. This method of data acquisition is both time consuming and expensive.

TABLE 3-18

EXAMPLE OF KERN COUNTY WATER AGENCY WATERSHED FACTOR EVALUATION*

WATERSHED: Ranch Canyon DATE: ______

AREA: 24.3 Inches AREA: 11.82 Sq.mi. Evaluated By: ______

(1) Sub Area	(2) Land Use	(3) Treatment or Practice	(4) 1/ Hydrologic Condition	Soils (5) 4/ Texture	Soils (6) Depth (Inches)	(7) 2/ H.S.G.	(8) CN (R)	(9) Area (Inch)	(10) Weighted CN Value 9 (8) / 3/ W.Area	Remarks
A	Perennial Grass		Good	M	20-40	C	74	4.7	14.3	
B	"		Poor	C	< 20	D	89	1.7	6.2	
C	Barren		Poor	C	< 20	D	93	0.8	3.1	
D	Woodland Grass		Fair	C	20-40	C	76	8.1	25.3	
E	Woodland		Good	C	20-40	C	70			
F	Broadleaf Chaparral		Good	C	20-40	C	71/71	9.0	25.9	
									74.8	Total

1/ Poor is thin or sparse cover denoting less than 50% of the ground surface protected by litter, or by plant cover.

Fair is moderate or scattered cover denoting from 50% to 75% of the ground surface protected by litter or by plant cover.

Good is heavy or dense cover denoting more than 75% of the ground surface protected by litter or by plant cover.

2/ Hydrologic Soil Group

3/ Total Watershed Area (Inches)

4/ Coarse, medium, fine.

*Source: Kern County Water Agency internal publication, 1976. This test watershed is within the study area.

213

Study Area

The study area as defined in the proposal and preceeding reports has been scales down to remain within budgetary constraints. The revised study area was chosen by KCWA as high priority due to:

- a lack of vegetation cover data;
- no time series of runoff data for a regression model;
- rapid residential, commercial, and recreational development;
- intense wind damage within the area in December 1977; and
- extensive flooding and siltation of Southern Kern County during the heavy rains of February and March, 1978.

The area under investigation includes 55 7.5 minute United States Geological Survey (USGS) topographic quadrangles containing mountainous watersheds within Kern County (Figure 3-17).

The study area posses a number of distinctive woody plant communities common to Mediterranean climates. These communities include: evergreen stands, woodlands, evergreen scrubs (chaparral or hard chaparral), and drought resistant scrubs (coastal sage or soft chaparral). Representative of the vegetation cover and: chamise (*Adensotoma fasciculatum*), mountain mahogany (*Cercocarpus betuloides*), mountain lilac (*Ceanothus spp.*), and several species of annual and perennial grasses and conifers. Excepting *Quercus spp.*, there are few deciduous trees in the study area. Chaparral communities occur at all elevations between 2000-4500 feet. It should be noted that the chaparral of California is evergreen, winter active, and summer dormant, whereas the Rocky Mountain (*Petran*) chaparral is winter deciduous and summer active. The Mediterranean climate of the area

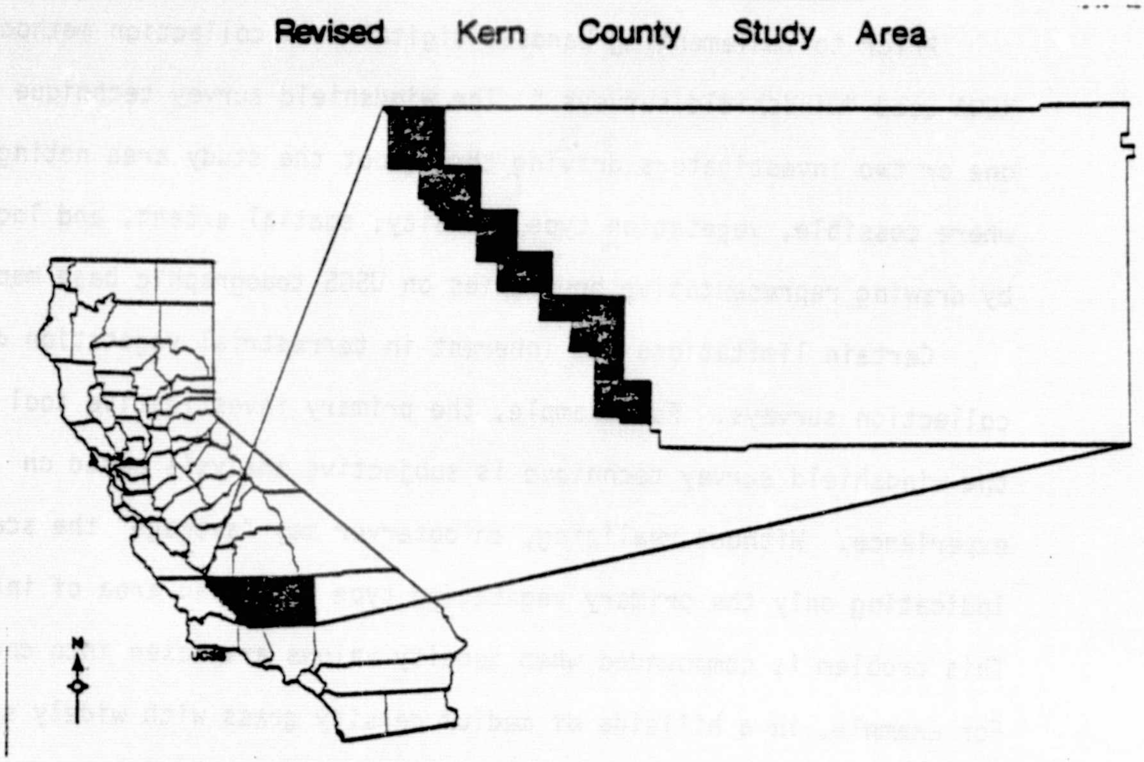

FIGURE 3-17. The revised Kern County study area includes mountainous watersheds on the west side of Kern County, California, and encompasses approximately 7,000 square kilometers.

produces favorable growing conditions during the winter and spring months. Annual/perennial grasslands and sage occur at lower elevations. Various types of woodland bisect chaparral brushfields in foothill areas (≈2000 feet) with riparian plant associations along canyon bottoms.

Limitations of Conventional Methodology

Prior to implementing Landsat digital data collection methods, KCWA used "windshield surveys." The windshield survey technique employs one or two investigators driving throughout the study area noting, where possible, vegetation type, density, spatial extent, and location by drawing representative boundaries on USGS topographic base maps.

Certain limitations are inherent in terrestrial vegetation data collection surveys. For example, the primary investigative tool in the windshield survey technique is subjective analysis based on experience. Without realizing, an observer may "average" the scene by indicating only the primary vegetation type within an area of interest. This problem is compounded when density values are taken into consideration. For example, in a hillside of medium density grass with widely spaced oak trees, the investigator may designate the area as oak-poor, or grass-excellent instead of indicating true area composition. The practice of averaging is acceptable if the thresholds between classes/densities remain constant for each and all observers. Ground observations of the type discussed above have limited spatial accuracies due to the investigator's "look angle" and instantaneous field of view. With near grazing look angles (not uncommon) some areas may be hidden. Errors in the determination of vegetation density can also occur at this look angle.

The time required to conduct a survey of this magnitude is another limiting factor. If there is a long data collection period, seasonal species may die or become dormant and thus lead to watershed cover inconsistencies. Attempts to increase the temporal resolution of the study by increasing the number of observers often results in a higher probability of internal inconsistencies; the greater the number of observers, the greater the opportunity for variance in the sampling method.

Due to the passage of Proposition 13, KCWA has had to drastically cut expenditures. Therefore, the survey techniques discussed above (for which Landsat classification accuracies were comparable) have been replaced by a less costly method. KCWA's new methodology incorporates very limited field checking. Vegetation types and density are interpreted from dated aerial photography (when it is available) by an inexperienced interpreter. Where photography is not available, vegetation types are mapped from the "green areas" on USGS 7.5 minute quadrangles, while density is determined from an observers recolection of the area. This technique saves several man-days of field work and the related transportation costs for each watershed study. However, the results are known by KCWA to have extremely limited accuracy.

APPROACH AND PROCEDURES

Digital Data Processing Techniques

In preceeding reports, digital analysis of Landsat computer compatible tapes (CCT's) was accomplished via the Digital Image Rectification System (DIRS) developed at NASA's Goddard Space Flight Center and the LARSYS multispectral pattern recognition package developed at Purdue University. Due to malfunctions in the DIRS software on this and other GRSU projects, high processing costs, and some unpredictable spatial errors during image rectification procedures, the DIRS package has been replaced.

Replacing DIRS and LARSYS is the Video Image Communication Analysis and Retrival (VICAR) systems developed at the Jet Propulsion Laboratory (JPL) in Pasadena, California. The VICAR software is far superior to the combined DIRS and LARSYS systems. VICAR has all the processing capabilities (plus many more) of DIRS and LARSYS, and operates in a single format, thereby allowing greater flexibility and reduction of costly reformatting routines. In addition, the Image Based Information System (IBIS), also developed at JPL, is now being implemented at UCSB, and will soon be operational. With the combined VICAR/IBIS package new capabilities in user oriented processing will be possible at UCSB. For example, if VICAR/IBIS was presently operational, GRSU personnel could furnish KCWA with computer derived acreage estimates of vegetation types within each watershed (see column 9, Table 3-18 Using soils data (see column 6 & 7. Table 3-18) as image data sets within IBIS, we could supply KCWA with actual CN values, thereby greatly reducing the manpower required for their CN determination procedures.

For this project, digital analysis of the study area incorporates 16 possible data channels into the categorization routine. The presence of all 16 channels does not, however, infer their use. Only those channels determined significant to the classification of a specific species and/or those necessary to obtain acceptable accuracies will be used.

The 16 data channels are derived from Landsat MSS and terrain data. Channels one through four are the four raw data MSS channels from Landsat. Channels five through ten are all possible ratios of channels one to four (i.e. 1/2, 1/3, 1/4, 2/3, 2/4. 3/4). These data have shown to be significant in vegetation studies conducted by Ron J. P. Lyon of Stanford, hence their inclusion. Channels eleven through thirteen are elevation, slope and aspect as computed from the Defense Mapping Agency's (DMA's) Digital Terrain Tapes (DTT's). Numerous studies demonstrate strong correlations of plant species to slope, aspect or elevation. Channels fourteen, fifteen, and sixteen are the Kauth greeness, brightness, and yellowness coefficents derived from linear combinations of channels one through four. The Kauth Matrix (shown below), although originally designed for agricultural data, is being implemented in this project to determine its usefulness as an enhancement technique for separation of native vegetation classes.

Kauth Landsat Agricultural Matrix

		MSS 4	MSS 5	MSS 6	MSS 7		
Brightness	=	0.43258	0.63248	0.58572	0.26414	=	CH1
Greeness	=	-.28972	.56199	.59953	.49070	=	CH2
Yellowness	=	-.82418	.53290	-.05018	.18502	=	CH3

Brightness = Sum of channels

Greeness = IR minus green

Yellowness = Red minus red

The purpose of initially analyzing all 16 channels is for the determination of only those significant to the results desired. By locating data channels unnecessary to the categorization, fewer channels can be used while maintaining high categorization accuracies in many classes. This should result in substantial reductions in processing costs for this and future native vegetation studies.

Digital analysis is preceeded by raw CCT reformatting and compilation of the data channels discussed above. For this project unsupervised categorization will be used to determine 200 initial spectral clusters. This large group of potential classes will be reduced to a definable subset using statistical and spatial criteria. Upon refinement of the classes, class statistics and the necessary data channels are input to the bayesian categorization routine which incorporates likelihood algorithms with a priori weights.

Using Ground Control Points (GCP's), whose precise geodetic and image coordinates have been determined, and the VICAR rectification routine GEOMA, a planimetrically rectified Landsat image output product at any chosen scale is produced. Our maps correspond to the existing USGS topographic base maps used operationally by KCWA at scales of 1:24,000 (where available) and 1:62,500.

Due to Landsat's spatial resolution of 79 by 57 meters, species type and density classes required for the SCS model are generalized to a level compatible with the data. Given this constraint, computer generated categorizations of vegetation types produced acceptable "Q" (runoff) calculations. "Q" determinations using both conventional and digital Landsat techniques varied less than 7 percent between the different approaches for two watersheds tested.

Tasks Performed During This Reporting Period

Prior to mid-June and the notification of Proposition 13 setbacks, GRSU staff were attempting to overcome rectification and registration problems in DIRS, and produce the necessary vegetation maps for KCWA. After learning of the funding cut, GRSU members began re-evaluating the study area for possible modifications. Interaction with KCWA led to the decision regarding the modified study area presented earlier in this report.

222

Due to the wind and flood damage during December 1978, February 1978 and March 1978, a more recent Landsat overpass (6/4/78) has been selected over the previously determined 8/7/78 data set. Reformatting of the raw CCT to VICAR compatible form and the six ratio channels, the greeness, brightness, and yellowness channels have been calculated.

Work to be Performed in the Near Future

- Registration of three terrain data sets (slope, aspect, and elevation) to the spectral data base;
- statistical and spatial aggregation of 200 clustered classes;
- categorization using parallelopiped and maximum likelihood with a priori weights, and
- rectification of the entire subscene, and extraction of 7.5 minute area corresponding to USGS topographic quadrangles.

Future Work/Plans

Our primary objective is to complete the rectification and classification of all 55 topographic quadrangles designated as the KCWA study area. However, research beyond the general grant requirements is planned in the areas mentioned below:

1. Registration of multidate imagery and non-remote sensing data bases for possible improvement of classification accuracies;
2. Continued updating of cost and accuracy data;
3. Comparison of spatial accuracies for several resampling/rectification routines;
4. Testing of digitally derived data in gauged watersheds, and calibration of SCS model to satellite data input, if necessary;

5. Test transferability of calibrated model on watersheds other than those used for calibration.

As our work progresses, specific examples of information extraction by Kern County resource management dicision makers of the data generated in connection with this applied research program will be highlighted. Kern County personnel are actively anticipating the inclusion of our digitally derived data as input to their decision-making process.

Proposed Future Work

- Provided match funding is obtained from the user agency (KCWA), GRSU would categorize all mountainous watersheds in Kern County, California, (see Figure 1) as was originally agreed. In so doing, KCWA would have vegetation data for all mountainous watershed in the county thereby greatly increasing their management controls throughout the county.

- Calibration of the SCS model to a specific watershed would allow fine tuning of the remote sensing inputs. By transferring the technique to different (but similar) watersheds, the transferability of the remote sensing techniques developed can be tested. This has been demonstrated by Blanchard (1973,1975). If the transferability were demonstrated, then a similar approach could be implemented on all ungauged watersheds within the County with a high degree of confidence. By monitoring precipitation, using the calibrated models, accurate determinations of runoff could be determined allowing the user agency to better model their county, thereby producing better services. As well, by demonstrating the transferability of the digital vegetation determination procedures a similar approach to vegetation categorization procedure could be implemented in a number of other Southern California counties using the SCS model.

224

SUMMARY

The Geography Remote Sensing Unit will provide Kern County with computer generated vegetation maps of the revised study area. These maps will correspond to existing USGS topographic quadrangles at scales of 1:24,000 or 1:62,500. Kern County Water Agency is using the vegetation information already obtained for input to the Soil Conservation Service's watershed runoff equation. Runoff curve numbers for Kern County watersheds are then determined and estimation of water runoff can be established.

Results to date indicate that computer aided classification of natural vegetation for input into the SCS runoff prediction model is as accurate as the traditional terrestrial survey methods of vegetation data collection previously used by KCWA (Table 3-19 The data generated by GRSU is currently being used by KCWA in their flood flow hydrology program. Kern County planners, in turn, use this information in their review of subdivisions, parcel maps, building permits, and the design of future flood control facilities. It is forseeable that the data generated by GRSU may well be used in the governmental decision-making process concerning structure strength or new subdivision location.

TABLE 3-19

SAMPLE CLASSIFICATION PERFORMANCE
FOR LAKE ISABELLA QUADRANGLE

	GROUP	NO. OF SAMPS	PCT. CORCT	NUMBER OF SAMPLES CLASSIFIED INTO					
				GRASS1	BRUSH/GR	PASTURE	WOOD/GR2	BRUSH1	WATER
1	GRASS1	19	94.7	18	1	0	0	0	0
2	BRUSH/GR	45	95.6	2	43	0	0	0	0
3	PASTURE	27	100.0	0	0	27	0	0	0
4	WOOD/GR2	48	81.3	0	4	0	39	5	0
5	BRUSH1	25	100.0	0	0	0	0	25	0
6	WATER	90	100.0	0	0	0	0	0	90
	TOTAL	254	95.3	20	48	27	39	30	90

OVERALL PERFORMANCE (242/ 254) = 95.3

AVERAGE PERFORMANCE BY CLASS (571.5/ 6) = 95.3

226

APPENDIX A

Cover and Land Use for Hydrologic Soil-Cover Complexes of a Typical Watershed in Land Resource Areas 19 and 20, Southern California Coastal Plains and Southern California Mountains

For the purpose of classifying cover on a watershed in coastal and mountain areas of Southern California, the land uses shown in Chapter 9, Table 9.1 Section 4, Soil Conservation Service National Engineering Handbook, October 1971, are here modified to apply more closely to Southern California conditions. It is emphasized that the classification of land use into kinds of plant cover is intended entirely for estimating runoff.* Only those classes pertinent to the study area are listed.

Wildland

Areas with such natural or native plant cover as grass, brush, woodland-grass or woodland. It may or may not be used for grazing livestock. It includes abandoned cropland. Because the description of grassland, woods, and forest on page 8.3, Hydrologic Handbook, is too broad for application in Southern California, Wildland Land Use has been substituted and divided into the following kinds of plant cover.

Annual Grass - Areas on which the principal vegetation consists of annual grasses and weeds.

Broadleaf chaparral - Areas where the principal vegetation consists of evergreen shrubs with broad, hard, and stiff leaves. The brush cover is usually dense or moderately dense.

Meadow - Areas with seasonally high water tables, locally called cienegas, on which the principal vegetation consists of sod-forming grasses and other plants.

Narrowleaf chaparral - Areas where the principal vegetation consists of diffusely branched evergreen shrubs with fine needle-like leaves. The shrubs are widely spaced and low in growth. Where narrowleaf chaparral shrubs are dense and high, such areas will be included with Broadleaf chaparral ground cover.

Open brush - Areas of which the principal vegetation consists of soft-woody shrubs which are grayish in color. It also includes vegetation on desert-facing slopes where Broadleaf chaparral species predominate in an open shrub cover.

Perennial grass - Areas of which the principal vegetation consists of perennial grass, either native or introduced, and which grows under normal dryland conditions. It does not include irrigated and meadow grasses.

Woodland-grass - Areas with an open cover of broadleaf or coniferous trees and with the intervening ground space occupied by annual grasses or weeds. The trees may occur singly or in small clumps. Canopy density, the amount of ground surface shaded at high noon, is from twenty to fifty percent.

Woods (Woodlands) - Areas where coniferous or broadleaf trees predominate. The crown or canopy density is at least 50 percent. Open areas may have a cover of annual or perennial grasses or of brush. Herbaceous plant cover under the trees is usually sparse because of leaf or needle litter accumulation.

Barren - Areas with no, or practically no, plant cover; where 15 percent or less of the ground surface is protected by plants or litter. This includes rocklands, land destroyed by erosion, and shaped or graded land.

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* Supplement to Chapter 9, Section 4 of the Soil Conservation Service National Engineering Handbook, October 1974.

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CHAPTER 3

PART V

The Ventura County Program

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231

THE VENTURA COUNTY PROGRAM

Recent legislation at all levels of government mandating stricter control of our nation's resources have added a great burden to the activities of resource planning and management personnel. Increases in decision-making and impact assessment activities have resulted in efforts to improve capabilities for monitoring and regulating our natural resources. Such activities typically require that resource managers analyze geographic/environmental data so that information may be extracted in order to influence effective decision making.

As part of its task to provide a guide for the accomplishment of an inventory of the resource complex, the Geography Remote Sensing Unit (GRSU), at the University of California at Santa Barbara (UCSB) is currently engaged in a cooperative effort with personnel of the Ventura County Public Works Agency which stemmed from work done on NASA grant - NASA NGL 404.

The objectives of that research were to:

1. Develop a Decision Oriented Resource Information System (DORIS) to enhance the application of remotely sensed data for inventory of the resource complex. To this end the GRSU has:
   a) demonstrated the Landsat classification capabilities for land cover in areas representative of the "resource complex" in Ventura County using remote sensing techniques,
   b) rectified and registered the Landsat data with Digital Terrain data, and
   c) evaluated the accuracy of the Landsat/Digital Terrain data combination.

2. Develop a viable approach to the long-term establishment of such a system where, ultimately, management action can be taken in an appropriate, efficient manner.

232

THREE PHASED APPROACH

The overall approach to the operational implementation of a Decision Oriented Resource Information System in Ventura County contains three elements. The approach has been designed so that each element "stands alone" on its merit and justification; that is, if Ventura County decides at any time that they wish not to continue with the effort, the work completed to date will yield useable results which will provide a sound basis for environmental management decisions regardless of further participation by either Ventura County, GRSU, or NASA. Although only preliminary work has actually been completed, the approach outlined here is considered very appropriate for Ventura County.

Phase I - User Need Survey (Assembly Bill 2560)

This survey, funded by the State of California (see Appendix B) through the initiative of Ventura County, will be conducted to determine:

1. which data is most pertinent to county-level decision making, i.e., what information is necessary to do the job;
2. what are the mutually required (inter-departmentally) data sets that would most efficiently be included in a common data base;
3. what are the unique departmental requirements in terms of spatial and temporal constraints;
4. what data is most appropriately derived from the manipulation of Landsat and other remotely sensed data; and
5. what are the most appropriate non-remote sensing data sources.

This element "stands alone" because the results of this survey will;

1. identify the flow of environmental data within the county,
2. reduce the redundancy in inter-departmental data acquisition, and

3. indicate the potential for the use of remotely sensed data for county-level decision making.

Phase II - Product Generation

Based upon the results of the user need survey, UCSB and Ventura County will generate products containing the required information for use by the county in selected portions of their everyday operations. These products will be generated for a variety of uses from a common data base (at UCSB) and will also include information concerning; 1) costs of data acquisition, manipulation, update and output, and 2) accuracy estimates.

This element "stands alone" because these products will;

1. identify the utility of remotely sensed data for county-level resource management; and
2. indicate the general efficiency, cost-effectiveness and utility of a data base approach to resource decision making.

Phase III - Evaluation of Available Information Systems

With this information in hand and a better grasp of their data processing requirements, Ventura County will embark upon an evaluation of available systems. Ventura County will evaluate these systems based upon a benchmark test formulated to test the system's appropriateness for the County's particular needs.

APPROPRIATENESS OF A COUNTY-LEVEL SYSTEM

The development of state-level remote sensing-based data systems has been retarded due in part to problems other than the technology involved. Many of these problems could be solved or at least substantantially reduced by state-county cooperation during the critical stage of system design. More specifically, a statewide system integrally designed to be upward compatible with county level systems would have the following merits:

- System definition and necessary modifications could begin at the county level with smaller data sets and correspondingly lower initial data acquisition, operation, and update costs. The results of county studies would be easier to confirm and there would be less area to ground truth. County level participation would provide local expertise (for classification and ground truth) which would be difficult to duplicate at the state level. County personnel are better prepared to do accurate classification in finer detail. In addition, assignment of confidence levels in statistical manipulations of the data can more easily be determined by county resource and planning personnel due to their more intimate knowledge of the data set and its utilizations.

- Within a single county there are fewer autonomous agencies to deal with than at the state level so procuring agency support and cooperation should therefore be an easier task.

- Although the initial set of user groups would be more limited, the potential user community for remote sensing-based data systems is much broader at the county level. And in addition to traditional resource management and planning activities, a county level system can be applied to functional "public works" projects that can provide some visible measure of cost-effectiveness and utility.

VENTURA COUNTY ACTIONS TO DATE

1. Ventura County, with "expert witness" testimony from GRSU staff, has initiated AB2560. This Assembly Bill, signed by the governor on September 28, 1978, appropriates $125,000 to "Counties applying for such grant...to conduct an information needs survey...[in order to help] speed the environmental decision making process required by the California Environmental Quality Act and other laws providing for the collection, storage, and transmittal of environmental information." Ventura County's portion of these monies was recommended by the Governor's Office of Planning and Research staff to be $50,000.

2. In cooperation with U.S.G.S., U.S.F.S., and UCSB, Ventura County has initiated a pilot study in the southern half of the county to acquire digitial map data (from the 7.5 minute series) for incorporation with Landsat and other remotely sensed data products. This map data includes elevation, transportation, hydrographic, and jurisdictional information.

3. Ventura County has established a communications link with the image processing equipment at UCSB (a modem link with the PDP 11/70) and is independently pursuing remote sensing training and education programs on contract with GRSU staff personnel

GRSU EFFORTS TO DATE

In order for Ventura County to proceed with the identification of their environmental information needs (which will eventually act as a guide in an applications project) it was necessary to provide some minimal staff time and travel monies. These monies from NSG-7220 were used for the following; 1) to confer with California legislators Senator Omer Rains and Assemblyman Charles Imbrecht (co-authors of AB2560) on the overall approach to the DORIS program; and 2) to provide testimony before legislative committees on the state-of-the-art in remote sensing and information systems. No further efforts are anticipated before the end of this funding period.

PROPOSED FUTURE WORK

Based upon the results of the user need survey, which will identify the information requirements for environmental document processing (EIR's for watershed management, wildlife management, fire planning, public works projects, etc.), a specific project will be identified as a demonstration of the functional utility, cost effectiveness, and general efficiency of remote sensing products over conventional data sources.

A REMOTELY SENSED INVENTORY OF SMALL DAMS IN VENTURA COUNTY, CALIFORNIA

INTRODUCTION

Background

Through the cooperative DORIS effort between the Ventura County Public Works Agency (VCPWA) and the University of California, Geography Remote Sensing Unit, (UCSB, GRSU) a project known as the Small Dams Inventory has grown out of an initial user priority information needs survey. VCPWA under a mandate from the Ventura County Board of Supervisors is required to carry out policy as defined by a draft ordinance known as the "Small Dam Ordinance." This ordinance involves regulating the construction, maintenance and operation of small dams in Ventura County. A "small dam" is defined as any barrier, enbankment, levee, revetment, spillway or outlet which does, is designated to, or intended to or may impound more than one acre foot of water or other fluids to a depth of more than three feet at the deepest part. However, under the ordinance a "small dam" is also restricted to be of certain ownership types (i.e. not one built under the jurisdiction of a state or county water management agency). In the construction of any "small dam" structure, the builder must first apply for an inspection and then a permit to be issued to a Flood Control Engineer-Manager.

Upon divulging that the regulation of this ordinance was a high priority item, it soon became clear to VCPWA that an immediate inventory of all dam structures in the south-half of Ventura County could only be accomplished with the use of remotely sensed data.* The decision to

* See study area description for explanation of which areas were to be inventoried.

use NASA CIR high-altitude imagery in a manual mapping mode was made by GRSU personnel following a critical analysis of the project's total information needs. VCPWA was also informed that of course it would be necessary for them to make ground-based checks and measurements to supplement information mapped from the imagery. It was also made clear that an important element of this project would be the training of VCPWA personnel (at County expense) to carry out this and other related tasks that may benefit from the use of NASA data projects. Ventura County has contracted with University of California personnel to carry out remote sensing training and education programs.

Study Area

The study area for the inventory of "small dams" for this project is the approximate southern-half of Ventura County, California. A south-half division of the county is often made to separate the more populated urban southerly portion from the sparsely populated forest and rangelands of the north (under jurisdiction of the Los Padres National Forest). VCPWA is principally concerned with regulating "small dams" in the urban-agricultural complex of the county's coastal region.

Objectives

The principal objectives of this research effort are to: (1) meet the specific policy-dependent information requirements of the Ventura County Public Works Agency (VCPWA) with NASA-supplied remotely sensed data; (2) determine type and method of analyzing remotely sensed data; and (3) transfer and adapt this technology as an integral part of the VCPWA's data collection effort in the establishment of DORIS, (Decision Oriented Resource Information System).

238

Meet Specific Policy-Dependent Information Requirements of the VCPWA with NASA-Supplied Remotely Sensed Data

The "Small Dam Ordinance" regulating the construction, maintenance, and operation of small dams requires the inventory of small dams and their associated reservoirs throughout the county. Such are the initial information requirements for this particular VCPWA policy function. But, if such a function is truly regulatory, the inventory must be continually updated.

Specific information requirements are related to the size, location, and regulatory status (i.e., state, other public agencies) of particular water bodies, as defined by the Small Dam Ordinance. Principal among these is the size requirement, which encompasses both areal extent and depth of water. Only dams whose reservoirs are greater than one acre in areal coverage are to be regulated by the VCPWA.

The need for remotely sensed data to satisfy many of the VCPWA's "small dams" information needs was immediately apparent to consulting UCSB/GRSU personnel upon being informed of the ordinance. Attributes of remotely sensed data that are particularly amenable to this type of data collection task are:

1. The ability to inventory the entire county from a single or simultaneous series of data acquisition.
2. Ease of differentiating water from land (particularly in the near infrared portion of the spectrum).
3. Ease at which water bodies can be identified and transferred to a base map.
4. Ability to easily update these base maps from subsequent data acquisitions.

Upon documenting these advantages of remote sensing (including a comparison with possible in situ data collection), it was then necessary to determine:

1. The optimum type of remotely sensed data to use; and
2. The techniques and procedures for mapping "small dams" on a particular base map.

Determining Type and Method of Analyzing Appropriate Remotely Sensed Data

Upon analyzing the information needs for inventorying "small dams" in Ventura County, a mini-User Needs Survey yielded the conclusion that manual mapping from NASA color-infrared, high altitude imagery would most satisfactorily supply the greatest amount of information in the most efficient manner. Other imagery types considered were existing low-altitude black and white and color photography (at several scales) and Landsat/MSS data in both image and digital form. A manual mapping procedure aided with an optical overlay was chosen as the optimal method of producing the desired inventory from the NACA CIR high altitude imagery.

The CIR high altitude imagery was selected over the other types of imagery mentioned previously based on inherent data characteristics, many of which were compatible with the specific data requirements of the inventorying. Some of these desirable characteristics being:

1. ability to best distinguish water from land with CIR imagery;
2. availability of imagery for flightlines covering the entire county by a non-cumbersome number of frames;
3. more than adequate resolution (.2-3 meters) for identifying water bodies; and
4. ability to view imagery stereoscopically.

240

Low-altitude aerial photography was deemed unacceptable because of the number of frames required to cover the county and the fact that no CIR imagery was available at this scale. Working with a large number of frames or a mosaic is less desirable than a few high altitude frames, where the resolution of either are more than adequate.

Landsat/MSS data analysis was concluded to be inadequate in terms of efficiency and resolution, but may be effective in future monitoring and regulation. The cost and time associated with analyzing the sub-scene of Landsat data that encompasses Ventura County, solely for an initial inventory will be too great. With its current resolution at about 1 acre, Landsat is not capable of accurately detecting and measuring the smaller dams that are not much larger than the one acre regulatory limit. Landsat data in the digital mode may be valuable in future work involved with updating the original data inventory.

Transfer of Techniques to VCPWA

The final objective of this project will be to successfully transfer the techniques and methodology developed, once it has been documented that VCPWA can more effectively obtain information, as well as administer and regulate policies concerning the presence of "small dams" through the use of NASA's high altitude CIR imagery. By training VCPWA personnel (at County expense) in image interpretation techniques for the inventorying of "small dams" and other pertinent data acquisitions, they may themselves be able to effectively utilize NASA-supplied data products in the future. As an offshoot, VCPWA in realizing the potential utility of remote sensing in meeting important information needs has also:

1. Begun to develop an information system (DORIS) based on remotely sensed data;

2. Designated a new technical position as a remote sensing/ cartographic specialist

3. Acquired NASA data products for other uses other than its "small dams" inventory.

Intensive training and technology transfer will be accomplished for the "small dams" inventory, as well as through continual workshop sessions aimed at exploring a wide range of county-level applications using remotely sensed data. Intensive training of a few VCPWA personnel in the methods developed for inventorying "small dams" will allow the county agency to produce future inventories, thus enabling them to carry out their regulatory duties. Wider scoped workshops serve the purpose of exposing future NASA data product users with background information and potential applications.

APPROACH AND PROCEDURES

Methodology

A manual mapping procedure, facilitated by the use of optical transferring equipment has been developed to inventory "small dams" in Ventura County from NASA high-altitude CIR imagery. Such mapping has produced a base map designating all water bodies in the county, with those meeting the size criteria of the "small dam" ordinance.

The inventory has been conducted with the use of NASA's 1:65,000 scale CIR imagery flown on March 13, 1978. As an off-shoot of flood emergency actions, the imagery was flown at the request of the Ventura County Flood Control Department (VCFCD) and the California State

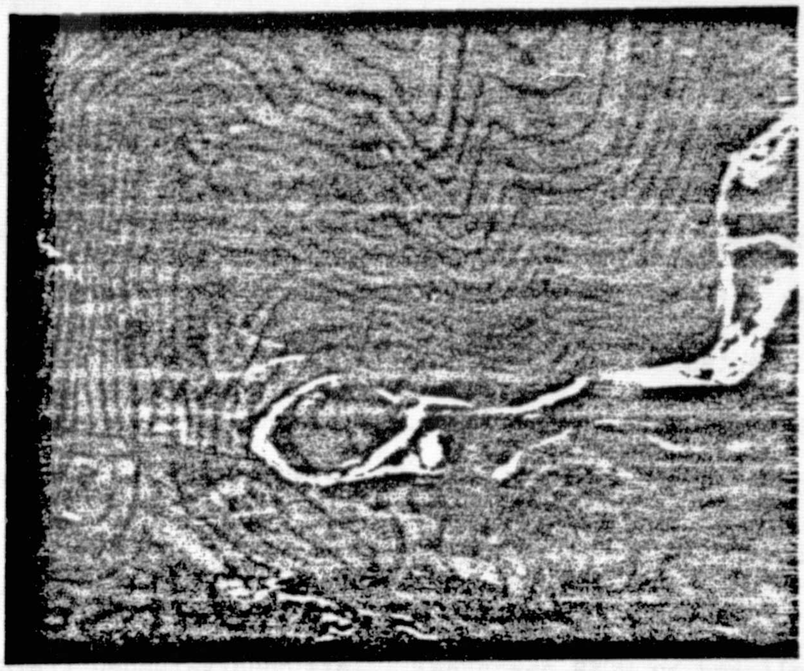
242

Official Emergency Services (OES). An original information need for assessing flood-related disasters in three south-central coast counties initiated the request for NASA-Ames Research Center to conduct the particular photo mission. However, the fact the imagery was acquired at a time following heavy rainfall is favorable for inventorying dam-resultant water bodies. Consequently, debris basins, industrial sinks, reservoirs and other structures which function as dams show up well on the imagery. This is an excellent illustration of the "multiple-use" concept of remote sensing where the same date of NASA imagery has been used for several important data acquisition functions.

USGS 1:24,000 scale topographic maps were chosen as base maps to inventory water bodies that may be created by the formation of "small dams." Such maps were chosen because of their availability and current utilization as the base for developing Ventura's DORIS.

The optical transformation of image data to base maps was achieved with the use of a Bausch and Lomb Stereo Zoom Transfer Scope (SZTS). This instrument allows its user to optically overlay the imagery and map at a compatible scale, so that water bodies may be directly plotted on the base map. The use of stereo optics facilitates the distinction between dams and their respective reservoirs versus standing surface water. With stereoscopy the user is able to identify faces, levees and other three-dimensional clues that distinguish the type of surface water that is being observed (see Figure 3-18A&B).

A.



B.

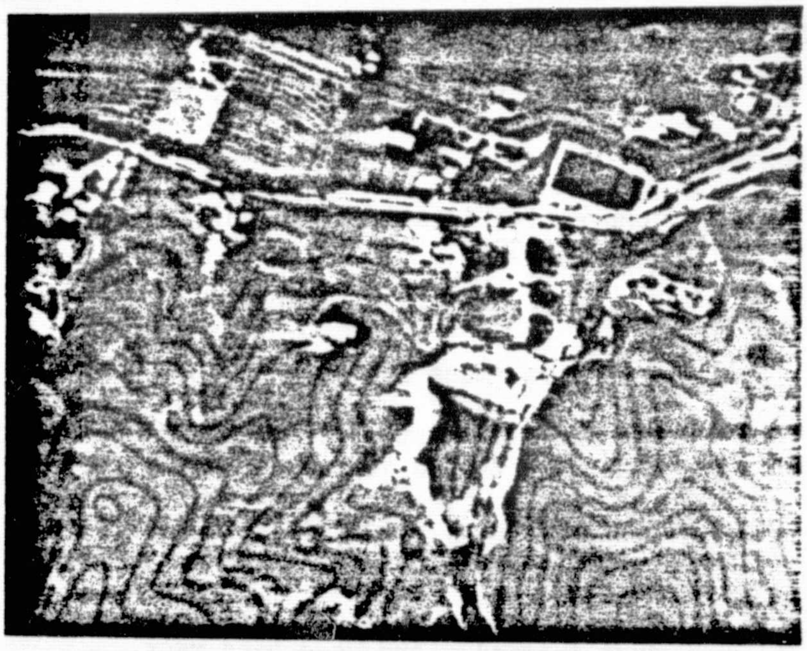


FIGURE 3-18. Photographic examples are shown of overlayed NASA high-altitude color infrared photography and a USGS 1:24,000-scale topographic map. Polaroid photography was taken through optics of a Bausch and Lomb Zoom Transfer Scope. Scenes depict locations of "small dams" on the NASA imagery, that were neither marked on the topographic map nor known to exist by Ventura County Flood Control Department personnel. "Small Dam" water impoundments are located in the center of color (Fig. A), and black and white polaroid (Fig. B) prints.

Objectives Completed

Project objectives, with the exception of the user agency's documentation of management action, have been successfully completed as outlined in the introductory section. Water bodies have been detected, identified and base-map plotted for the entire designated study area. Those water bodies that are a result of damming have been further designated with distinction of those measured to be greater than one acre.

The intensive training of a VCPWA member has also been accomplished by UCSB personnel. This county-funded training included familiarization briefings concerning the NASA high altitude imagery, guidelines to specific mapping criteria, and the operation of the SZTS.

The following is a more complete, itemized list of objectives achieved:

1. Cooperative identification of information needs with VCPWA and UCSB/GRSU.
2. Formulation of methodology.
3. Intensive image analysis/mapping training of VCPWA personnel.
4. Mapping all substantial water bodies in designated study area on 1:24,000 scale base maps.
5. Designation of water bodies 1 acre or greater that are a result of dams, levees, retaining walls, etc.
6. Initial ground observations for water depth, and ownership from initially produced base maps.
7. Formulations of broader scoped training sessions for VCPWA personnel.

Documentation of the superior information from NASA high altitude imagery products, (superior as opposed to using conventional ground based and other remote sensing data), has been achieved in several manners. These being:

1. Identification of several "small dam" structures not previously known to have existed; includes one or two VCPWA reports documenting regulation of specific structures.

2. Statement of further VCPWA usage of NASA high flight imagery upon their realization of its potential utility in their policy making and regulatory procedures.

It is unfortunate that the principal objective, the documentation of the user's (VCPWA) management action cannot be demonstrated at the time of submission for this report. The reasons for the delay in management action as stated by VCPWA personnel are:

1. "Higher priority" projects have occupied the time of a staff suffering from "Proposition 13 cutbacks;"

2. A lower than average rainfall year resulting in little to no complications in or requests to build "small dam" structures.

Therefore, VCPWA has not yet submitted their proposal to their County Board of Supervisors, for the establishment of a "Small Dams Ordinance" in Ventura County. VCPWA have acknowledged though:

1. that they were suprised to see that as many small dam structures existed, as were indicated on the photo-derived map;

2. that they could have never afforded the time or manpower that would have been necessary to create similar maps by on-site mapping; and

3. currently they are using reduced copies of the "Small Dams" maps for their on-site flood control inspections and plan on using the maps for future related work.

Proposed Future Work

Future work as an extension of this initial project will be in the areas of: 1) continual monitoring and updating of "small dam" structures using NASA high altitude CIR imagery; 2) research into the use of digital Landsat data to update existing "small dams" base maps as a peripheral project in the development of a county-wide digital Landsat data base; and 3) further training of VCPWA personnel in image analysis techniques useful in dealing with NASA high altitude imagery (in conjunction with 1 & 2 above, the training function would be county funded).

It is hoped that the above proposed work will be carried out as part of future NASA, California State and Ventura County projects involved with developing remote sensing data in the resource management and planning aspects of local, regional and state governments.

Summary

The main conclusions that have been reached from this project to date are:

1. NASA CIR high altitude imagery appears to be the best data product in satisfying information toward the inventorying of small dams and related water bodies;

2. many other users of the imagery are becoming evident to VCPWA personnel in satisfying other information needs;

3. that further remote sensing oriented training of other VCPWA personnel would be extremely beneficial to their activities; and

4. the development of a digital Landsat data base with other collateral data may be beneficial for future monitoring of small dams and the updating of the newly acquired inventory.

247

APPENDIX B

Assembly Bill No. 2360

CHAPTER 1343

An act making an appropriation for a pilot program to develop an environmental information needs system, and declaring the urgency thereof, to take effect immediately.

[Approved by Governor September 28, 1978. Filed with Secretary of State September 28, 1978.]

LEGISLATIVE COUNSEL'S DIGEST

AB 2360, Imbrecht. Environmental information pilot program grant.

Existing law does not provide for a grant by the Environmental Data Center, Office of Planning and Research to the County of Ventura, and to other counties applying for such grant, to conduct a pilot program to develop an environmental decision-oriented information needs system utilizing computer data to speed the environmental decisionmaking process required by the California Environmental Quality Act and other laws providing for the collection, storage, and transmittal of environmental information.

This bill would appropriate $125,000 from the California Environmental Protection Program Fund to the center for expenditure, during the 1978–79 and 1979–80 fiscal years, for a grant to such counties to conduct such program; provided that the counties submit detailed work programs and budgets.

The bill would require counties receiving grant moneys to render a progress report on the pilot program not later than 6 months from the date of the receipt of grant moneys and a final report not later than 1 year from such date.

The bill would take effect immediately as an urgency statute.

Appropriation: yes.

The people of the State of California do enact as follows:

SECTION 1. (a) The sum of one hundred twenty-five thousand dollars ($125,000) is hereby appropriated from the California Environmental Protection Program Fund in the State Treasury to the Environmental Data Center, Office of Planning and Research for expenditure, during the 1978–79 and 1979–80 fiscal years, as a grant to the County of Ventura, and to any other county applying for such grant, to conduct a pilot program to develop an environmental decision-oriented information needs system utilizing computer data to speed the environmental decisionmaking process required by the California Environmental Quality Act (commencing with Section 21000 of the Public Resources Code) and other laws providing for the collection, storage, and transmittal of environmental information;

93 40

APPENDIX B

Assembly Bill No. 2560

CHAPTER 1343

An act making an appropriation for a pilot program to develop an environmental information needs system, and declaring the urgency thereof, to take effect immediately.

[Approved by Governor September 23, 1978. Filed with Secretary of State September 25, 1978.]

LEGISLATIVE COUNSEL'S DIGEST

AB 2560, Imbrecht. Environmental information pilot program grant.

Existing law does not provide for a grant by the Environmental Data Center, Office of Planning and Research to the County of Ventura, and to other counties applying for such grant, to conduct a pilot program to develop an environmental decision-oriented information needs system utilizing computer data to speed the environmental decisionmaking process required by the California Environmental Quality Act and other laws providing for the collection, storage, and transmittal of environmental information.

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95 40

248

provided, that such counties shall submit detailed work programs and budgets.

(b) The pilot program shall develop an inventory of environmental data needs of county agencies and develop an inventory of data requirements associated with state and federal permits. The design of the data system shall be coordinated with the Environmental Data Center, Office of Planning and Research to ensure compatibility with its environmental resource inventory system.

(c) Counties receiving grant moneys shall render a progress report on the pilot program to the Environmental Data Center, Office of Planning and Research not later than six months from the date of the receipt of grant moneys and a final report not later than one year from such date.

SEC. 2. This act is an urgency statute necessary for the immediate preservation of the public peace, health, or safety within the meaning of Article IV of the Constitution and shall go into immediate effect. The facts constituting such necessity are:

In order that this vital program may be commenced as soon as possible, it is necessary that this act take effect immediately.

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93 60

249

CHAPTER 4

SOUTHERN CALIFORNIA STUDIES

Co-Principal Investigator: Leonard W. Bowden (Deceased)

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Ken Weinstock (graduate)
Craig Gooch (undergraduate)
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Agency Contributor: Teri Jamin (San Bernardino County)

Outside Participants:
1. Desert Planning Staff, Bureau of Land Management
2. California Avocado Advisory Board (now California Avocado Commission)
3. San Bernardino County Planning Department
4. Agricultural Experiment Station, University of California, Riverside

Earth Sciences Department
University of California
Riverside Campus

May 1, 1979

Table of Contents

APPLICATION OF REMOTE SENSING TO SELECTED PROBLEMS WITHIN SOUTHERN CALIFORNIA

4.1 INTRODUCTION

This is the third year of funding under the NASA grant dealing with selected resource management problems. The research efforts of the Riverside Campus during the year were concentrated in two areas: 1) desert planning; and 2) agricultural planning. Special attention has been given to the relation of these projects with grant objectives. The desert planning activities of the Bureau of Land Management (BLM) have been aided with the application of a sampling technique for estimation of the total recreational road and wash mileage in the California Desert. The San Bernardino County planning staff, with our guidance, employed a method of updating their land information base using remote sensing methods.

Continuing studies will emphasize cooperation with the California avocado industry in solving their resource management problem, a problem created by the sudden expansion of avocado plantings from 25,000 acres to 50,000 acres in a five year period. Due to reduced funding we were able to allocate only minimal NASA funds to the avocado project. The industry did provide $10,000 with a matching $6,000 grant from the University of California Agricultural Experiment Station to perform some preliminary investigations. The industry is anxious to provide additional matching funds to assist our NASA funded research in the avocado production research in the forthcoming year. Remotely sensed imagery from three platform levels (low altitude, high altitude, and satellite) will be applied in the data gathering phase of the project, leading to the development of an Avocado Production Information System (APIS).

We anticipate reserving a portion of our NASA funding in pursuing 'problems of opportunity'. At this time we do not have a definitive problem, but recently received a request from Riverside County to participate in a problem dealing with surface hydrology and public health. It is premature to determine if this problem might be suitable for research under the NASA guidelines, but it does indicate that we are continually being contacted by various agencies to perform research in connection with the NASA grant.

2520

4.2 REPORT OF WORK COMPLETED THIS GRANT YEAR

4.2.1 Resource Management Problems in County Planning

San Bernardino County, with support from the California Office of Planning and Research (OPR), began a program of evaluating the county agricultural resources in early 1978. The outcome of this study is to be an agricultural element for the county general plan. County planning personnel came to us to determine if remote sensing techniques were suitable in the data gathering and evaluation efforts. Tasks were identified which either directly or indirectly involved remote sensing. These tasks include county personnel participation and training, land use mapping and information system development, and Landsat imagery evaluation. Each of these tasks are described below.

4.2.1.1 County Personnel Participation

San Bernardino County expressed interest in assigning one of their staff to assist part time in some of the agricultural land use data gathering efforts in order to gain an expertise in remote sensing and related fields. A planner was assigned 20% time for that purpose throughout the data gathering phase. This arrangement led to a good understanding on the part of both San Bernardino County and the Riverside group as to the role remote sensing had to play in the project. The planner who was assigned to us is now, as a result of her activities, looked to by other planners for guidance in matters having to do with remote sensing applications.

4.2.1.2 Land Use Mapping and Agricultural Information System Development

A county general plan is a document which states policies used to guide the orderly development of a county. A very important aspect of development, especially in San Bernardino County, is the conversion of agricultural land to urban/residential uses. In order to establish policies relating to agricultural development, and development at the expense of agriculture, it was necessary for the county planners to know the extent of the agricultural resource, its location, and the trends toward conversion of that resource for other uses. Of equal importance, especially with regard to plan acceptance and implementation, is the necessity of presenting that information in a clear, concise form both to the citizen's agriculture advisory committee and to the county board of supervisors. These requirements lead to the determination of the desirability of soil suitability and multi-date land use data, presented in map and tabular form. It was felt that remote sensing provided the best means to acquire one date of land use data (the other date was already available) and that a geographic information system would not only aid in map and statistical report generation but also assist in the interpretation process itself.

Land use data for 1975 were derived from Department of Water Resources (DWR) land use maps. The DWR data were useful because of considerable crop-specific detail in the agricultural classes. DWR maps an area only once every 10 years so additional land use information had to be gathered to establish recent trends. The DWR maps also present problems because they are in such crude form. The standard DWR land use map is only partially readable and many polygons are either unclassified or have conflicting classifications. Several trips to DWR offices in Los Angeles were required to resolve ambiguities.

The entire study area, the valley portion of San Bernardino County, was divided into map modules. Each map module is based on a USGS 7 1/2' quadrangle. A map module was entered into the geographic information system by digitizing the land use or soils polygons. The geographic information system utilized in the project was the Spatial Information Processing System (SIPS), which has been developed, partly with NASA support, over the past 5 years.

Upon completion of a 1975 land use map it was possible to use aerial photography to update the land use map for 1977. The 1975 land use maps were digitized and then digitally reproduced (plotted) at the image scale (1:12,000) and directly overlaid on the imagery to establish 1977 land use conditions. As a result of digitizing the 1975 land use data, it was possible to: 1) produce a statistical summary of land use; 2) produce maps with various classifications of land use; and 3) speed the interpretation process for 1977 by essentially making it an updating procedure.

Figure 1 shows a 1975 land use map produced on the line plotter with the digitized data base. Fifteen such map modules (quadrangles) constitute the 1975 data base. Figures 2a and 2b show examples of statistical summaries of the 1975 land use data produced by the information system and aggregated by census tracts and planning districts. Figure 3 shows a 1977 land use map, for the same map module as shown in Figure 1, which was produced by updating the 1975 data base with remotely sensed imagery. Six map modules, determined to be critical areas, were interpreted and mapped for 1977. Figure 4 shows the soils map which also corresponds to the same map module as the land use maps. The addition of a soils map to the data base provided for information relating to agricultural suitability.

4.2.1.3 <u>Landsat Imagery Evaluation</u>

As part of our effort in mapping land use, San Bernardino County requested an evaluation of the potential of Landsat imagery to provide agricultural

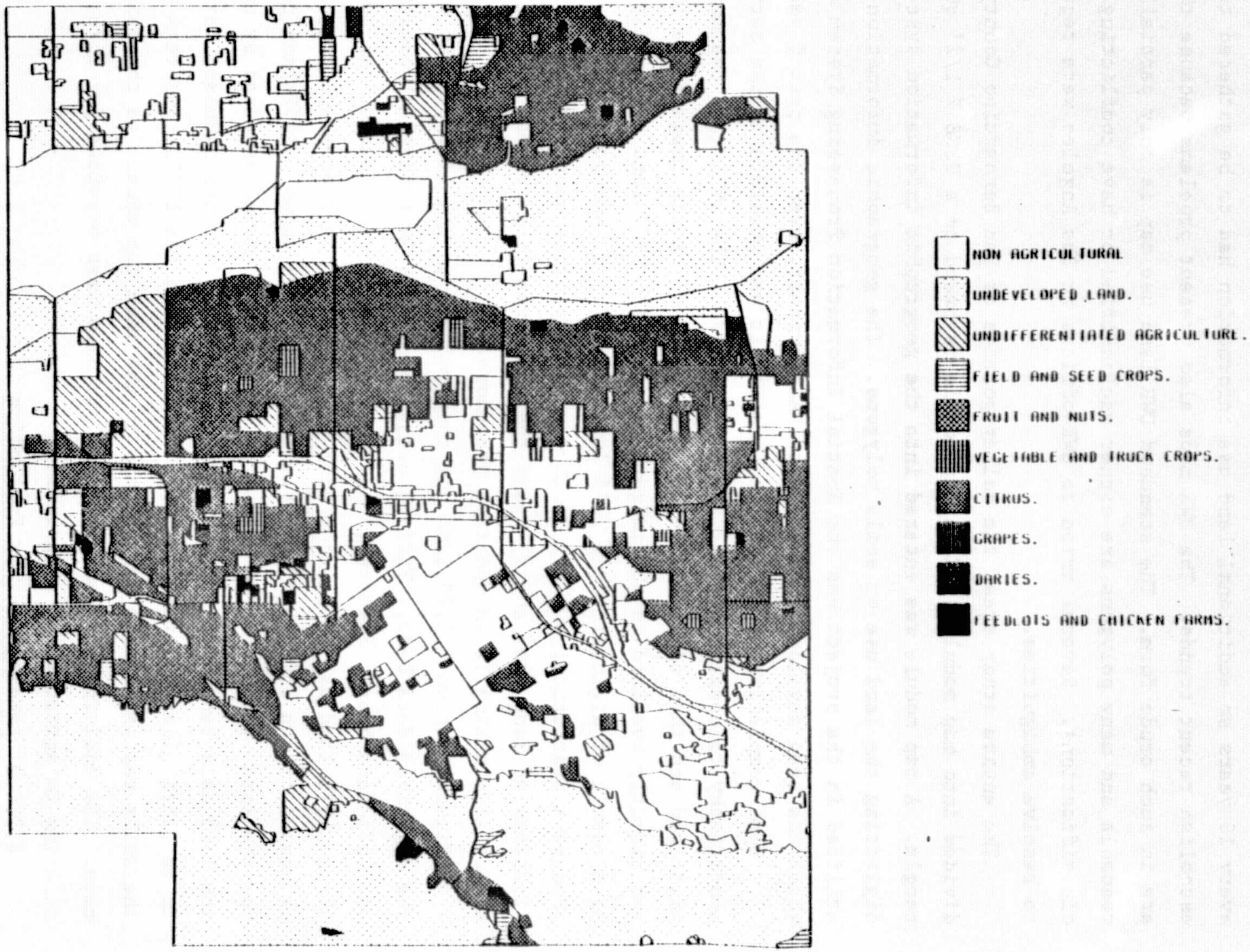

Figure 1

Agricultural land use map of Redlands Quadrangle, 1975

SAN BERNARDINO COUNTY

LAND USE FOR CENSUS TRACT 26.00

LAND USE	ACRES
UNDIFFERENTIATED URBAN	0.0
RESIDENTIAL	1133.39
MANUFACTURING	16.92
TRANSPORTATION	198.40
TRADE	12.56
SERVICES	92.88
CULTURAL	0.0
UNDIFFERENTIATED RESOURCE EXTRACTION	124.56
UNDEVELOPED LAND	2107.31
UNDEVELOPED RIPARIAN	32.67
TRANSITIONAL	0.0
URBAN VACANT	2308.13
UNDIFFERENTIATED AGRICULTURE	0.0
FEEDLOTS AND CHICKEN FARMS	209.07

	(IRRIGATED)	(NON-IRRIGATED)
FIELD AND SEED CROPS	74.15	0.0
VEGETABLE AND TRUCK CROPS	86.09	0.0
GRAPES	1972.29	0.0
DECIDUOUS FRUITS AND NUTS	0.0	0.0
CITRUS	514.29	1.37
UNDIFFERENTIATED FRUITS AND NUTS	0.0	0.0
DARIES	0.0	0.0
NON-PRODUCING CROPLAND	524.77	7.33
PASTURE	38.90	26.30

Figure 2a

Computer generated land use tabulations for Census Tract 26

SAN BERNARDINO COUNTY

LAND USEFOR PLANNING DISTRICT 9

LAND USE	ACRES	
UNDIFFERENTIATED URBAN	5138.66	
RESIDENTIAL	1845.16	
MANUFACTURING	22.75	
TRANSPORTATION	245.40	
TRADE	31.58	
SERVICES	123.46	
CULTURAL	5.91	
UNDIFFERENTIATED RESOURCE EXTRACTION	124.58	
UNDEVELOPED LAND	4134.48	
UNDEVELOPED RIPARIAN	32.67	
TRANSITIONAL	0.0	
URBAN VACANT	8893.45	
UNDIFFERENTIATED AGRICULTURE	0.0	
FEEDLOTS AND CHICKEN FARMS	370.34	
	(IRRIGATED)	(NON-IRRIGATED.
FIELD AND SEED CROPS	74.15	0.0
VEGETABLE AND TRUCK CROPS	86.09	0.0
GRAPES	2188.87	964.70
DECIDUOUS FRUITS AND NUTS	0.0	0.0
CITRUS	670.06	1.37
UNDIFFERENTIATED FRUITS AND NUTS	0.0	0.0
DARIES	0.0	0.0
NON-PRODUCING CROPLAND	529.29	185.12
PASTURE	43.94	26.30

Figure 2b

Computer generated land use tabulations for Planning District 9

257

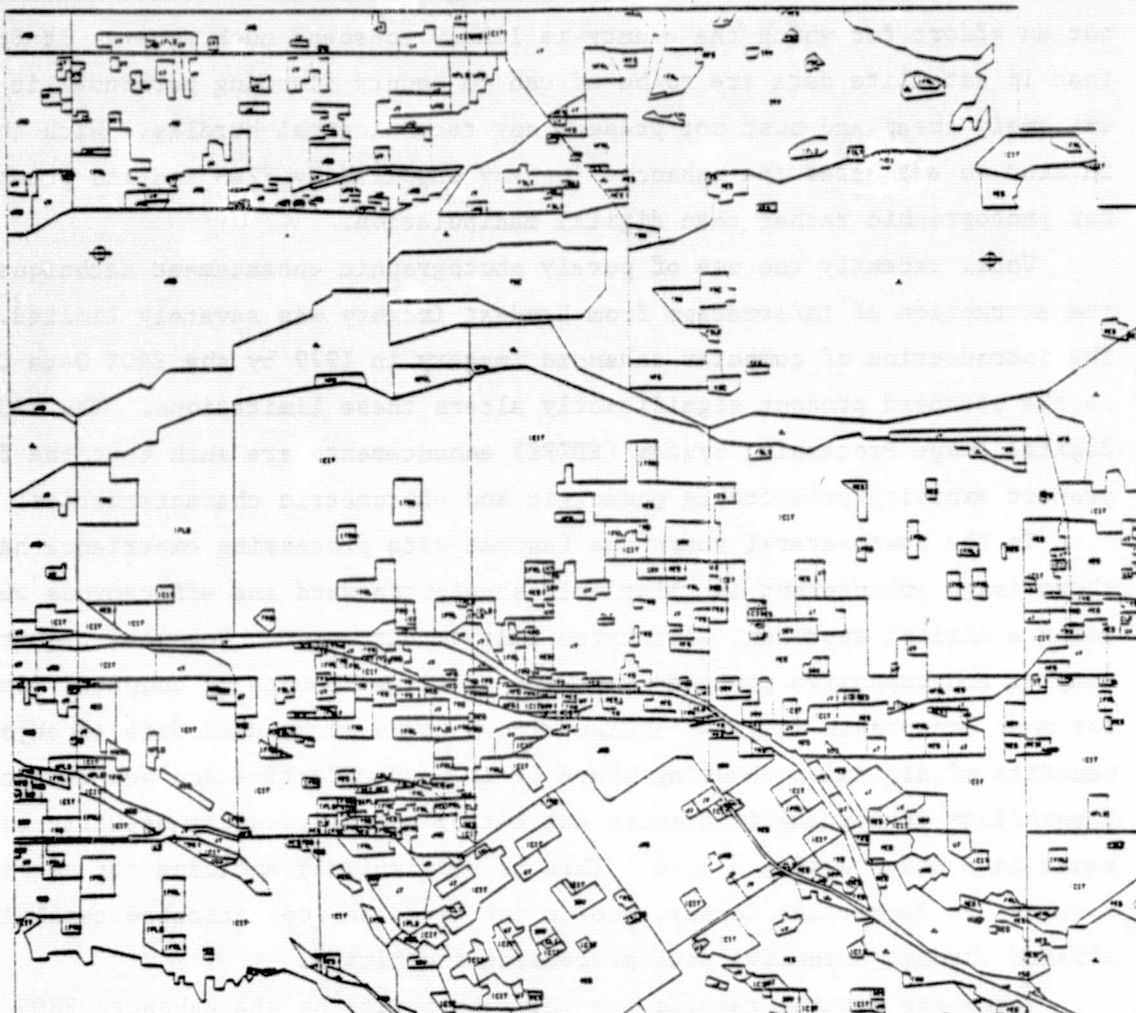

Figure 3

Agricultural land use map for Redlands Quadrangle, 1977

encroachment data. It should be pointed out that agriculture in San Bernardino County is usually in the form of relatively small parcels of land which are interspersed with other (usually urban) land uses. Landsat imagery is of such a resolution that it can only be used for gross change detection and monitoring-not an effort for which the county is likely to spend much money. It follows that if satellite data are to be of use to county planning personnel it must be extremely cheap and must not present any technological hurdles. With this in mind we evaluated the enhanced imagery supplied by EROS and its potential for photographic rather than digital manipulation.

Until recently the use of purely photographic enhancement techniques for the extraction of information from Landsat imagery was severely limited. The introduction of computer enhanced imagery in 1979 by the EROS Data Center as the standard product significantly alters these limitations. The EROS Digital Image Processing System (EDIPS) enhancements are such that the film product exhibits predictable geometric and photometric characteristics.

In the past several years the Landsat data processing experience has shown image enhancement is relatively straightforward and efficacious when using a digital approach. Automated feature extraction, however, requires complex and expensive computer hardware or large amounts of computer time for most acceptable results. EDIPS allows users of Landsat data to enjoy the benefits of digital processing where it is most effective and yet retain the flexibility of systematic feature extraction and application-specific enhancements in a cheap analogue mode. This is particularly exciting for users, such as San Bernardino County, who do not have the sophisticated capabilities offered through expensive data processing facilities.

There are several reasons for the superiority of the enhanced EROS imagery. Processed with the EROS Digital Image Processing System (EDIPS)* and photographically produced with a Laser Beam Recorder (LBR), the final film product exhibits geometric and radiometric corrections as well as contrast and edge enhancement. Destriping, synthetic line generation and edge enhancement are applied to standardize image quality and thus the number of variables which might tend to confuse visual interpretation are reduced. However, the most significant changes brought about by EDIPS are a result of the LBR and the contrast enhancement of the spectral bands.

The LBR produces images with a nearly linear grey scale display (i.e. step wedge). The significance of the step wedge is that it reveals the

*EDIPS is the operational system which is scheduled to go into production sometime in early 1979. The proto-type system was termed EDIES (EROS Digital Image Enhancement System) and the preliminary tests we have carried out were with the EDIES product.

information transfer characteristics of the recorded image. Using this step wedge, the photographic technician can precisely control photographic manipulations of the image. The ideal step wedge for photographic manipulation is a neutral grey scale in which maximum and minimum densities are separated by steps of equal density change with a constant slope of one. When the slope is one, the maximum tonal separation between the maximum number of steps is achieved. Figure 5 shows an ideal grey scale used in the graphic arts for image control. When the EDIPS imagery is compared with the earlier Landsat film product (Figure 5), it is seen that the new product more closely corresponds with the photographic ideal. See Figures 7 and 8 for examples of color combined images made with the non-enhanced and EDIPS photographic products.

Due to limitations inherent in the photographic process, information contained in the toe and shoulder of the non-enhanced Landsat image is essentially lost for precise photographic manipulation. Accurate photographic control is limited to the straight line portions of the step wedge graphs because it is increasingly difficult to photographically separate steps recorded on the imagery with either extremely high or extremely low slope values. In essence, to realize the full dynamic range of Landsat data, a duplication method (film or films and developer combinations) would have to be found which would appropriately compensate for the non-linearity and slope deviations of the unprocessed Landsat images. The problem is minimized if the user is only interested in relatively small density ranges in the imagery, since the slope change deviates little through small increments. Accurate photographic manipulation of the entire scene over the full density range is facilitated by utilizing the computer enhanced imagery.

A photographic laboratory can use the grey scale as a control guide in an analogue approach to many digital image processing operations. The compatability of the EDIPS film product with standard photographic materials is further apparent when the maximum and minimum densities are compared. This density difference is precisely 1.6 as opposed to the earlier Landsat film products which were measured as having maximum and minimum density differences ranging from 1.19 to 2.0 units. A density range of 1.6 corresponds with the sensitivity range of a wide variety of photographic films and papers. There are relatively few photographic materials which exhibit a straight line portion in their D log e curve longer than 1.6 density units (Figure 6). Using the enhanced EDIPS film product many image processing tasks (most with digital corollaries) can be easily accomplished in the photographic laboratory using readily available materials.

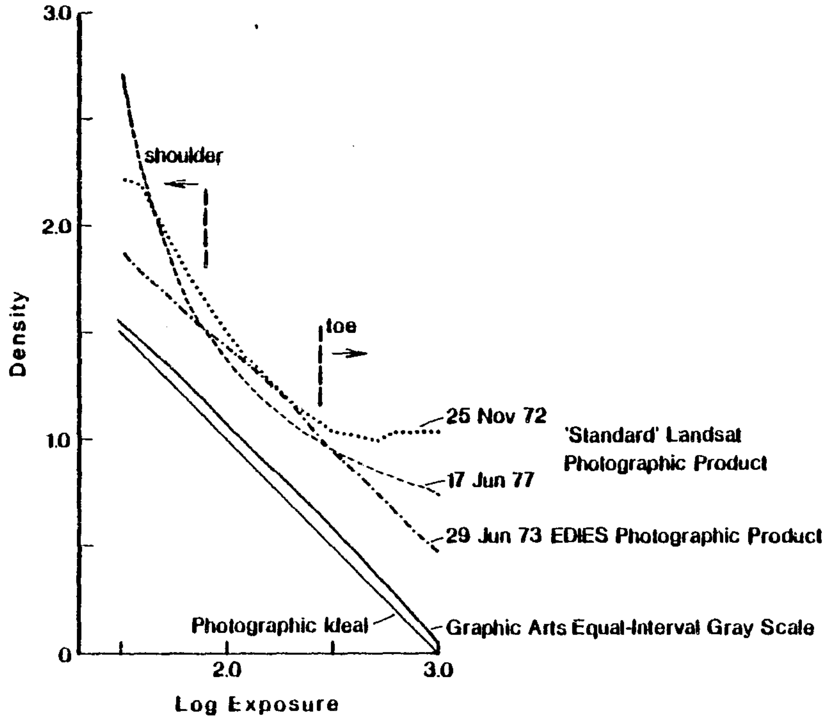

Figure 5

Density/log exposure census measured for Landsat standard and enhanced photographic products compared with those for typical graphic arts materials and the photographic ideal.

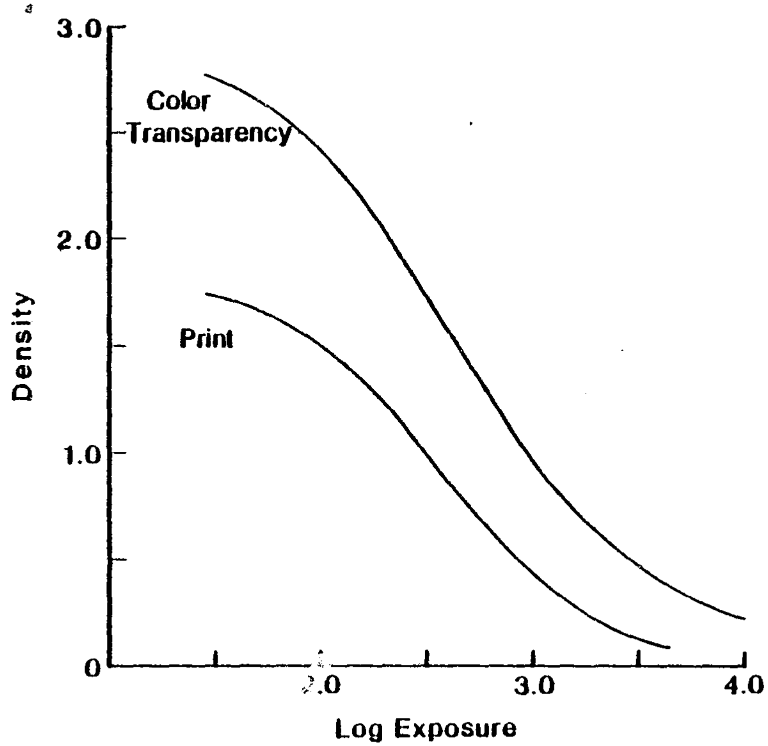

Figure 6

Density/log exposure curves for typical photographic materials.

Figure 7

Non-enhanced color-combined Landsat scene
of San Bernardino, California area.

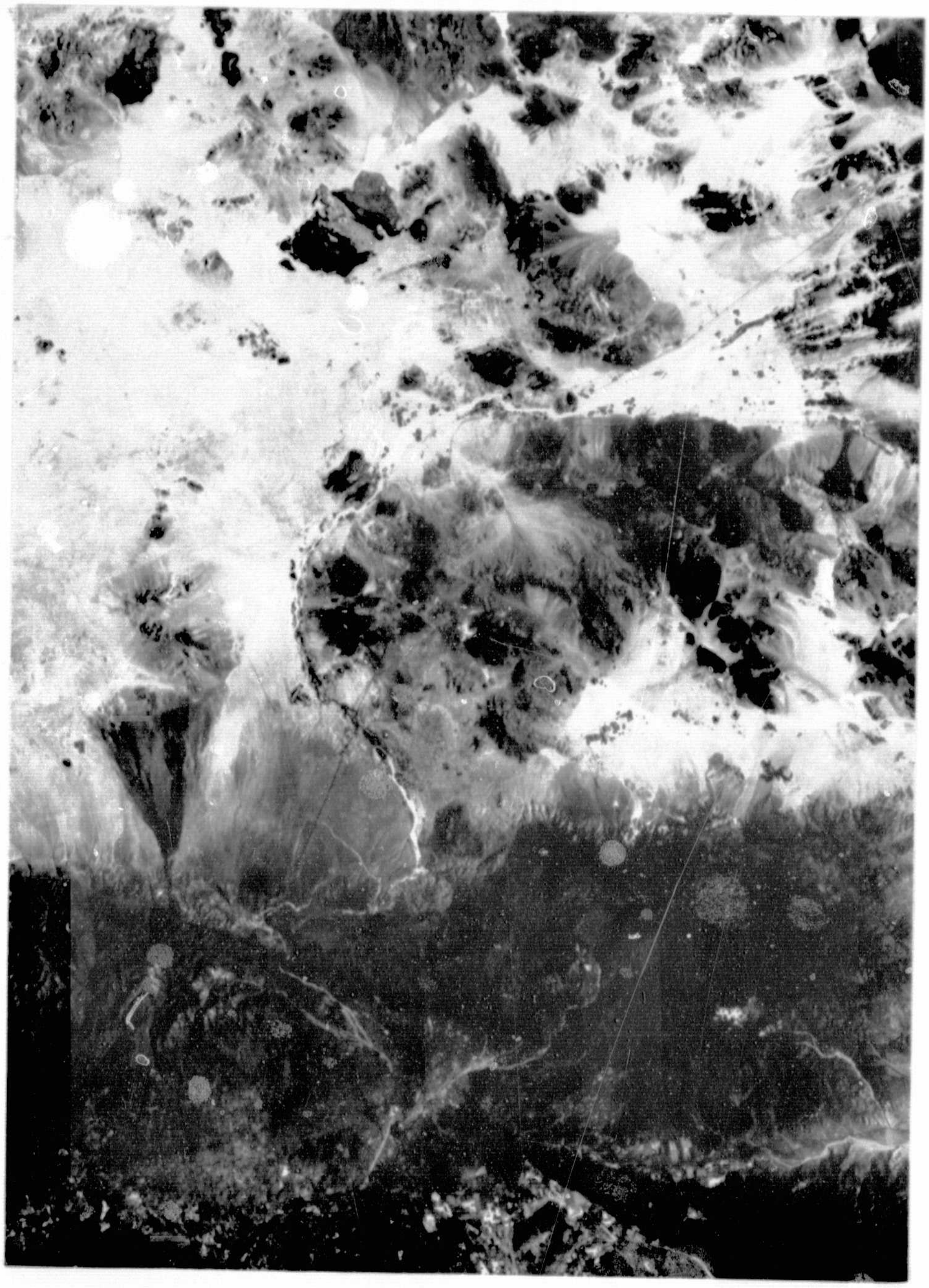

Figure 8

EDIES enhanced color-combined Landsat scene of San Bernardino, California area

Photographic image processing is not new. Many techniques which can be employed were developed 10 to 20 years ago when multi-spectral photography was first being investigated. However, the success of these experiments has always been hampered by poor photometric control of the source image. There are several techniques utilizing EDIPS imagery which should be explored and rigorously evaluated in a research program.

Photographic enhancement of the EDIPS imagery has two advantages over digital methods. First, photography allows almost instantaneous processing of the large amounts of data available in each Landsat image, and secondly, the cost of implementing photographic processing and optical quantification of images is significantly less than even the most basic digital image processing systems. The possibilities of photographic manipulation techniques warrant close investigation by potential users of Landsat images not willing or able to invest in the sophisticated digital sytems.

4.2.2 Resource Management Problems in the California Desert-Desert Recreational Road Estimation

The California desert is an area stretching from the Mexican border to Death Valley, some 25,548 square miles (Figure 9). The Bureau of Land Management (BLM) Desert Plan Staff of Riverside came to us to determine if remote sensing could be used to estimate the road mileage in the California desert. With the aid of statistical sampling techniques and the good fortunes of reasonably complete U-2 high altitude photographic coverage we were able to perform such an analysis.

The method employed permits separate estimates of road mileage for the entire desert and subareas (strata) within the desert for the purpose of identifying the spatial distribution of roads and washes. The immense size of the area prompted the use of a random sampling strategy. In particular, a stratified random sample was selected as most appropriate because it provides for subarea estimates. Since the sampling technique is based on the laws of probability, the estimate is couched in terms of a confidence limit, which describes how close to the true values the estimates are likely to be.

4.2.2.1 Sampling Procedure

The total area was divided into eight smaller areas, each of which is termed a stratum, to allow estimation of road and wash lengths within each stratum. After delineating the strata, a grid overlay of longitudes and latitudes at 15 minute intervals was constructed. A single block of this

264

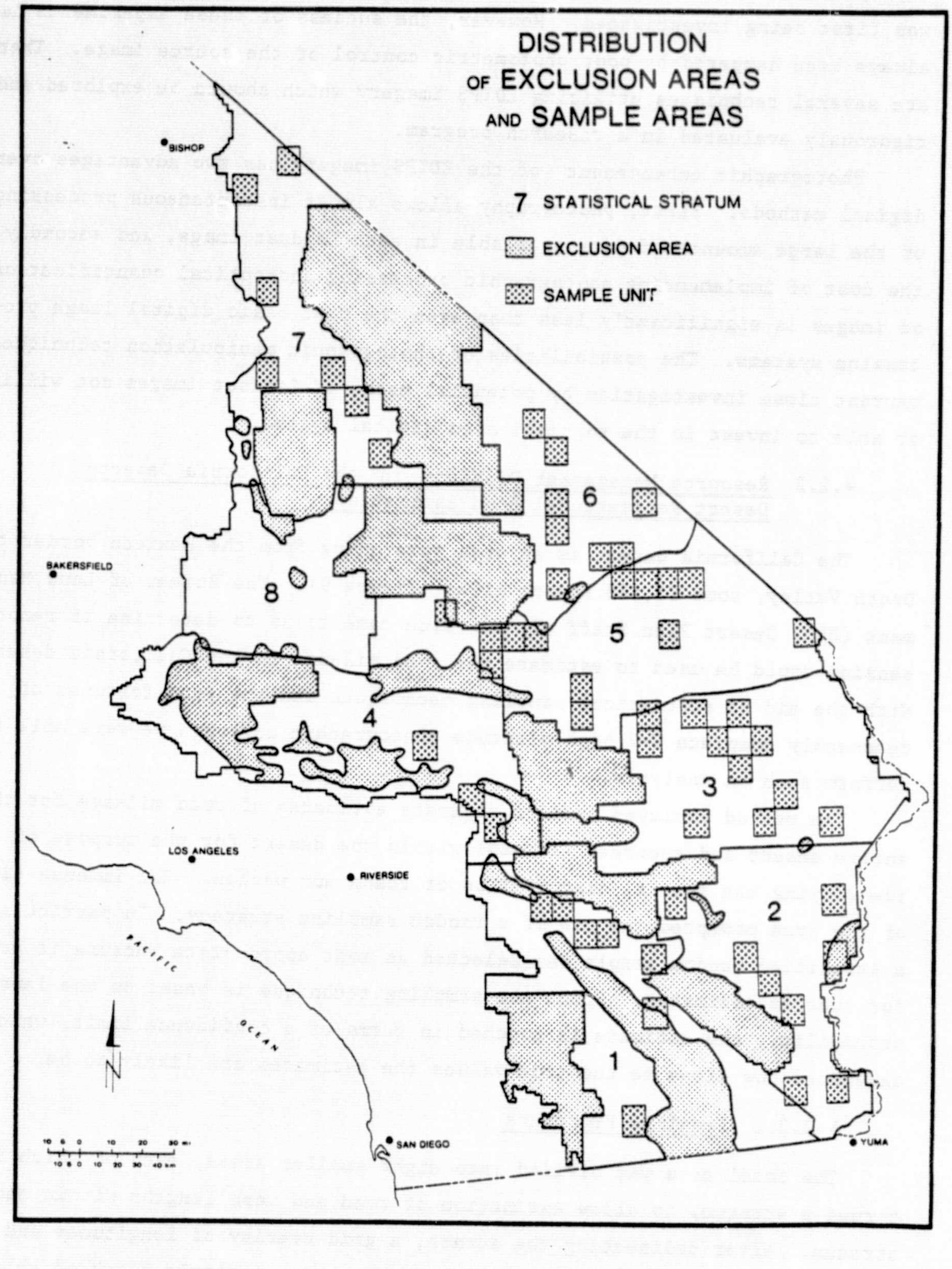

Figure 9 The California Desert

grid represents a U.S.G.S. 15' topographic quadrangle. Each block was further subdivided into four smaller blocks, each in turn representing the area covered by a U.S.G.S. 7 1/2 minute topographic quadrangle. These 7 1/2 minute blocks constituted the possible sampling units. Each 7 1/2 minute block within a stratum was assigned a number which could then be compared against a table of random numbers. A random number table provided the basis for selection or non-selection of the sample. Sampling units that fell on strata borders required a decision as to exclusion or inclusion. The criterion used was whether or not more than half of the unit fell within the stratum. Table 1 provides data on the area, the number of sampling units, and the percentage of the total area sampled for each stratum.

Stratum	Total area (mi^2)	# of sample units	Area sampled (mi^2)	% of total area sampled
1	2368.3	7	361.8	15.3
2	3046.2	8	483.7	15.9
3	4027.5	11	676.6	16.8
4	3692.3	6	340.9	9.2
5	3837.8	10	610.2	15.9
6	3090.7	8	484.9	15.7
7	3123.7	7	419.4	13.4
8	2361.7	0	0	0
	25,548.2	57	3377.6	13.2% of 25,548.2

Table 1

Area, number of sample units, sample area, and percent sample area, for each stratum.

The number of samples, 57, was selected on the basis of an initial sample done in stratum three. Eight sample units were selected and total mileage and the variance were calculated. Based on time and cost factors it was decided to draw a total sample that would provide 88% accuracy at a 90% confidence level (see Confidence Levels). The formula for calculating the total sample size based on these parameters and the initial sample is:

$$N = \frac{2.69S^2}{r^2 \bar{X}^2} \quad (1)$$

where N is the total sample size, S^2 the variance of the initial sample, r the desired relative error fraction (1 - .88), $\overline{X}$ the mean of the initial sample, and 2.69 is a value associated with the 90% confidence limit.[1]

The data for strata four and eight require explanation. No imagery at a suitable scale was available for stratum eight, thus no sampling was possible. In stratum four, suitable imagery was available for only the eastern portion, so that only limited sampling could be done. Locations of all sample units are shown on Figure 9. As mentioned, sample units correspond to 7 1/2 minute quadrangles, each representing an average surface area of 61-62 square miles. At a scale of 1:130,000, these were approximately 3 1/2 inches by 4 1/4 inches in size.

Area calculations were performed in two ways. First, the map, "California Desert Conservation Area", May 1977, provided by the Bureau of Land Management (BLM), was digitized and a computer program was used to calculate the area of each stratum. Within a stratum are many areas of urban or agricultural land use, within which the roads cannot be considered primarily for recreational use. These areas were also digitized; areas calculated and subtracted from each stratum. Exclusion areas are shown on Figure 9. The second method of area calculation applied only to the sample units. Because the sample units were based upon geographic coordinates, account had to be taken of both the convergence of meridians toward the poles and the nonspherical shape of the earth. The Clarke Spheroid of 1866 provided the model for the calculation of areas defined by geographic coordinates.[2] The value for a sample unit varied from a maximum of 62.68 mi^2 for the southern most sample unit to a minimum of 59.33 mi^2 for the northern most sample unit.

4.2.2.2 Photo Interpretation

Aerial photography was available for most of the California desert at varying scales. The imagery selected for interpretation was color infrared (CIR) film taken by NASA's U-2 aircraft from an altitude of approximately 65,000 ft. This imagery, with a scale of 1:130,000, was particularly well suited because an entire sample unit could normally be interpreted from one frame. Imagery at the scale of 1:130,000 has been flown on various dates. The most recent date for a given sample unit was utilized. Table 2 gives the

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[1] Cochran, William G. Sampling Techniques, John Wiley & Sons: New York, 1977.

[2] Department of the Army, Grids and Grid References, TM 5-241-1 GPO: Washington D.C., June 1967.

Maling, D. H., Coordinate Systems and Map Projections, George Philip & Son LTD: London, 1973.

dates of the imagery used and the corresponding percent of total sampled area taken from each date.

	Date	Percent of area sampled
1.	Jul 77	47.3
2.	Jun 77	21.1
3.	Mar 73	19.3
4.	Jun 73	1.8
5.	Nov 72	1.8
6.	Oct 72	5.3
7.	Oct 72	3.4
		100.0%

Table 2

Flight dates and percent of area sampled from those dates.

Each sample unit was interpreted to identify roads and negotiable washes. Roads were generally easy to identify. Roads are linear features and are lighter in tone than surrounding areas due to the disturbance of the surface. In some areas, they were impossible to distinguish visually from the surroundings. In those places where surface reflectance was high there was little tonal difference; thus roads tended to merge with background. Areas such as extensive sand or dry lake beds typically have light coloration so that roads within these areas could not be delineated with a great deal of confidence. In those cases where a road could be detected entering into a light area and leaving on approximately the same track and orientation the presence of the road was inferred.

Negotiable washes presented a problem of definition as well as interpretation. Once a rigid set of criteria was developed, interpretation was rapid and consistent. Three criteria were used to define a negotiable wash. First, the wash had to be reasonably wide, nominally about 40' wide on the ground in the flat portion of the channel. Secondly, the wash had to be relatively free of debris such as boulders and vegetation so as to permit vehicular passage. The third criterion was that the surrounding area had to provide some local relief, generally greater than 25-50 ft. Washes in areas of relatively flat terrain and with a local relief of only 5 to 10' were not delineated. The rationale for excluding washes based on the third criterion was that surrounding flat ground offered little resistance to ORV movement, while in areas of greater relief washes provided the only possible access.

After all 57 sample units had been interpreted the mylar overlays were digitized on a line-following digitizer. The digitizer used has a pencil-like stylus that was used to follow the lines representing either roads or washes. Measurements as fine as .01 inch can be registered and by application of the proper conversion factors the final result can be output in terms of miles. Additionally, the system provides a reproduction of the digitized map that can be used to insure that all lines have been measured.

3.2.2.3 Statistical Analysis of Data

Data were analyzed at two levels; for each individual stratum and for the entire desert. To estimate total road and wash lengths within each stratum the following formula was used for estimating the total (length of roads and washes):[3]

$$\text{estimated total} = N\overline{X} = \frac{N\sum_{i=1}^{n} X_i}{n}, \qquad (2)$$

in which N is the total number of possible sample units within a stratum, Xi is the actual road or wash length within a sample unit, and n is the actual number of sampled units. The variance about the mean road or wash length within a stratum is:

$$\text{variance } (S^2) = \frac{\sum_{i=1}^{n} (X_i - \overline{X})^2}{n - 1}, \qquad (3)$$

in which all symbols have the same meaning as in formula 1. The N term is a calculated value related to the total area of a stratum relative to the area sampled. The formula for calculating N is:

$$N = \frac{n \times \text{total area of a stratum}}{\text{area sampled within stratum}} \qquad (4)$$

This method of approximating N was employed to avoid problems introduced by the inclusion of areas comprising less than half of a 7 1/2 minute quadrangle in the total area calculation but which had no chance of being selected as

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[3] Statistical formulae from, Mendenhall et al, Elementary Survey Sampling, Wadsworth Publishing Co., Belmont, CA 1970.

a sample unit, as well as the exclusion of certain areas from sample units based on land use.

The analysis of data at the desert-wide level simply requires aggregation of the individual stratum parameters. Thus the estimator for total road and wash lengths of the entire desert is given by the formula:

$$\text{total estimator } (\hat{E}) = \sum_{i=1}^{L} N_i \bar{X}_i, \qquad (5)$$

in which L is the number of strata, N_i is the N term of the ith stratum, and $\bar{X}_i$ is the mean road or wash length for the ith stratum.

Stratum four, in which only a part of the area was sampled, and stratum eight, in which no sampling was done, presented cases in which the above formulae could not be applied. The single best estimator for stratum four is the estimator derived from the sampling that could be done in the eastern portion. For stratum eight, the single best estimator is a per-area average derived from the other seven strata. These special assumptions and formulae (2-5) were used to compile the results that are presented in Tables 3 and 4.

Tables 3 and 4 give the estimates of total road and wash lengths, within each stratum and for the desert as a whole. The standard deviation (s.d.) compared to the mean value of each stratum gives an idea of how good the estimate is.

Stratum	Mean Rd. Length (mi)	s.d.	N	Total Rd. Length (mi)
1	59.1	36.7	45.8	2707.1
2	53.1	27.3	50.4	2676.2
3	42.3	24.5	65.5	2771.8
4	61.8*	30.5*	65.0*	4017.1*
5	54.7	33.4	62.9	3442.0
6	43.1	33.2	51.0	2199.2
7	30.0	6.1	52.2	1563.2
8	0	27.4	0	1973.6*
				21,350.0 total road length for California desert

* Asterisks indicate use of special assumptions to calculate value

Table 3

Mean road length, standard deviation (s.d.), N, and total road length of each stratum.

270

Stratum	Mean Wash Length (mi)	s.d.	N	Total Wash Length (mi)
1	15.7	11.6	Same as roads	720.8
2	11.5	10.9		577.9
3	27.3	15.0		1789.6
4	4.6*	5.1*		300.2*
5	18.5	12.5		1160.3
6	14.8	13.5		756.7
7	12.9	6.0		672.6
8	0	10.7*		608.9*
				6586.9 total wash length for California desert

* Asterisks indicate use of special assumptions to calculate value.

Table 4

Mean wash length, standard deviation (s.d.), N, and total wash length of each stratum.

As explained earlier, a value of 90% selected as the level of confidence. That is to say, in nine cases out of ten the true estimator can be expected to fall within the range of numbers given by the confidence limits. Tables 5 and 6 give these confidence limit values for each stratum and for the desert as a whole (strata 1, 2, 3, 5, 6, and 7). The accuracy implied by these limits is also given.

Confidence limits for 90% were calculated according to the following formula:

$$90\% \text{ confidence limit} = 1.64 \sqrt{N^2 \frac{S^2}{n} \frac{N-n}{N}} \qquad (6)$$

Since no samples were taken from stratum eight, confidence limits could not be calculated. Stratum four confidence limits have been calculated but they have little meaning since the values used do not rigidly meet the random sampling assumptions. Confidence limits for the total estimated road and wash lengths for strata 1, 2, 3, 5, 6, and 7 (all but four and eight), are given in Table 7.

Stratum	Total Road Length	90% Confidence Limits	Accuracy (%)
1	2707.1	± 959.3	64.6
2	2676.2	± 731.1	72.7
3	2771.8	± 723.6	73.9
4	4017.1*	± 1262.2*	68.6*
5	3442.0	± 998.5	71.0
6	2199.2	± 900.6	59.0
7	1563.2	± 184.5	88.2
8	1973.6*	—	—

Table 5

Total road lengths (from Table 3), 90% confidence limits, and the accuracy (as a percent of total road length).

Stratum	Total Wash Length	90% Confidence Limits	Accuracy (%)
1	720.8	± 302.9	58.0
2	577.9	± 292.8	49.3
3	1789.6	± 444.1	75.2
4	300.2*	± 213.1*	29.0*
5	1160.3	± 374.3	67.7
6	756.7	± 366.9	51.5
7	672.6	± 179.3	73.3
8	608.9*	—	—

Table 6

Total wash lengths (from Table 4), 90% confidence limits, and the accuracy (as a percent of total wash length).

* Asterisks indicate use of special assumptions to calculate value.

272

1. Strata 1, 2, 3, 5, 6, and 7 (all except 4 and 8)

total miles of road	15,359.5
90% confidence limits	± 1954.6
Accuracy	87.3%
total miles of washes	5677.9
90% confidence limits	± 825.6
Accuracy	85.5%

2. Strata 1, 2, 3, 5, 6, 7 and 4 (all except 8).

total miles of road	19,376.9
90% confidence limits	± 2326.7
Accuracy	88.0%
total miles of washes	5978.1
90% confidence limits	± 852.7
Accuracy	85.7%

Table 7

Confidence Limits for the entire desert (roads and washes).

4.2.2.4 Sources of Error

A number of error sources can be identified in the method described, all tending to underestimate the total number of miles of roads and washes. One source of error, already mentioned, was the failure to distinguish between road surfaces and surrounding surfaces. This error source is relatively small because the amount of area with light coloration or other characteristics that tended to minimize surface-road contrast was small. Another relatively minor error source was that certain samples had to be interpreted at the extreme edges of a photo frame and in some cases a single sample had to be interpreted from two frames from adjacent flight lines. This means that the optimal portion of the image was not used, as distortion increases toward the edge as well as obscuring effects of slopes facing away from the photo center.

Two more important sources of error exist. One relates to the differing dates of imagery used for interpretation. The oldest imagery is over six years old and many new roads may have been created in the interim. Undoubtably, however, the largest single source of error resides in the inability to transfer and accurately measure the sinuosity of a road. There are actually two parts to this source of error. The first is that in areas with a lot of road curvature the pencil line width on the overlay is so wide that much road curvature can occur within the line width. The error might be minimal on flat surfaces, but in areas of complex terrain the error probably increases. The second part of this source of error occurs in the digitizing process and is affected by the digitizer sampling resolution of .01 inches.

274

4.3 CONTINUING STUDIES

4.3.1 RESOURCE MANAGEMENT PROBLEMS IN CALIFORNIA AVOCADO PRODUCTION

4.3.1.0 INTRODUCTION

Avocados have been commercially grown in California since the early 1920's. The industry, located primarily on the coastal slopes and plateaus from Santa Barbara to San Diego (Figure 10) gradually increased from a few hundred acres to a few thousand acres as gentleman farmers entered the business. A large expansion period occurred from 1945 to 1959 which resulted in the creation of the California Avocado Advisory Board under a state marketing order. The question may arise as to why such a well organized quiet industry would need help. For some of the reasons outlined below, the industry finds itself in a new expansion period (since 1972) that has made it impossible to make any reasonably accurate crop forecast. The havoc that has been created within the industry because of inadequate information could (although not likely) cause a complete collapse of the industry with cash return to the growers falling below the cost of production.

The number of acres of California agricultural and undeveloped land converted to avocado production in the past five years has more than doubled (from 25,000 acres to more than 50,000 acres). The rate of increase has been holding at 5,000 acres of new avocado groves per year; 5,000 new acres can be translated into 25 million pounds of fruit (25% of 1977-78 production) within 5 years of planting and 50 million pounds of fruit (10% of the 1977-78 production) within 10 years. The industry is aware that these annual increases will be cumulative during the next several years. The full impact of the rapid increase in producing acreage is being felt for the first time during the present production year (November 1 through October 31).

Annual production has gradually increased to 200 million pounds. The 1978-79 forecast is 314 million pounds of fruit (a 65% increase in one year!). The major marketing techniques of the California Avocado Commission are constrained by the ability of the industry to provide quantities of fruit to each of the newer markets as well as a continual supply to older markets. To guarantee market deliveries, the industry must know how much fruit will be available each week during the year. The present method of obtaining forecast data has become antiquated due to:

1) Entry into the industry via speculative plantings on lands of marginal climatic and edaphic suitabilities.

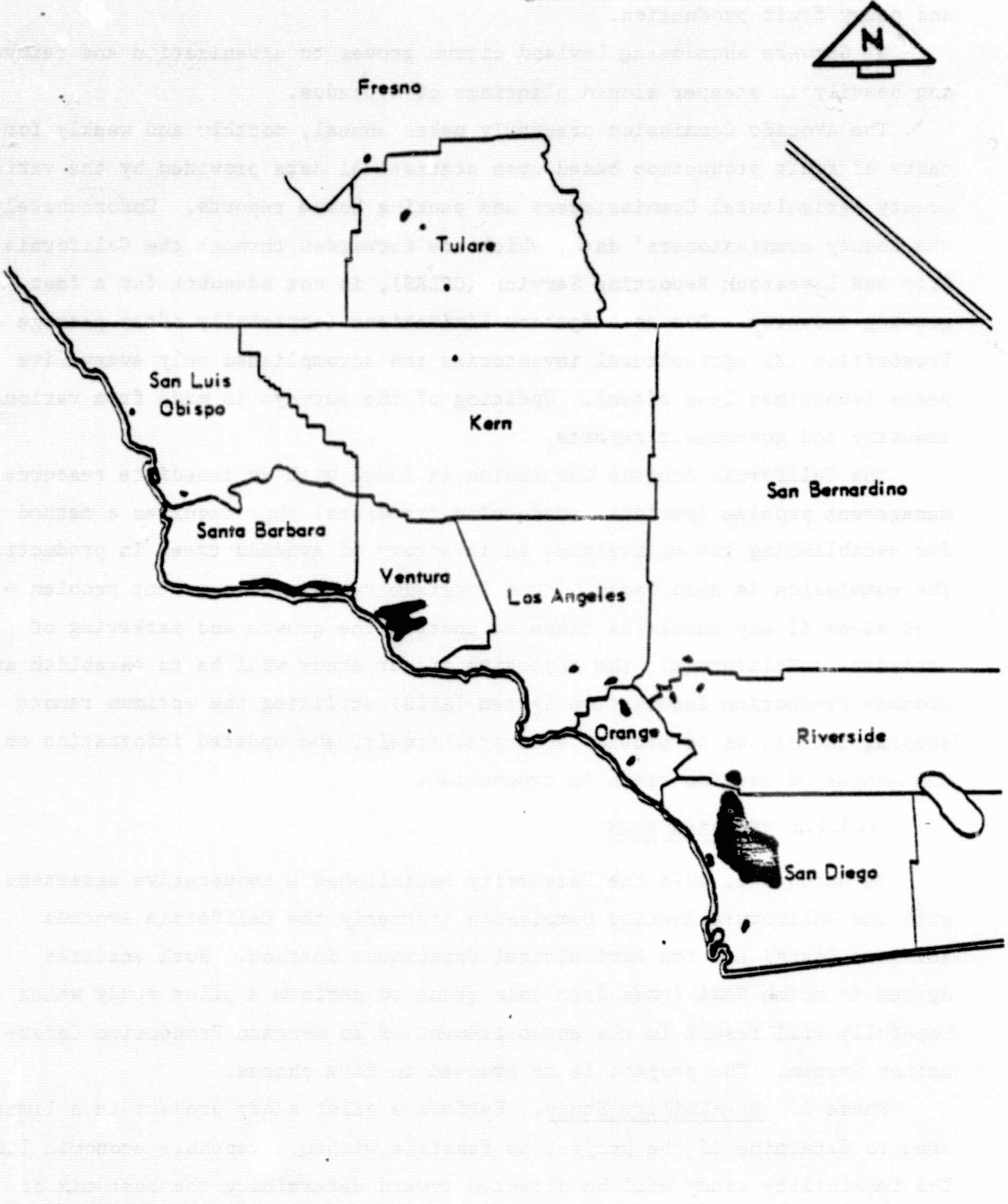


Figure 10

Commercial Avocado Production Areas in southern California

276

2) Deference by the developers to scientific cultivation practices in opting for short term fruit gain, but unknown tree life. (e.g. no root rot prevention techniques).

3) Introduction of new varieties planted in hopes of obtaining early and heavy fruit production.

4) Growers abandoning lowland citrus groves to urbanization and reinvesting heavily in steeper sloped plantings of avocados.

The Avocado Commission presently makes annual, monthly and weekly forecasts of fruit production based upon statistical data provided by the various county Agricultural Commissioners and packing house reports. Unfortunately the county commissioners' data, which are forwarded through the California Crop and Livestock Reporting Service (CCLRS), is not adequate for a fast growing industry. Due to budgetary limitations (especially after passage of Proposition 13) agricultural inventories are accomplished only every five years (sometimes less often). Updating of the surveys is made from various industry and government reports.

The California Avocado Commission is faced with an immediate resource management problem (periodic production forecasts) that requires a method for establishing and maintaining an inventory of avocado trees in production. The commission is also faced with a longterm resource management problem - what steps if any should be taken to control the growth and marketing of Avocados in California? The objective of our study will be to establish an Avocado Production Information System (APIS) utilizing the optimum remote sensing techniques to provide accurate, timely, and updated information on the status of avocado trees in production.

4.3.1.1 RESEARCH PLAN

On October 1, 1978 the University established a cooperative agreement with the California Avocado Commission (formerly the California Avocado Advisory Board) and the Agricultural Experiment Station. Both entities agreed to match NASA funds from this grant to perform a pilot study which hopefully will result in the establishment of an Avocado Production Information System. The project is to proceed in five phases.

Phase 1. Feasibility Study. Perform a pilot study project in a limited area to determine if the project is feasible within acceptable economic limits. The feasibility study will be directed toward determining the best mix of imagery (low-altitude, high-altitude, and satellite) to provide accurate annual avocado production information.

Phase II. Design an Information System. This phase is to design and develop an Avocado Production Information System (APIS) that will incorporate data from remotely sensed imagery, public records, and industry packing house records. The intent of the information system is to provide statistical data that will enable a forecast to be made at any time for any period of time. The information would include the number of acres of avocado land, the number of trees by variety, and the bearing status (life) of the trees.

Phase III. Implementation of the Pilot System. To test the design of the information system, it will be applied with the data produced from the test site during the feasibility phase. Changes will be made to the system as indicated during this testing phase.

Phase IV. Development of a California State Wide System. Upon the completion of the first three phases a total statewide system will be developed. At this time it would be appropriate to consider the decreasing of NASA contributions to the project and an increase of the industry funding.

Phase V. State Wide Implementation of the System. At this point the system will have reached a point to be turned over to the California Avocado Commission for their use and implementation in forecast procedures.

4.3.1.2 CURRENT OBJECTIVES

The objectives of the avocado study for the FY 79-80 grant year encompass phase I of the plan and portions of phases II and III. The objectives are:

1. Provide the following graphical and statistical data within the pilot study area:
   a) number of trees and acreage of each grove,
   b) variety of tree(s) in each grove,
   c) the bearing capability (age) of the trees, and
   d) statistical tabulations for the total area.
2. An estimate of the accuracy of remote sensing from three platform levels to provide the basic data for an avocado crop forecast.
3. An evaluation, including imagery requirements, of the ability to detect diseased trees.
4. An estimate of the cost to perform an inventory of all avocado producing areas of Southern California.

4.3.1.3 PRELIMINARY INVESTIGATIONS

Matching funds of $10,000 provided by the Avocado Industry along with $6,000 matching funding from the University of California Agricultural

278

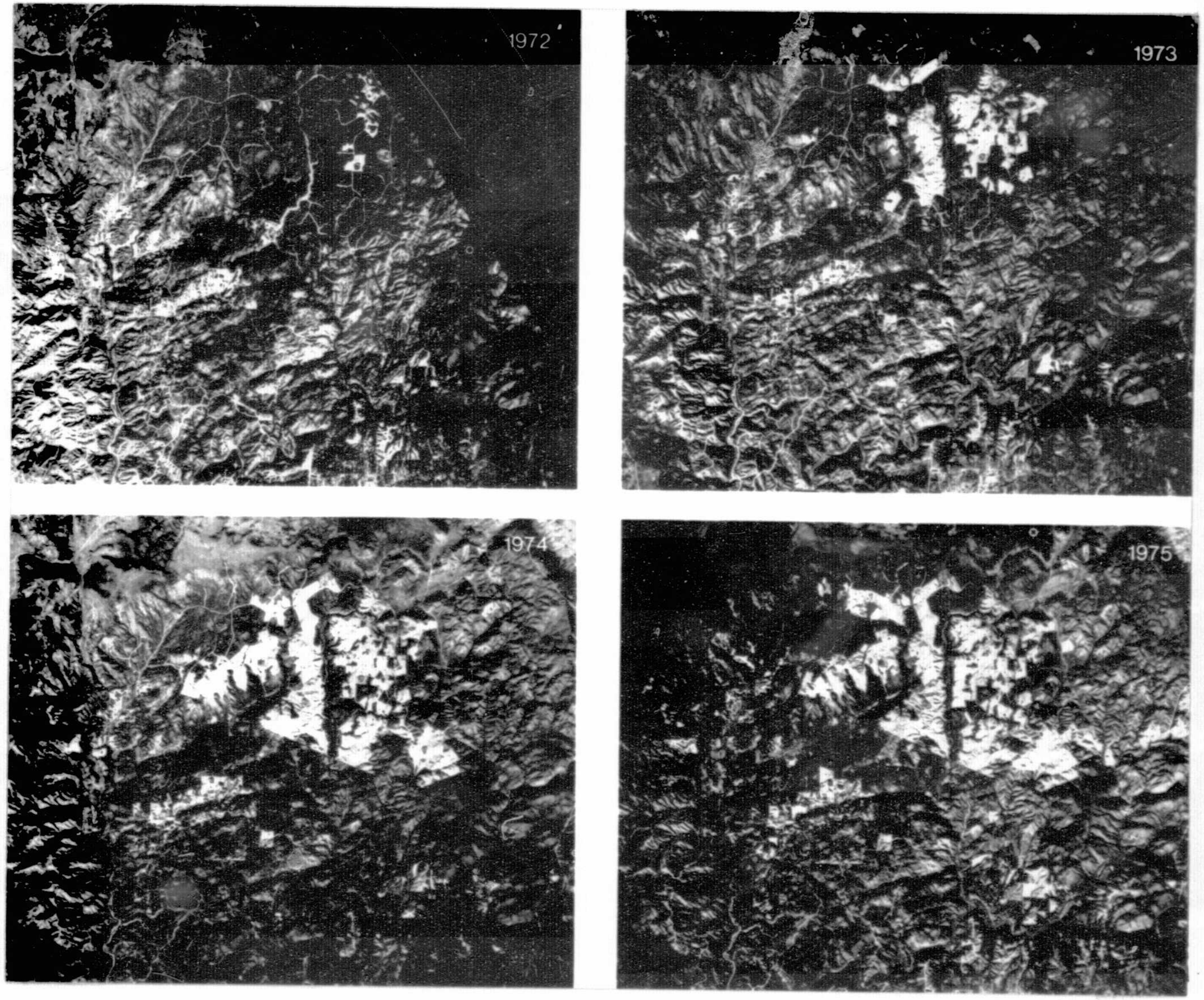
Experiment Station has made possible some preliminary investigations on the avocado study. Initially we have been experimenting with establishing an automated mapping base, reviewing NASA imagery that is in our files from previous studies dating back to 1965, and investigating current methods of data gathering by the industry.

1) Preliminary Results of Review of Historical High Altitude Imagery.

High altitude (RB-57 and U-2) imagery on file,of the selected test site, (Northern San Diego County) dates back to 1971 and is repeated in some form through the year 1975. In viewing this old imagery we noticed an additional area of interest, the West Mesa area of Rancho California in southern Riverside County. The imagery of Riverside County revealed an unexpected result. We were able to monitor the annual increase in plantings of avocados in the Rancho California West Mesa area beginning with the initial 100 acres planted in 1972 to more than 4,000 acres planted by 1975. This essentially means that we can date the year of planting and thus provide the age of each avocado grove, which is a major objective of the research project. Since similar imagery from Santa Barbara to San Diego is readily available, it appears that we can eventually determine the year of planting for each of the groves that have been planted since 1972. The most essential age differentiation for most groves will be possible because 10 years is considered by the industry to be a fully mature tree. Figures 11 a,b,c,d present an annual sequence of high-altitude images displaying the growth of the avocado industry in Rancho California.

2) Results of Preliminary Review of Historical Satellite Imagery.

One objective of the research is to determine the feasibility of using satellite imagery to detect areas of new agricultural plantings and to locate sites that need closer visual inspection and verification of agricultural activity. Knowing that the growth of avocados in the Rancho California area could be detected with U-2 imagery we reviewed archived Landsat I imagery to see what it would show. The same growth area displayed on the U-2 imagery was very much in evidence on the Landsat band 5 images for 1972-73-74 (Figures 12 a, b, c). The results from the low resolution Landsat imagery must be viewed with caution. The groves in question were contiguous fields of 40 acres or more planted next to coastal chaparral. In other locations one might expect to see new groves replacing citrus in an area contiguous to active agriculture lands. Recently available pre-processed (EDIPS) satellite



Figures 11 a, b, c, d: Sequence of high altitude aircraft (NASA U-2) photos showing the growth of avocado acreage in the west mesa area of Rancho California in southwest Riverside County. In 1972 the Kaiser-Aetna Corporation planted 100 acres of avocados. Additional acreage was planted to avocados in succeeding years with a total of 3,400 acres being planted by 1975.

28

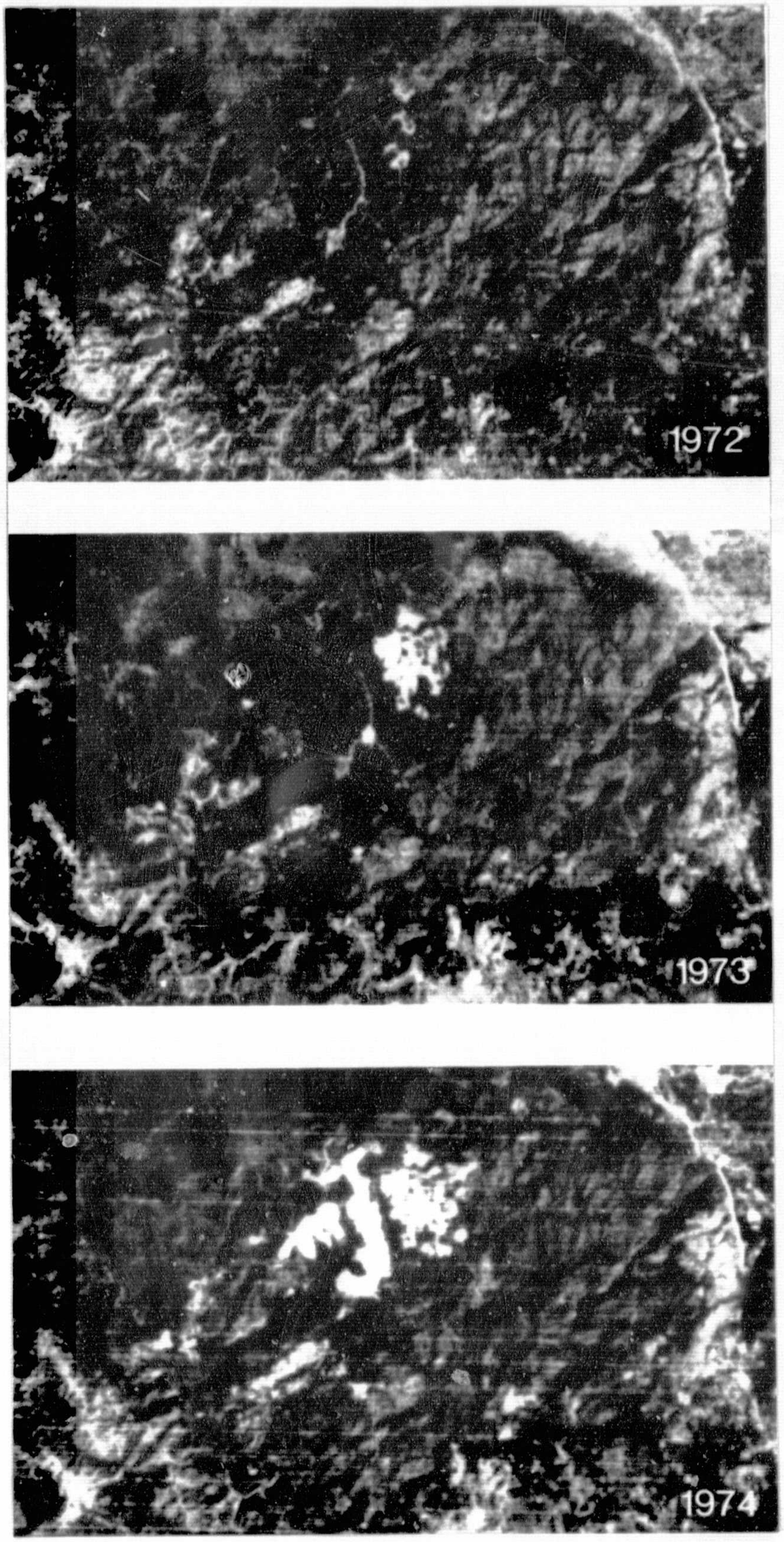


Figure 12 a, b, c: Sequence of Landsat I images showing the growth of avocado acreage in the West Mesa area of Rancho California in southwest Riverside County. 1972 photo shows the first 100 acres being planted. An additional 800 acres was planted in 1973 and another 1,700 acres in 1974.

imagery of much higher quality and resolution has not been examined. It may be possible to detect smaller objects in agricultural areas, but at this time it is not known how useful satellite imagery will be to the study overall. We do know that low resolution Landsat I imagery gives promise for the detection of large new plantings.

3) Current Avocado Data Gathering Efforts

Investigations to date indicate that the most difficult parameter to be obtained in the study will be the varieties of avocados in each grove. In attempting to determine the present methods of obtaining the data we have found that there does not exist within the industry any accurate or up to date information from which the present production forecasts are being made. The Avocado Commission is depending upon the county agricultural commissioners for data and we find that some county agricultural commissioners believe the Avocado Commission has more accurate data! The California State Crop and Livestock Reporting Records are only as accurate as their last survey (5 years ago) and whatever is supplied in the interim by the County Agricultural Commissioners. The interdependance and faith between the various statistical agencies indicates that there truly does exist a need for the Avocado industry to establish an accurate Avocado Production Information System.

4.3.1.4 RESEARCH APPROACH

To achieve the above outlined objectives, it is proposed UCR investigators, working in close cooperation with personnel presently collecting avocado production data, proceed as follows:

1) Select a Sample Survey Area

To provide an adequate sample that can be used to extrapolate the results to the entire avocado population, it is proposed that an area surrounding Fallbrook, California be used for the test site. The area is bounded on the north by the Santa Margarita River; on the south by Gopher Canyon Road; on the west by Camp Pendleton; and on the east by Highway 395 (115).

2) Acquire Imagery from Three Platform Levels

To permit determination of how often and at what cost a remote sensing survey must be flown to provide tree count data, we will require remotely sensed data at three scales.

282

a) Low Altitude Aerial Survey

To determine the accuracy obtainable for area (acreage) calculations of each avocado grove and to obtain a complete tree count, a commercially available low altitude aerial survey will be flown of the selected area. It is anticipated that at least three flight altitudes will be flown to determine the maximum altitude (most cost effective) that can be flown and still achieve the desired accuracy of tree count and acreage calculations. The flights will be flown with Color Infra Red (CIR) film to enable investigators to determine if other useful data can be obtained. The low altitude flight survey should provide the following data:

1) Tree count accuracy obtainable from remote sensing.
2) Acreage calculation accuracies obtainable from remote sensing.
3) The cost of obtaining tree count data on a per tree and a per acre basis. (Costs to include data reduction and analysis).
4) Accuracies obtainable in determining the size (age) of avocado trees from remote sensing.

b) High Altitude (U-2) Imagery

The availability of NASA flown U-2 imagery of parts of California obtained on a periodic basis for various research projects may make it practical to utilize high altitude imagery in lieu of or in conjunction with low altitude surveys to gather avocado forecast data.

An evaluation will be made to determine the usefulness, accuracies obtainable, and costs of obtaining tree count and acreage data from high altitude imagery. If high altitude imagery proves practical, it may be most cost effective to utilize the smaller scale imagery to update tree count and/or acreage data in alternate years when low altitude surveys are not deemed necessary.

c) Landsat Imagery

Once an Avocado Production Information System has been initially established the program will be to continually update the information on an annual basis. The intent of the second phase of investigation is to determine a cost-effective method of continual updating of the avocado data base.

We anticipate the improved (EDIPS) Landsat imagery can provide the user, having limited technical and economic capabilities, with a product that can be analyzed by innovative photographic techniques. Basic research to develop the photographic techniques is necessary. We will cooperate with the California Avocado Commission to develop a means for detecting changes in agricultural production and acreage. This procedure may eliminate the need for annual but costly low-altitude aerial surveys and replace or improve the present unsatisfactory reporting systems.

3) Establish an Automated Avocado Crop Production Information System

To provide an effective and current data base for analysis purposes in Avocado Production and Marketing Research, an Avocado Crop Production Information System will be designed. A map base will be established from interpretation of the remotely sensed imagery. An associated attribute file would be established to provide an index to each grove plotted on the map with associated data mutually selected by the members of the research committees and the UCR investigators. Examples of attribute items might be: acreage of grove, number of trees in the grove, estimated age of trees in the grove, ownership, leasee, mailing address, county parcel code, production record over the past several years, and packing house affilliation.

Any single attribute, or a combination of attributes can be displayed from the system by means of computer processed maps, or as statistical tabulations.

4) Determination of Optimum Remote Sensing Techniques for Obtaining Data

An analysis of the various methods of gathering remotely sensed avocado crop production data will be made to determine the most cost-effective method of obtaining avocado crop information on an annual basis. The cost of obtaining and processing the data for the test area will be extrapolated to provide costs for the complete coverage of the southern California area.

4.3.1.5 CONCLUSION

The avocado industry, once stable and well managed by dedicated family farmers, is now threatened by the influx of many non-agriculturally oriented developers. The result is thousands of acres of haphazardly planted orchards that is making it impossible to obtain useful and timely production data by the present data gathering techniques.

The need for better data gathering techniques is manifested in two very important decisions that the California Avocado Commission will have to make.

1) Has the avocado production in California reached the point where the California Avocado Commission must establish market quotas?

284

2) Should the Commission consider limiting the development of new acreages?

Regardless of how unpleasant the words 'quota' and 'limitations' may be to farmers and ranchers it is becoming a possibility for the avocado industry. It may become mandatory for survival.

Regardless of what action the Commission does or does not take, the need for remote sensing input to production data gathering is clear.

4.3.2 'BASIC' RESEARCH

It has been indicated above that Landsat imagery will be investigated for its utility in providing early warning indications of future avocado developments. Any development for the use of Landsat imagery must be designed to provide the best product of Landsat without the necessity of expensive digital computer processing techniques. We plan, in conjunction with the avocado project, to incorporate some 'basic' research that may provide a unique, but inexpensive means for the general user to employ Landsat imagery. Many varying photographic techniques of image enhancement have been developed, but we believe with a modest research effort these various methods can be combined with the sophisticated methods used by EROS Data Center to provide an inexpensive tool for planners and managers. In association with the avocado project we propose to develop such a system based upon the results of our preliminary investigations outlined in Section 3.2.1.2.

4.3.3 PROBLEMS OF OPPORTUNITY

Frequently we are asked by public agencies if we can solve a particular resource management problem. All of these requests are evaluated as to their appropriateness for investigations under this NASA grant. Last year the proposal by San Bernardino County to assist in the development of the agricultural element for their County General Plan was such a request. We have become involved with the Avocado industry by a 'problem of opportunity' request for assistance.

Recently the Public Health Department of Riverside County requested assistance in indentifying perched water tables within the county which have resulted from the two years of above normal rainfall. The problem in this case is the issuance or denial of tract housing permits for septic tanks and fields. It had become apparent that engineers could not always conduct tests which would be applicable in 100 year hydrologic conditions (our current situation). The desire was for the assistance of remote sensing in detecting these perched water tables through surface expression of hydrological differences.

It may be that the exigencies of the situation in early spring have been superceded by time and this is no longer a valid project for the grant. However, we will follow through with our contacts with the county to see if the data is needed for future resource management decisions.

A similar type project may be developing within the joint area of Riverside and San Bernardino Counties. There exists a critical need for a toxic waste disposal site within the joint land area. An existing site, that has not been used for several years, is still posing a threat to the water quality of the Santa Ana River basin because of recent above normal rainfall. The old toxic waste basins became flooded and were threatening to overflow. By pumping the basins down several feet and hauling the toxic wastes to another disposal site the threat of pollution was overcome. However, there still exists a need for a new 'safe' toxic waste disposal site within the two county area. We are following this development for a potential 'problem of opportunity'.

There are a few examples of the problems we encounter each year. More time is needed to study these latter two projects before we commit NASA grant funds to their solution. Meanwhile there will certainly be other problems that may be more appropriate to the grant. That is why we desire to reserve some funding for use later in the grant year.

286

CHAPTER 5

SPECIAL STUDIES

Some Important Remote Sensing Concepts

Developed and/or Tested

Under NASA Grant NSG 7220

by

Robert N. Colwell

287

CHAPTER 5

Some Important Remote Sensing Concepts Developed and/or Tested Under NASA Grant NSG 7220

Robert N. Colwell

During the nearly 40 years that the present writer has been engaged in remote sensing activities he has sought from time to time to elucidate various principles and concepts that appeared to be valid in such fields as photographic interpretation, photogrammetry, and remote sensing. He has found that some of these principles and concepts, while theoretically valid, did not prove out when scrutinized in the light of operational use. Others, however, including the ones dealt within this chapter, certainly did prove to be valid. Rarely has there been an opportunity comparable to the one provided by this grant for making such tests of validity. As indicated by the title of the project, our emphasis that permits highly meaningful tests to be made of otherwise theoretical concepts. Here, then, are some of the more important concepts which have repeatedly been subjected to practical testing under our present NASA grant and which thus far appear to be of such importance as to justify their being assembled and elucidated upon in this chapter.

A. Image Quality Concepts

It seems increasingly obvious that there are three attributes of photographic images that govern their interpretability, viz., the photographic tone or color contrast between a feature and its background; (2) the sharpness of the photographic images; and (3) the amount of stereoscopic parallax exhibited by them when overlapping photographs are viewed three-dimensionally. Other concepts of image quality and image interpretability have been developed, including those based on "acutance" and "modulation transfer functions". While they are more rigorous, and often quite useful, they do not properly acknowledge the importance of stereoscopic parallax.

288

The practical importance of these image interpretability concepts is as follows: For any given image interpretation task, one of the above mentioned attributes is likely to be found potentially more limiting than any of the others. Once this has been established, it usually is possible to exploit a knowledge of what can be done to improve that factor. Specifically as the imagery is acquired, a maximum effort can be made to improve the quality of this "most limiting" attribute.

Some related concepts assume importance as we seek to decide whether our efforts to improve image interpretability should be directed solely toward the improving of this most limiting attribute. One such concept is expressed (although in a somewhat different context) in "Liebig's Law of the Minimum", which asserts that the desired improvement (e.g., increased interpretability) can come only from improvement in this most limiting attribute. A seemingly discordant concept is expressed in "Misterlich's Law of the Minimum", which asserts that (a) improvement in the desired result can come about through improvement in any of the governing attributes; and (b) the amount of improvement that will be achieved, per unit improvement in the attribute, will depend upon the "decrement" of that attribute from its optimum state.

In practice, these seemingly opposing concepts usually become reconciled, however. For even as the "most limiting" attribute is progressively improved, the eventual result is that it no longer is most limiting, at which time we turn our attention to the improving of some other attribute which, in consequence, has now become the most limiting one.

B. The "Visual Acuity" Concept

Of the various image quality attributes considered in the previous section, the first three are the most meaningful ones in relation to the visual acuity of the image analyst (i.e., in terms of the ability of the photo interpreter to see relevant image attributes of the features that he is trying to identify). Specifically: (1) with respect to tone or color contrast (and the associated detection of certain features), some photo interpreters have serious visual deficiencies—especially those who are color blind; (2) with respect to sharpness (and the associated recognition of features through the perception of fine detail), some photo interpreters have serious visual deficiencies—especially those who are most susceptible to fatigue; and (3) with respect to stereoscopic parallax (and the associated perception of the three-dimensional configuration of features) some photo interpreters have serious visual deficiencies—especially those who have a "master eye" that is far stronger than the other eye. Through a realization of these facts it is possible to ensure that those called upon to interpret various kinds of features on a given type of photography have visual acuity capabilities that are equal to the task.

C. The "Selective Search" Concept

To paraphrase the treatment of this subject by Rabben (1960): A job of interpretation could be begun by close examination of all details which are thought to be relevant; but most experienced photo interpreters prefer to begin by scanning the area as a whole or a large part of it. They are then prepared for intelligent selection and study of details. To amplify: Photo interpreters have learned that aerial photography is full of surprises, and they are often tempted to examine every image in every photograph so as

290

not to miss anything. This is the fishing expedition, a method of search that is all too frequently used. Fishing often yields large amounts of information, including much that is not pertinent to the subject at hand. It requires a more leisurely effort than the interpreter can usually afford to make. By resorting to probabilities, the interpreter can work more efficiently in the time available. He searches only those areas in which the objects of interest are likely to be found, and disregards large areas which are not likely to contain the desired information. This selective method is logical search, a combination of quick scanning and intensive study. It demands more experience than the fishing expedition, since the interpreter has to decide where intensive study will yield the best results, but is much more productive in relation to time and effort expended. The time spent on intensive study at the expense of rapid scanning must be determined by the nature of the work". Our experience under this NASA Grant 7220 corroborates Rabben's statement in all respects.

D. <u>The "Discrimination vs. Identification" Concept</u>

Frequently the photo interpreter finds it possible to draw accurate boundaries (i.e., to discriminate) between one resource type and another (usually by virtue of tone, color and/or texture differences) without being able to identify either of the resource types. Ultimate identification usually requires that he employ either additional aerial photos of representative areas, taken at larger scale and higher resolution, or direct on-site inspection--or both. Despite the fact that his initial photo interpretation did not provide all of the desired information, it

C-4

usually will have proved to be a highly useful and efficient first step in a multistage sampling scheme. In fact it is sometimes found that the "spatial filtering" of the low resolution first-look photography usually facilitates the drawing of meaningful discrimination boundaries.

E. The "Photo Interpretation Key" Concept

Identification keys, used with great success by taxonomists in the biological and physical sciences, are also useful aids to photo interpretation. A photo interpretation key has been defined as "reference material designed to facilitate the rapid and accurate identification of objects and conditions from a study of their photographic images" (American Society of Photogrammetry, 1960). Usually such a key consists of two elements: (1) annotated stereograms and other photographs which illustrate the objects and conditions to be identified, and (2) word descriptions that systematically set forth the distinctive characteristics of these objects and conditions. A key may be organized for identification by selection or by elimination. A selective key illustrates and describes classes of phenomena, and the interpreter chooses (selects) that example which most closely mathces his unknown. An elimination key provides a step-by-step method of identification; the interpreter proceeds through a series of possible identifications, eliminating all incorrect choices. Quite commonly, the dichotomous key is regarded by [some] photo interpreters as the most efficient mode of elimination. It consists of a series of paired choices which lead the interpreter through progressively less general categories to the ultimate identity of the object or condition. An advantage of the dichotomous (two-branched) key is that at each step the interpreter chooses one of two attributes rather than one of several, thereby improving his chances of arriving at the correct answer.

All of the above concepts are proving to be highly relevant to the work which we are doing under this NASA grant. The resource manager, whose acceptance of modern remote sensing technology we seek under this grant, needs to have the imagery attributes of resource-related features presented to him in a concise, well organized form. This need often is best satisfied by means of photo interpretation keys in general--and dichotomous keys in particular.

F. The "Convergence of Evidence" Concept

Photographic interpretation has been defined as "the act of examining photographic images for the purpose of identifying objects and judging their significance". (American Society of Photogrammetry, 1960). Often the concept that is at the very core of photographic interpretation is one known as "Convergence of Evidence". This concept can perhaps be best expressed by once more paraphrasing the words of Rabben (1960).

"The photo interpreter, in order to identify objects he has not seen before, or to understand the meaning of objects, once identified, exploits the principle of convergence of evidence. There may be many clues to the identity of an unknown object. None of the clues is infallible by itself; but if all or most of the clues point to the same conclusion, the conclusion is probably correct. Photo interpretation, then, is actually an art of probabilities. Few things are actually certain in photo interpretation in the way that one and one certainly make two; but many interpretations are so probable, when all visible evidence has been considered, that they may safely be regarded as correct. The difficult part of photo interpretation consists in judgement of degrees of probability". Again, our grant-related work confirms this.

G. The "Multi" Concept

As suggested by its name, this concept seeks to treat in a systematic fashion, the entire array of factors that govern the acquisition, enhancement and analysis of remote sensing data and the presentation of information that is thereby derived. Among the components of this "multi" concept that are most commonly exploited in relation to the remote sensing of natural resources are the following:

1. More information usually is obtainable from multi-station photography than from that obtained from only one station.*

*The term "multistation photography" (not to be confused with "multistage photography") pertains primarily to successive overlapping photographs, taken along any given flight line as flown by a photographic aircraft of spacecraft. When two such photographs are studied stereoscopically the photo interpreter is better able to perceive features than if a photo from only one of the two stations were available.

2. More information usually is obtainable from multiband photography than from that taken in only one wavelength band.
3. More information usually is obtainable from multidate photography than from that taken on only one date.
4. More information usually is obtainable from multipolarization photography than from that taken with only one ploarization.
5. More information usually is obtainable from multistage photography than from that taken from only one stage or flight altitude.
6. More information usually is obtainable through the multienhancement of this photography than from only one enhancement.
7. More information usually is obtainable by the multidisciplinary analysis of this photography than if it is analyzed by experts from only discipline.
8. The wealth of information usually derivable through intelligent use of these various means usually is better conveyed to the potential user of it through multi thematic maps, i.e., through a series of maps, each dedicated to the portraying of one particular theme, rather than through only one map.

All of the foregoing principles of the "multi" concept are illustrated in the various progress reports that we have prepared under this grant. In fact, they served as the basis for Chapter 1 of the recently published "Manual of Remote Sensing", which we wrote.

H. The "Complexity-of-Structure" Concept

This concept recognizes that, in each of several respects, some of the geographic areas in which the remote sensing of natural resources might be attempted are so constituted or "structured" as to ensure that the inventory and analysis problems will be quite simple; other geographic areas, however, may be progressively more complex in this regard, with the result that the inventory and the analysis problems associated with them also are progressively more complex. Other factors being equal, a remote sensing-based solution to such problems is likely to be far more complete in the simply structured areas than in the complexly structured ones. While this assertion might seem to be intuitively obvious, failure to recognize its validity already has led to the gross over-estimating of the usefulness of remote sensing in some geographic areas and to the gross underestimating of its usefulness in others.

The validity of this "complexity-of-structure" concept can be adequately illustrated merely by giving consideration to one category of vegetation resources viz. agricultural crops. In a simply structured area (such as the Great Central Valley of California, for example), the following attributes tend to be found, as shown by work we have done there under this grant.

1. the fields are large and rectangular in shape, with little interspersion of non-cropland among the cropland areas;
2. the predominant crops, and varieties of them, are few in number; and
3. all fields that are dedicated, in any given year, to the production of a given type of crop are planted on about the same date and hence they all change from one seasonal appearance to the next on about the same date. (This is at the very heart of our "crop calendar" concept.)

In complexly structured agricultural areas, such as those in south-east Asia, for example, the opposite condition, in each of the above respects, almost always is found.

295

I. The "Favorableness-of-Contributory-Factors" Concept

Table 1 provides a summary of most of the factors which, in any given instance, are likely to affect the usefulness of any given type of aerial or space photography to those charged with the inventory and/or management of a particular area's natural resources. For each of the factors listed in that table an entire "spectrum" or range of conditions is theoretically possible, ranging from very unfavorable to very favorable in terms of its effect on the usefulness of remote sensing for the purpose that is being considered. It follows that, in any given instance, the overall usefulness of remote sensing for that particular purpose will be determinable quantitatively by the aggregated effects of these various factors. Usually, however, a weight will need to be assigned to any given factor; hence the aggregated value normally will reflect these individual weights.

To the extent that the factors listed in the left column of Table 1 pertain in any given situation, there will be only a minimum benefit derived from this particular use of remote sensing. To the extent that the factors listed in the right column pertain, however, maximum benefit will be derived from this particular use of remote sensing.

J. The "Half-Life-of-Usefulness" Concept

Consideration usually must be given to how quickly and how frequently some particular kind of remote sensing-derived information is needed by the resource manager. With respect to the resource manager's requirements for information pertaining to vegetation and land use, for example (Colwell, 1978), such consideration yielded the results that appear in Table 2. It will be noted from that table that there are remarkably close parallels in the three columns dealing with vegetation resources, i.e. in the columns that deal,

1. Area to be analyzed is very complexly structured	1. Area to be analyzed is very simply structured
2. Only photos having a GRD of, say, 10 feet are available for use.	2. To the extent desired, photos having a GRD of, say, 10 feet plus any or all other forms of remote sensing can be used.
3. Clouds usually obscure the area that is to be analyzed.	3. Clouds rarely obscure the area that is to be analyzed.
4. Remote sensing can only done on one date and at one time of day.	4. Remote sensing can be done on each of many dates and at many times of day.
5. There is a very long delay after the photos have been taken before they can be retrieved and placed in the hands of analysts.	5. There is only a very short delay after the photos (and other remote sensing data) have been obtained before they are retrieved and placed in the hands of the analysts.
6. Because of rigid time constraints, only a "quick look" analysis can be made.	6. For all practical purposes there are no time constraints; hence the making of a complete data analysis is feasible.
7. Only one data analyst is available and he is inexperienced, poorly trained, poorly funded, poorly equipped, little appreciated, and poorly motivated.	7. An entire multidisciplinary team of analysts is available and each of them is well experienced, well trained, well funded, well appreciated, well supported by consultants (when they are needed), and well motivated.
8. The analysis required is limited to only one natural resource and consists of a one-time inventory of it in its static state.	8. The analysis required is one which will integrate all components of the entire "resource complex", including renewable resources, and will make repeated inventories to monitor them in their dynamic state.
9. The resource classification scheme that is used is of limited extensibility because it is locally specific.	9. The resource classification scheme that is used has great extensibility because it comprises one component of an overall scheme that is globally uniform.
10. The derived inventory data must be tightly held because of sensitivities that relate to the economic or military security of the area under study.	10. The derived inventory data can be made freely available to all interested parties without fear of economic or military sensitivities.
11. The sole purpose of obtaining the inventory data is to facilitate resource preservation.	11. The multifaceted purpose of obtaining the inventory data includes the facilitating of resource development.
12. Few funds are available with which to implement decisions derived from a study of the resource information that has been acquired; furthermore the decisions, themselves, are suspect because they were based on inadequate information as to the cost-effectiveness of each of several resource management alternatives.	12. Very substantial funds are available, and with them the necessary equipment, engineering knowledge, and local political stability, to ensure that both short-term and long-term benefits will derive from implementation of the resource management decisions; furthermore the decisions themselves are sound because they were based on reliable information as to the cost-effectiveness of each of several resource management alternatives.
Note: To the extent that the factors listed in the above column pertain, there will be minimum benefit derived from the use of this type of photography in relation to the inventory, development, and management of natural resources.	Note: To the extent that the factors listed in the above column pertain, there will be maximum benefit derived from the use of this type of photography in relation to the inventory, development, and management of natural resources.

Table 1. Tabulation of Highly Favorable Factors (Right Column) and corresponding Unfavorable Factors (Left Column) that govern the usefulness of modern remote sensing technology in any given instance, as discussed in the text.

respectively, with agricultural crops, timber stands, and rangeland vegetation. At the risk of some oversimplification, this table lists six time intervals that are indicative of the frequency with which various kinds of information about vegetation and land resources are needed (10-20 minutes; 10-20 hours; 10-20 days; 10-20 months; 10-20 years; and 20-100 years).

As we consider relationships between the frequency with which the listed types of Earth resource data should be collected and the rapidity with which the collected data should be processed, we may find it useful to employ the term "half-life" in much the same way as it has been employed by radiologists and atomic physicists. The shorter the isotope's half-life, the more quickly a scientist must work with it once a supply has been issued to him. One half-life after he has acquired the material only half of the original amount is still useful; two half-lives after acquisition only one quarter of the original amount is useful, etc. By coincidence or otherwise, this half-life concept seems to apply remarkably well to nearly every item listed in Table 2. Specifically, if the desired frequency of acquisition of any given type of information, as listed in that table, is divided by two, a figure is obtained indicating the maximum time after data acquisition by which that particular item of information should have been extracted from the data and put to use. It is true that some value will accrue even if that item of information does not become known to the resource manager until somewhat later. But the rate at which the value of the information "decays" is in remarkably close conformity to the half-life concept, judging from our work under this NASA grant.

K. The "Cost-vs.-Accuracy" Concept

Any method that might be used for the gathering of information about an area's natural resources lends itself to the construction of an "accuracy-vs.-cost" curve, as exemplified by the lower of the two curves that appear in

TABLE 2
USER REQUIREMENTS FOR VEGETATION AND LAND RESOURCE DATA
Frequency With Which the Information is Needed (Examples Only)
To Convert This Table to "Rapidity With Which Information is Needed", Use "Half-Life Concept" (See Text)

For Agricultural Crops	For Timber Stands	For Rangeland	For Land-Use Decisions
10-20 mins. - Observe the advancing waterline in croplands during disastrous floods. Observe the start of locust flights in agricultural areas.	10-20 mins. - Detect the start of forest fires during periods when there is a high "Fire Danger Rating".	10-20 mins. - Detect the start of rangeland and brushfield fires during periods when there is a high "Fire Danger Rating".	10-20 mins.- Not applicable.
10-20 hrs. - Map perimeter of on-going floods and locust flights. Monitor the Wheat Belt for outbreaks of Black Stem Rust due to spore showers.	10-20 hrs.- Map perimeter of on-going forest fires.	10-20 hrs.- Map perimeter of on-going rangeland and brushfield fires.	10-20 hrs.- Not applicable.
10-20 days - Map progress of crops as an aid to crop identification using "crop calendars" and to estimating date to begin harvesting operations.	10-20 days - Detect start of insect outbreaks in timber stands.	10-20 days - Update information on "Range Readiness" for grazing, on forest utilization in critical periods and also information on times of flowering and pollen production in relation to the bee industry and to hay fever problems.	10-20 days - Monitoring compliance with certain codes and construction itself in critical areas of land-use change or during peak construction periods.
10-20 mons.-Facilitate annual inspection of crop rotation and of compliance with federal requirements for benefit payments.	10-20 mons.- Facilitate annual inspection of firebreaks.	10-20 mons.- Facilitate annual inspection of firebreaks, range production and range conditions.	10-20 mons.- Monitoring development and land-use change in critical areas for enforcement of codes and keeping valuations equitable and up-to-date.
10-20 yrs.- Observe growth and mortality rates in orchards.	10-20 yrs.- Observe growth and mortality rates in timber stands.	10-20 yrs. - Observe signs of range improvement or deterioration, study the spread of noxious or poisonous weeds. Observe changes in "Edge Effect" of brushfields that affect suitability as wildlife habitat.	10-20 yrs.- Reasses situation as per Table 2, Col. 4 to fine-tune long term land-use plan and reevaluate policies. Provide improved data for prediction models and trend analysis. Revise or set long-term economic development goals.
20-100 yrs. - Observe shifting cultivation patterns.	20-100 yrs.- Observe plant succession trends in the forest.	20-100 yrs.- Observe major plant succession trends on rangelands and brushfields.	20-100 yrs.- Document long-term changes in land-use and monitor attainment of long-term development goals.

Figure 1. Such a curve signifies, usually in highly quantifiable terms, the amount of accuracy that can be achieved, at each of several levels of cost, with the method that currently is in use. Alternately stated, such a curve documents the fact that, when that method is used, there is a "trade-off" between the cost entailed and the accuracy achieved. After a considerable amount of experience with the use of that method has been obtained, it is common practice to select some optimum point on its "accuracy-vs.-cost" curve such as the point that has been labellled "0" in Figure 1. Thereafter, the combination of accuracy and cost exemplified by the point "0" serves as a standard that should be maintained each time that particular method is used.

When there are new developments in the technology for gathering information, it is common practice to conduct tests that will establish various "accuracy-vs.-cost" relationships that are applicable to this new technology. Typically such tests will provide a sufficient number of results to permit the plotting of a new curve of "accuracy-vs.-cost" such as the upper of the two curves appearing in Figure 1.

A comparison of the "old technology" curve with the "new technology" curve usually will show that there are 3 ways in which this new technology can be used advantageuosly as a replacement for the old technology:

1. by maintaining the same standard of accuracy but at reduced cost, (compare Point "1" with Point "0").
2. by improving the accuracy while maintaining the same cost, (compare Point "2" with Point "0").
3. by achieving both a modest increase in accuracy and a modest reduction in cost (compare Point "3" with Point "0").

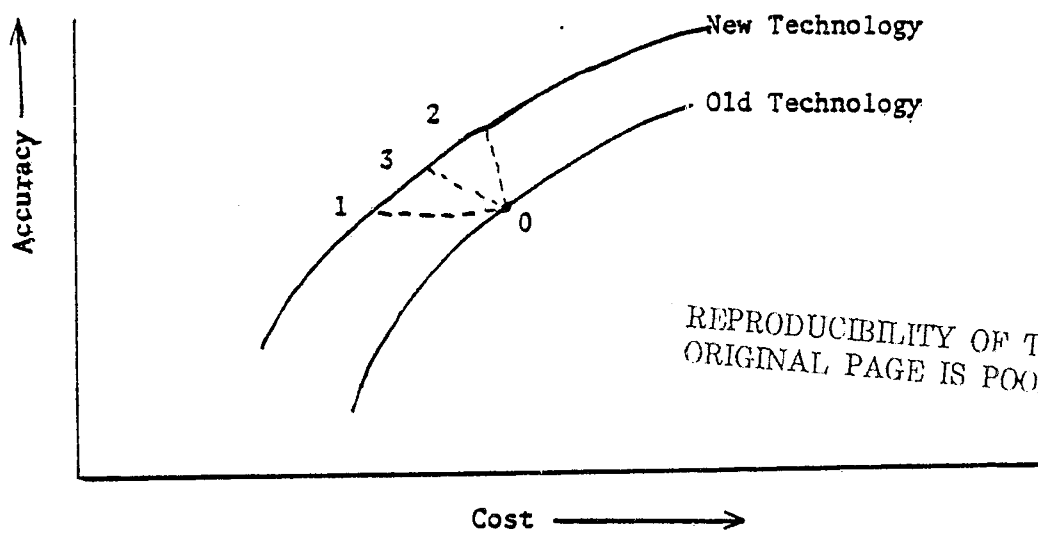


Figure 1. The lower of these two curves portrays the relationships of accuracy vs. cost under some old or "conventional" means of acquiring information about natural resources. The upper curve, based upon our experience under this NASA grant, portrays these same relationships under a new technology that derives from the intelligent use of modern remote sensing capabilities. For further explanation, see text.

L. The "Confusion Matrix" Concept

As indicated in Figure 2 there are many factors which, in any given instance, can affect the accuracy and consistency with which remote sensing-based indentifications of natural resource features can be made. That figure shows an optimum means of compiling information on photo interpretation accuracy and consistency. To simplify the explanation of how such a table is compiled and used, we have made the following assumptions, based on our experience under this grant, with respect to the hypothetical example of Figure 2:

1. Only 5 classes of features (A, B, C, D, and E) are needed in order to make a complete and meaningful classification of the area.
2. "Ground truth" has previously been compiled (e.g., by the administrator of the test) for 100 examples of each of the 5 classes of features. (Usually the ground truth survey will also have identified at least 3 or 4 additional examples of each class for training purposes prior to administration of the test).
3. The tabular summary shown in Figure 2 applies only to the results obtained by one interpreter, using one kind of imagery, viewing it with the aid of only one kind of lighting and viewing equipment and exhibiting, at the start of the test, only the "noraml"degree of fatigue. (Through the use of additional tests, similar in nature, realistic variations in each of these parameters usually should be made, both individually and in various combinations, and in each such additional test the results should be summarized in a form similar to that shown in Figure 2).

When a test of the type summarized in Figure 2 is being prepared a small numbered dot usually is placed at each of the 500 spots. The person being tested studies each spot, in turn, and merely records, opposite the corresponding

PHOTO INTERPRETER'S RESULTS	GROUND TRUTH A	B	C	D	E
A	80	10	0	0	0
B	20	90	0	0	0
C	0	0	100	0	0
D	0	0	0	85	5
E	0	0	0	15	95
TOTAL	100	100	100	100	100
% Correct	80	90	100	85	95

Figure 2. Shown here is a method that has been tested under our present grant to present information on (1) the "percent" accuracy with which each of 5 different resource-related features can be identified on a given type of remote sensing imagery; (b) the nature and frequency, in percent, of each kind of omission error, and (c) the nature and frequency of each kind of commission error. Such a tabular display of results is referred to as a "confusion matrix". For further explanation, see text.

303

number on a suitable form, the letter A, B, C, D, or E according to his interpretation of the area in the immediate vicinity of that spot. Ordinarily he also will be required to report on the form the time when he started the test and the time when he completed it, together with any other information which he considerd relevant to those seeking to evaluate his performance on the test (e.g., too much noise, too many interruptions, significant obscuring of a particular feature by numbers or other annotations, test photo appears to be of abnoramlly good or poor quality, etc).

An examination of the results that have been tabulated in Figure 2 permits one to draw a large number of highly relevant conclusions with respect to this specific test including the following:

1. Feature class A is rarely if ever confused with anything except feature class B, and vice versa.
2. Feature class C is indentifiable with essentially perfect accuracy.
3. Feature class D is rarely if ever confused with anything except feature class E, and vice versa.
4. Unlike classes A and B, there is need for some means of substantially reducing the confusion between classes D and E (e.g., through the obtaining of photographs having better spatial, spectral, and/or temporal resolution).

A tabulation of the type appearing in Figure 2 is likely to show that some of the desired indentifications have not been made to acceptably high levels of accuracy. In such instances the photo interpreter may be able to improve the accuracy through use of the previously mentioned principle known as "Convergence of Evidence". For example if preliminary tests show that A is too frequently confused with B, further study may show correlated features that usually are associated with A but not with B. Similarly D may in some in some way be related quite consistently to C, while E rarely or never is so related.

Once a study of the type summarized in Figure 2 has been completed it can serve several purposes. It will, of course, facilitate attainment of the primary objective--that of determining photo interpretation capabilities and consistencies actully achieved (preferably as a function of image quality, interpreter training, interpreter fatigue, etc). It also may lead to revision of the preliminary photo interpretation keys so that the features or characteristics, which these extensive tests have shown to be the most consistently indentifiable, will be highlighted in the key while the less identifiable ones will be listed only secondarily or entirely omitted. Finally, the study may suggest needed revision in the resource classification system to better achieve the aforementioned compromise between the categories that would be the most meaningful and those that have proved to be most consistently indentifiable. Our experience under this grant confirms all of the above.

M. The "Technology Transfer" Concept

Because of our frequent reference in this chapter to the potential usefulness of remote sensing, we need to consider here the socio-economic factors that govern technology transfer. More specifically, what factors govern the acceptance and use of modern remote sensing technology by those having the responsibility to inventory and manage the earth's natural resources? As pointed out by two of the scientists who have been investigating this matter for quite some time (Hoos and Sharp, 1978): "The transfer of technology (such as remote sensing) can be considered as having been completed only when that technology, being readily available in the marketplace, becomes generally accepted practice by the user agency, and when the chief officer of that agency, upon routinely assessing all available technologies, decrees that use of the new technology will be made.

As a further pointed out by Hoos and Sharp the many factors that govern technology transfer can be categorized as institutional, bureaucratic, historical, legal, and psychological. From this mix one usually can indentify the following six features that significantly influence a user's receptivity to the data potentially available to him through use of a new technology such as remote sensing: a) complexity of (and hence ease of comprehending) the data acquisition technology; b) specificity, i.e., the degree to which the technology can provide data that will bear on the user's particular problems; c) availability, in terms of both the ease and the speed with which a user can obtain data from the new technology; d) reliability, with respect to both (1) the quality and consistency of the data and (2) the continued availability of the data source; e) accessibility, a factor that is closely related to availability but that pertains more specifically to constraints imposed on access to the data because of military security, political sensitivity, institutional confidentiality, or guarentees against the invasion of privacy, and f) compatibility, i.e., ease with which data acquired by the new technology can be integrated with conventional data for use in prediction models and decision models.

In addition, we must recognize three emerging trends on the social landscape each of which, by affecting our understanding of resource issues, may alter our information requirements and thereby govern the usefulness of resource-related, remote sensing technology. These are a) an increased awareness of the pressure that can be brought to bear on the resource manager by a host of new "publics" or special interest groups that have been spawned by legislation concerned with social justice; b) an increased awareness of the need to manage natural resources with a view to preserving and, if possible, enhancing man's environment, and c) an increased awareness that many of the earth's natural resources (e.g., fossil fuels) are nonrenewable and in limited supply, thus raising the question of how much should be reserved for use by future generations on the grounds that a fair share of such resources constitutes their legitimate birthright.

As implied by this discussion, modern remote sensing technology will not transfer itself. Instead there is commonly a five-stage "adoptive process" by which this new technology is perceived, internalized and used: a) awareness, b) interest, c) evaluation, d) trial, and e) adoption. Since this process may take years, there frequently are problems in maintaining the necessary momentum, especially when there commonly are disruptions in personnel and support along the way that can undermine both creditability and morale. And even after remote sensing technology has been adopted, it still may take years before this new technology will begin to bear fruit.

In addition, the following pitfalls are likely to be encountered: a) Oversell, (resulting in the raising of user expectations to levels beyond what current capabilities can deliver); b) Overkill, (as when the user is urged to use elaborate techniques of computer assisted analysis even when the desired information could have been derived quite adequately through the use of simple, inexpensive, and more readily understood manual interpretation techniques); c) Undertraining, (most commonly exemplified when a novice who has just completed an "appreciation" course in remote sensing is required to plunge directly into the demanding tasks that are involved in making operational use of modern remote sensing technology); d) Underinvolvement, (as when the user agency, plagued by a lack of qualified and/or motivated personnel, turns over the bulk of the work to consultants or others who lack familiarity with the user agency's resource problems, information needs, and perhaps even with the resource itself); e) Spurious Evaluation, (as when the user, forced by a higher authority or others into a "rush to judgement" produces premature, incomplete,

307

incestually-validated, and usually overly-optimistic appraisals); and f) <u>Misapplication</u>, (resulting in part from the sheer glamour of the shiny new tool known as remote sensing).

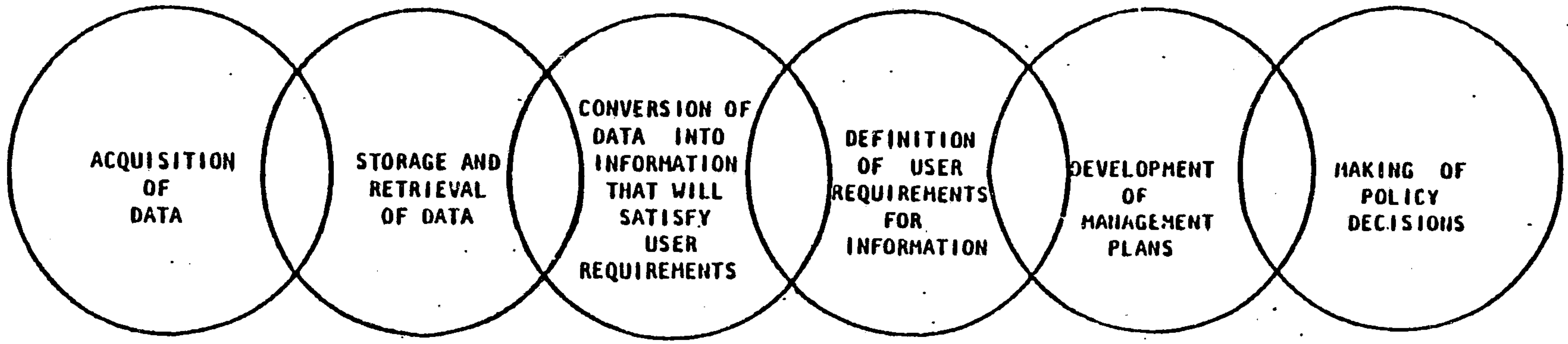
N. The "Links-of-a-Chain" Concept

As indicated by Figure 3 it is sometimes helpful to consider that there are several links comprising the chain of events by means of which remote sensing techniques can be used to satisfy the information requirements of various resource management groups. There are two approaches, suggested by Figure 3, to the realization of this worthy objective. On the one hand, the "hardware oriented" person is likely to view the matter as proceeding from the left links of the chain forward and to the right. On the other hand, the "management and policy" oriented person is likely to view the matter as proceeding from the right links of the chain backward and to the left.

Up to the present time the first approach has predominated, even from the days of the first experiments in space photography when the weight, power, and volume requirements of available sensors dictated what the sensor package would be that might be privileged to fly "piggy-back" on the next space shot. But we can predict with confidence that in future space shots, especially those in which the satellite is specifically dedicated to the collection of resource-related data, both the sensor capabilities and the resource classification schemes will be far more responsive to information requirements of the types suggested in Table 2, as imposed by resource policy decisions and management objectives.

O. The "Improvement-Through-Experience" Concept

This concept is best comprehended by our considering the use of remote sensing in relation to the inventory of some specific natural resource, such as the timber resources dealt with in Figure In that figure it is presumed that the simplest of remote sensing-based inventory procedures is used, viz. one which employs 1) conventional aerial photographs as the means of delineating



Specify spectral and spatial resolution characteristics of sensors, atmospheric constraints, target illumination and weight, power and volume requirements of the sensors. Specify performance characteristics of vehicles needed to transport sensors, including speed, attitude control, service ceiling, stay time and ability to satisfy weight, power and volume requirements of the sensor package.

Specify the "model" or "models" that will best facilitate the storage of data and its retrieval periodically by those who are to convert the data into information that will satisfy specific requirements of the various users.

Establish the "signature" for each type of earth resource feature that is to be identified, as a function of its spectral, spatial, goniometric and temporal characteristics. By proper use of humans and ADP machines, provide an "in-place" delineation, area-by-area, of each type of earth resource, including vegetation type, soil type, water quantity and quality, topography, culture, and multi-resource interrelationships.

Precisely define the kinds of earth resource information needed by those who must develop and implement management plans and policy decisions; also define the speed with which these types of information must be provided following acquisition of remote sensing data, and the frequency with which these kinds of resource information are likely to be needed by the various users.

Determine, for example, how best to manage the watershed with a view to multiple use management; also how and where to store water and to develop and distribute hydroelectric power from it. Also, how best to transport water to farmlands, urban areas and other places of water consumption.

Determine, for example, whether to encourage or discourage (1) the growth of a megalopolis in a particular area, (2) the intensification of agriculture in a second area, etc.

Figure 3. Links by means of which remote sensing techniques can be used to satisfy the information requirements of various resource management groups.

Timber Resource Attribute	Accuracy of Estimate of Resource Attribute As a Function of Method(s) Used In Acquiring Inventory Data		
	Ground Survey Alone	Photo Survey Alone	Ground Survey plus Photo Survey*
Volume per Acre or Hectare Within Stratum	High	Low	High
Area of Stratum in Acres or Hectares	Low	High	High
Total Volume of Timber Within Stratum	Medium	Medium	High

*Assumes that Volume per unit area within Stratum is obtained by ground survey and Area of Stratum is obtained by photo survey.

Figure 4. Accuracy with which resource attributes can be measured or estimated, expressed as a function of Method(s) Used in Acquiring Inventory Data. In most instances the ability to identify and delineate strata from photos improves with experience; hence overall estimates of timber volume tend to improve, year-by-year.

homogeneous timber types or strata, and 2) direct on-site measurement of timber volume within representative portions of each stratum. The entries appearing in that figure are self explanatory and are clearly indicative of the validity of the "improvement-through-experience" concept.

CHAPTER 6

PROJECT SUMMARY

312

CHAPTER 6

PROJECT SUMMARY

Robert N. Colwell

Note: Because of the lengthiness of this Annual Progress Report, it has been deemed desirable to conclude it with a chapter-by-chapter summary. Even though the present chapter is intended to be no more than a summary, the highlighting of certain relevant details is considered necessary if the essence of each phase of our multicampus work under the grant is to be adequately grasped. Herein lies the explanation for the fact that even this summary chapter is a rather lengthy one.

Chapter 1 of this progress report first sets forth the rationale for applying modern remote sensing technology to selected problems in California. Consideration is then given to the means by which research teams such as ours can help bring about the acceptance of such technology by those who manage California's natural resources. Consistent with our goal of gaining technology acceptance, the overall objective of work done under this NASA grant is to demonstrate, by means of specific case studies, that information about natural resources as derived through the use of modern remote sensing techniques can lead to the development and implementation of more intelligent measures for resource management than would otherwise be possible. While all of our case studies, (as later described in Chapters 2, 3, and 4) deal with applications that can be made of remote sensing in California, virtually all of our findings are considered to be applicable in many other geographic areas also. Chapter 1 concludes with (1) the reminder that our primary goal under this NASA grant is to bring about the acceptance and adoption of modern remote sensing technology by California's resource managers and (2) the highlighting of specific instances in which that goal is being achieved. Among such instances are those pertaining to (a) fuel mapping in relation to the management of brushlands and timberlands in California; (b) the assessment of wild turkey habitat; (c) the selection of sites best suited to forest regeneration by artificial means; (d) the identifying of sites where flood control structures are urgently needed; (e) the identifying of areas in which there are agricultural problems arising from the existence of perched water tables and/or high salinity; and (f) the monitoring of avocado acreage and avocado production. In each instance emphasis is placed on the fact that action either is now being taken, or soon will be, by the resource managers, themselves, based primarily upon the remote sensing-derived information.

Chapter 2 deals with case studies that are being performed in northern California by personnel of our Remote Sensing Research Program on the Berkeley campus. The first of these deals with fuel mapping by remote sensing as an aid to the management of brushlands and timberlands in Mendocino County, California. It is emphasized that the primary objective of fuel management within California is to break up large homogeneous fields of brush into smaller brush-grassland mosaics. In this way, not only are fire hazards reduced, but the "edge effect" around brush fields is increased so as to provide more shelter and forage to wildlife and domestic animals. In addition, soil stability will improve if stands of grass can replace the decadent brush. Information acquired by means of remote sensing is needed because it can be (1) efficiently gathered for extensive inaccessible areas of the type encountered in much of Mendocino County, and (2) easily manipulated to meet the various objectives relating to fuel management.

During the past year, a team consisting of Mendocino County's wildland fuel management experts and the University's remote sensing scientists has accurately mapped the fuel types present in a 190,000 hectare (476,000 acre) study area in the northeastern part of the county, at an average cost of approximately one cent per acre, through the use of computer assisted analysis of digital data obtained from the Landsat satellites. Based primarily upon this remote sensing-derived information, (but augmented as necessary by ancillary data such as large scale aerial photography of small, representative sample areas, together with existing topographic and soils information), fuel management plans for this area are rapidly being developed and put into operation on the ground. The specific actions taken include construction of fuel breaks, prescribed burning of 200 to 400 acre blocks of brushland, planting grass seed, and the annual burning of strips through the standing brush in order to develop an uneven brushland mosaic.

Cooperating with the University's remote sensing scientists and with officials of the Mendocino Ranger Unit on this project have been personnel from a great many other interested agencies, federal, state, and private, all of whom have a strongly vested interest in reducing wildland fire damage in Mendocino County and/or in nearby areas. Among these cooperating agencies have been NASA, California Department of Forestry, California Department of Fish and Game, Mendocino County Board of Supervisors, Mendocino County Planning Commission, Mendocino County Fuel Management Committee, U.S. Forest Service, U.S. Bureau of Land Management, U.S. Bureau of Indian Affairs. At present it is anticipated that these cooperating agencies will continue to employ (collectively) 17 full time personnel, 17 part time personnel, plus bulldozers and other mechanized equipment as necessary to take prompt action on our fuel management recommendations as arrived at primarily from the analysis of remote sensing-derived information.

The second of our Case Studies in northern California that has entailed a major cooperative effort during the past year between the University's RSRP personnel and resource management agencies of Mendocino County relates to the mapping of wild turkey habitat throughout the County. This work, like the fuel management-related work, has of necessity entailed a mixture of basic remote sensing research and prompt and effective application of such research in order to facilitate the making and implementing of important resource management decisions. This work has been occassioned by three facts: (1) One of the most prized game birds in California is the wild turkey; (2) With a view to improving the supply of this important wildland resource, the California Department of Fish & Game wishes to determine the location and extent of potential turkey habitat and to identify future turkey release (transplant) sites; and (3) Once such sites have been identified that Department is able to act promptly by transplanting into them wild turkeys captured from flocks already established in nearby areas.

During the past year, personnel of our RSRP, working in close cooperation with the California Department of Fish and Game, have used Landsat 2 data to map turkey habitat within an area of nearly 800,000 hectares (2 million acres) in Mendocino County. For a site in this county to be considered as potentially suitable turkey habitat: (1) it must have the proper mix of vegetation associations (specifically, it must be some form of oak/grassland association); and (2) it must occupy a contiguous area of at least 2,000 hectares (5,000 acres).

As a result of this remote sensing work, 4 areas have been identified and field checked, primarily by experts of the California Department of Fish and Game, at no cost to this Project. Several important factors have been investigated during this field checking operation even though an initial appraisal of most of these factors already had been made by means of remote sensing. These factors include the availability of potable water, topographic suitability of the site, proposed land use, land ownership, and proximity to other potential or already stocked turkey sites. An integrated appraisal of these many factors, as derived by remote sensing and field checking, has convinced personnel of the California Department of Fish and Game that the Potter Valley area constitutes a highly favorable turkey release site. As a result 19 turkeys were released in this area in February, 1979, and are now being monitored to verify their adaptability to that site.

Information gained thus far will be used in the coming year as we refine or otherwise modify the spectral classes used in our computer assisted analysis of Landsat digital data for the mapping of wild turkey habitat. This aspect of our work, like most of the other aspects, entails the judicious mixing of "basic" and "applied" research components.

Chapter 3 of this progress report deals with work done during the past year by personnel of the geography remote sensing unit (GRSU) on the Santa Barbara campus.

As indicated in Figure 1 of Chapter 1 Central California has been the site for all 5 of the studies that have been conducted during the past year by GRSU personnel. Titles for these 5 studies are as follows: (1) Cotton Mapping from Landsat Imagery; (2) Green Fuel Moisture Estimation Using Landsat Data; (3) Remote Sensing of Perched Water and Soil Salinith; (4) Watershed Runoff Predictions Using Landsat Digital Data; and (5) Applications of Remote Sensing in Ventura County. For each of these 5 studies, at least one thesis at the master's degree level either has been written or is now in the process of being completed, all under the direction of Professor John E. Estes, our Co-Investigator on the Santa Barbara campus. The following is a brief summary of progress made during the past year on these 5 case studies:

1. Cotton Mapping from Landsat Imagery. This project arose from an interest by the California Department of Food and Agriculture to incorporate remote sensing techniques into their cotton mapping surveys that are conducted annually in an effort to control the pink bollworm. Key to such control throughout California's vast San Joaquin Valley is the plow down, shortly after harvest, of all remaining cotton vegetable matter on which the bollworm might feed. The interpretation of multidate, multiband Landsat imagery is proving to be a potentially effective means for (1) identifying and mapping all cotton fields during the winter to detect instances of non-compliance by farmers with the "plowdown" regulations. Our success to date has been sufficiently variable, however, to suggest the need for further research.

2. Green Fuel Moisture Estimation Using Landsat Data. The objective of this project is to determine the potential of using Landsat digital values of "scene reflectance" to provide a quantitative estimate of the moisture content of green fuels in the wildland areas of central and southern California. The containment of potentially catastrophic fires in this vast area hinges upon an accurate assessment of the expected behavior of the fires in order to efficiently allocate the available fire control resources. Green fuel moisture content is a key factor governing the behavior of such fires. Forest Service personnel of California's Los Padres National Forest expressed an initial interest in this Landsat-based project and have cooperated very substantially throughout the project. The research seeks to exploit the high correlation that is known to exist between leaf water content and vegetative biomass, since the latter property is far more photogenic than the former. Our tests to date have failed to show a suitably high correlation between scene brightness values and green fuel moisture content, but Forest Service cooperators urge us to continue our research, because of the tremendous benefit that would derive from a successful remote sensing-based system.

3. Remote Sensing of Perched Water and Soil Salinity. Many arid agricultural regions are experiencing crop yield losses and deteriorating soil conditions due to the excessive build-up of shallow or "perched" water tables and salts in the soil root zone. Problems associated with the presence of shallow water tables are significant

at the global and national, as well as local levels. In the United States alone, more than 20 million acres of potentially arable land have high water tables in the rooting zone of the soil horizon. The problem is perhaps more serious in California's San Joaquin Valley. In many arid environments where irrigation is practiced the total acreage affected by soil drainage problems continues to increase.

Various remote sensing systems offer potential means for timely and cost-effective collection of perched water and soil salinity related data. As part of their research effort, personnel of the GRSU are directing attention towards the operational use of remote sensing techniques to collect this type of data.

It is extremely unlikely that any remote sensing technique or combination of techniques will ever completely replace conventional monitoring of test wells in drainage control programs. However, there do appear to be three potentially significant ways in which remote sensing may aid the collection of perched water data. These include: (1) general reconnaissance of an area to aid in optimum siting of test well locations; (2) interpolation and extrapolation between point samples provided by test well data based on environmental factors interpreted from remote sensing data, including possible use of such data in hydrologic models: and (3) direct collection and interpretation of perched water table conditions or some surrogate indicator of perched water table conditions.

321

Personnel of our GRSU are building upon information which we and others have obtained in previous research to assess the operational utility of various remote sensing systems for satisfying specific information requirements with respect to perched water and soil salinity problems. The most promising systems appear to be Landsat, aerial photography, thermal infrared, passive microwave, and active microwave (SLAR). Fortunately, sizable portions of our test area in California's San Joaquin Valley have already been covered by all of these sensor systems and we are proceeding vigorously in making a comparative analysis of the usefulness of these various kinds of remote sensing data. The Kern County Water Agency is cooperating with us very extensively on this project. This cooperation ranges from direct financial support for our work to the costly drilling of test wells at sites which our remote sensing analyses indicate as having perched (subsurface) water tables. Mindful of our goal for obtaining user acceptance of remote sensing technology we are conducting a "user survey" to define the informational needs of various groups of potential users in the area. Specifically we are studying their needs in terms of their accuracy, frequency, and timeliness requirements and the costs that they would be willing to bear in order to satisfy such needs. Among these users, all of whom are well represented in our survey are (1) individual farmers in the area, (2) local water districts, (3) the Kern County Water Agency, and (4) the California State Department of Water Resources.

Presently, the most feasible system for these users appears to be a combination of aerial photography and Landsat multidate color composites. Thermal infrared imagery has been found to have a unique potential, however, for the detection of perched water tables, exploiting the fact that these water tables fluctuate diurnally, seasonally, and annually, with resultant changes in their thermal profiles.

4. Watershed Runoff Predictions Using Landsat Digital Data. In Central California, the Kern County Water Agency (KCWA) is mandated by the Kern County Board of Supervisors, under authority of the California State Legislature, to provide storm runoff predictions for approximately 10,000 km^2 of mountainous watershed within the county. KCWA must develop storm runoff predictions for all watersheds in Kern County in order to (1) delineate flood plain boundaries which affect building standards for commercial and residential structures; (2) establish building standards for specialized flood control facilities such as dams, debris basins and spreading ponds; and (3) provide base-line data for flood insurance.

Initially our approach to providing the desired information was to use both the NASA Goddard Digital Image Rectification System (DIRS) and Purdue's LARSYS multispectral pattern recognition package to make a digital analysis of Landsat computer compatible tapes. We have since demonstrated, however, that the Video Image and Communications Analysis and Retrieval (VICAR) system developed at JPL is far superior for this particular purpose, especially when combined with JPL's Image Based

323

Information System (IBIS). Hence we are proceeding now to map the entire study area (parameter-by-parameter) with the VICAR/IBIS system. KCWA personnel have seen such promise in our work that they allocated $10,000 to us several months ago to meet computer processing costs for mapping an 89 quadrangle area. We have since learned, however, that they must withdraw that allocation because of economies that they must effect as the result of California's passage last fall of Proposition 13. Both we and they are therefore seeking other sources of support for this "production" phase in order to ensure operational use of our remote sensing-based technology.

5. Applications of Remote Sensing in Ventura County. To an ever-increasing extent, each county in California is being required through state and federal legislation, to assume responsibility for (1) the wise management of that county's entire "complex" of natural resources and (2) the preservation and/or enhancement of that county's environmental assets. Consequently there is an ever-increasing need, county-by-county, for a resource information system that will facilitate the making of wise decisions with respect to resources and environmental considerations. Ventura County has been among the first to clearly enunciate this need and to recognize the potential of remote sensing for helping to satisfy it. Consequently Ventura County (partly because of its close proximity to GRSU personnel on the Santa Barbara Campus) has strongly supported the efforts of remote sensing scientists there to develop a "Decision Oriented Resource Information

System" (DORIS) that would facilitate the application of remotely sensed data for resource inventory and management at the county level. During the past year the GRSU, under NASA funding provided for our multicampus project, has (a) demonstrated to Ventura County officials the feasibility of mapping that county's resource complex from Landsat MSS data augmented, to a limited extent, by U-2 color photography and ground truth; (b) rectified and registered the Landsat data with Digital Terrain data; and (3) provided a preliminary evaluation of the accuracy and utility of this Landsat/Digital Terrain data combination. Now, with the aid of substantial state funding and extensive cooperation by Ventura County officials, the GRSU's objective is to further develop DORIS so that its information will permit resource management decisions to be made at the county level quickly, economically and accurately.

From the foregoing it will be apparent that both "basic" and "applied" research aspects continue to be entailed in the work that is being done under this NASA grant by remote sensing scientists on the Santa Barbara Campus.

In Chapter 4 a description is given of work done by personnel of the remote sensing unit on the Riverside Campus during the past year.

The research efforts of that group during that period have been concentrated in three areas: (1) desert planning; (2) regional urban/agriculture planning; and (3) agricultural crop estimation. To be more specific with respect to each of these 3 areas: (1) the desert planning activities of the Bureau of Land Management (BLM) have been aided with the highly successful application of a sampling technique developed by the Riverside group for estimation of the total recreational road and wash mileage in the California desert; (2) the San Bernardino County Planning Department staff, with that group's guidance, has successfully employed a method of updating their land use information base using remote sensing methods; and (3) the fast growing avocado industry has come to the Riverside group with the problem of providing estimates of crop production in a useful time context with the result that remote sensing is being applied in the data gathering phase of a project which is expected to lead to an operational crop production information system. A very large amount of additional information with respect to each of these areas of remote sensing application is given in Chapter 4 of this progress report and is summarized below under 3 major headings.

1. Desert Recreational Road Estimation

The California desert is an expansive, remote, and sparsely settled region for which the Desert Plan Staff of the Bureau of Land Management is responsible. One of the most important uses of the desert is for recreation, and among the primary recreational resources are the roads and traversable washes. Any future decisions relating to land management in the California desert are going to have an impact on the availability of the recreational road resources to the recreationists. The BLM has been unable to make a systematic survey of the roads. Ground surveillance is almost useless as one can sometimes be standing next to a road and not be aware of it. The only practical method by which the road resource can be evaluated is with remote sensing.

Due to the vast extent of the desert, a full inventory was deemed too expensive. It was therefore decided to take a sampling approach. The resolution of Landsat imagery, which covers the entire area, is not adequate to detect all roads. Landsat ground resolution is approximately 60 meters whereas most desert roads are less than 10 meters wide: NASA U-2 imagery (CIR 1:130,000) proved to be the only feasible imagery for the sampling project, providing a good compromise between coverage extent and resolution.

Sampling was carried out in 8 strata (sub-regions). U-2 image coverage was available for 6 strata and part of a seventh. Sampling units were 7 1/2' quadrangle equivalents ($\sim$ 62 sq. miles) based on the USGS 15' topographic quadrangle grid. An initial sample of 6 sites was taken to provide an estimate of the number of samples required to achieve 90% accuracy with a 90% confidence limit. The number of samples required was 57 (3378 sq. miles) which is 13.2% of the total area. All samples were interpreted and measured and the total roads estimated as 21,350 linear miles. Statistical analysis of results obtained by field checking showed this figure to be 88% accurate at the 90% confidence limit. Information on washes, however, is highly suspect (most likely under-estimated) due to interpretation difficulties in the assessment of traversability.

This survey represents the first systematic approach to evaluation of the desert recreational road resource. With additional time and money it could have been more accurate; however the utility of increased accuracy is questionable. It is undeniable that the information gained as a result of this project could not have been obtained had not remote sensing, and the U-2 imagery in particular, been available.

The application is straightforward. One of the provisions of the Wilderness Act is that wilderness cannot contain roads. BLM now has a system to carry forward on their own to determine what areas of the California desert are candidates for inclusion under the Wilderness Act.

2. San Bernardino County Agricultural Element

San Bernardino County, with support from the California Office of Planning and Reserach (OPR), began a program of evaluating the county agricultural resources in early 1978. The outcome of this study is to be an agricultural element for the county general plan. County planning personnel came to the Riverside group to determine if remote sensing techniques were suitable in the data gathering and evaluation efforts. Four tasks were identified which either directly or indirectly involve remote sensing. These tasks and progress related to them are outlined below.

a) County Personnel Participation

San Bernardino County expressed interest in assigning one of its staff to assist part time in some of the agricultural land use data gathering efforts in order to gain expertise in remote sensing and related fields. A planner was assigned 20% time for that purpose throughout the data gathering phase. This arrangement has led to a good understanding on the part of both San Bernardino County and the Riverside group as to the role remote sensing can play in the project. The planner who was assigned is now, as a result of her activities, looked to by other planners for guidance in matters having to do with remote sensing applications.

b) Agricultural Information System Development

An agricultural information system was planned which would place data pertaining to land use and soils at the disposal of the planners and the agricultural advisory committee. An information system was developed utilizing the software, (developed under this and previous NASA grants), of the Riverside group's Spatial Information Processing System (SIPS). The data which is now in the information system includes agricultural land use for 1975 and 1977 and soil data from a recent (1977-1978) survey. The 1975 land use data were derived from Department of Water Resources (DWR) land use maps and the 1977 data were established by using remote sensing to update the DWR maps. The information gathering and encoding phases of the information system implementation are now essentially completed.

c) Land Use Trend Mapping

Because the use of remote sensing allows inexpensive land use surveys, it is possible to compile land use data for sequential years with higher frequency than previously possible. Most development within San Bernardino County has occurred within the last several years. In order to identify the nature and location of land use change in this region, the land use data for 1975 and 1977 needed to be combined within the context of the information system to yield computer generated maps and statistics of the changes. The techniques for performing this operation have now been developed by the Riverside group and are detailed in this report.

d) Landsat Imagery Evaluation

Landsat imagery is being used by the Riverside group to provide delineation of the urban/agriculture interface and assist in identifying dynamic areas for closer inspection. It is felt that the only viable approach to transferring Landsat technology to many local agencies is to provide low-cost data which does not require a major shift in philosophy toward data collection. The film product of the enhanced Landsat imagery (EDIES, EDIPS) now provided by EROS presents a great opportunity to demonstrate to county planners the utility of the satellite platform, in a form to which they are accustomed. Evaluation of the EDIES (EROS Digital Image Enhancement System) film product has led the Riverside group to the conclusion that it exhibits predictable radiometric and photometric characteristics, heretofore not found in any remotely sensed images. A whole new realm of highly controlled photographic image processing is now a possibility. An evaluation of this product and associated image processing techniques, especially with applications in agricultural change detection, is currently in progress, and already is being applied to the avocado project by the Riverside group as described below.

3. Avocado Crop Production Estimation

As in most agricultural industries, production forecasts and subsequent market strategies are based upon an accurate knowledge of the number of bearing trees. At the present time the avocado industry must depend upon the California Crop and Livestock Reporting Service (CCALSRS) for the number of producing acres. The budgetary and technical limitations of the CCALSRS and the County Agricultural Commissioners (especially after passage of Proposition 13) are such that they are unable to inventory crops at more frequent intervals than five years. Obviously such infrequent reporting of avocado production is inadequate because that crop is approximately doubling in production every five years. In an effort to establish a better basis for its crop forecast the California Avocado Commission has come to the Riverside group to seek better methods of obtaining production data.

On October 1, 1978, the University reached a cooperative agreement whereby the avocado industry will furnish matching funds with NASA funds from this grant to perform a pilot study of the feasibility of establishing an Avocado Production Information System. Personnel of the Riverside group have since been obtaining background information on the avocado industry and meeting with industry personnel to determine the peculiarities of the problems. A pilot study areas has been established in the vicinity of Fallbrook and a low altitude flight (financed by the industry) was flown of that area in early December, 1978. With the aid of that photography the initial base mapping of individual groves has begun. As a result of further meetings with appropriate personnel (e.g. the County Agricultural Commissioner) the elements of the information system are now being established.

As the Landsat EDIPS products become available, the Riverside group is obtaining EDIPS coverage for the area of study. A primary objective in using this Landsat imagery is to identify new avocado acreages in the area. Most new acreages being planted are by the agribusinesses and therefore are likely to be in the 40 acre size orchards. Inspection of 1975 Landsat imagery indicates that the detection of plantings of this size should be within our capabilities.

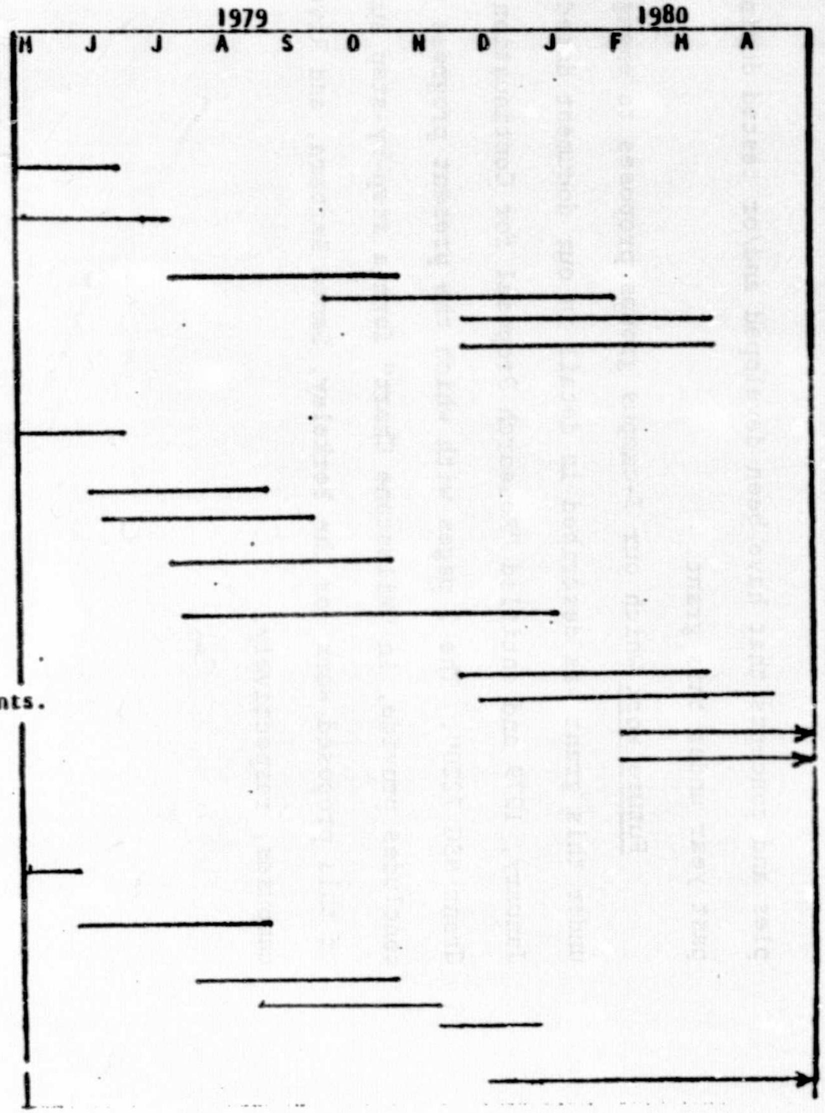
If the Riverside group's present research on improvement of the EDIPS products at low cost and for various highly specific purposes is successful, we anticipate considerable upgrading of the application of satellite remote sensors to a current agricultural problem.

Chapter 5 deals, as in our previous progress reports, with "Special Studies". In this particular progress report emphasis is placed on the elucidation of various important remote sensing principles and concepts that have been developed and/or tested during the past year under this grant.

Future work which our 3-campus groups proposes to engage in under this grant was described in detail in our document dated 5 January, 1979 and entitled "Research Proposal for Continuation of NASA Grant NSG 7220". The 3 pages with which the present progress report concludes provide, in "Milestone Chart" form a step-by-step summary of this proposed work for the Berkeley, Santa Barbara, and Riverside campuses, respectively.

MILESTONE CHART FOR ACTIVITIES PROPOSED BY THE REMOTE SENSING RESEARCH PROGRAM ON THE BERKELEY CAMPUS
1 May 1979 - 30 April 1980

ACTIVITY



Wildland Fuel Management

- o Refine present Landsat classification scheme.
- o From analysis of Landsat classification. select areas for fuel modification.
- o Interpret U-2 photography and ancillary data of selected areas.
- o Develop specific fuel modification plans.
- o Implement fuel modification plans.
- o Monitor implementation actions.

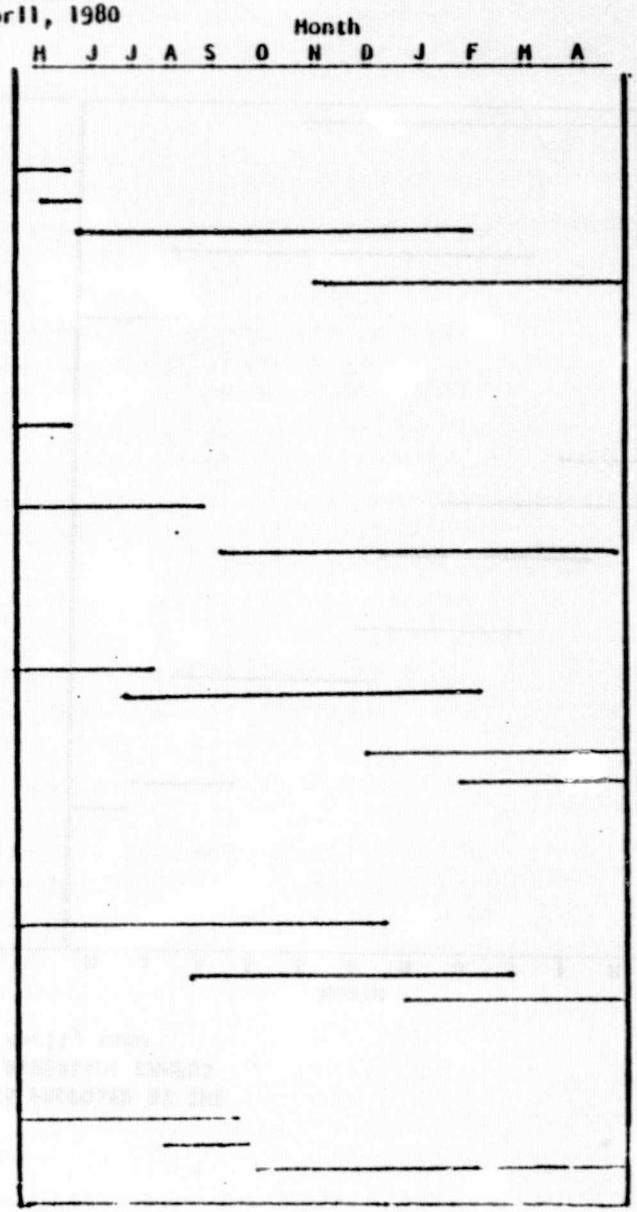
Coordinated Resource Planning

- o Develop area-specific objectives.
- o Revise present Landsat classification scheme.
- o Superimpose ownership boundaries.
- o From analysis of Landsat classification, select areas for detailed analysis.
- o Interpret U-2 photography and ancillary data of selected areas.
- o Develop specific resource management plans.
- o Obtain approval of plans by CRP participants.
- o Implement plans.
- o Monitor impact of plans.

Turkey Habitat Analysis

- o Revise present Landsat classification scheme.
- o From analysis of Landsat classification, select areas for detailed analysis.
- o Interpret U-2 and ancillary data of selected areas
- o Develop plans for turkey releases.
- o Release turkeys in appropriate sites.
- o Test applicability of approach to Cascade and Sierra Nevada mountain region.

MILESTONE CHART FOR ACTIVITIES PROPOSED BY THE
GRSU ON THE SANTA BARBARA CAMPUS
1 May, 1979 through 30 April, 1980



ACTIVITY

1. Cotton Mapping from LANDSAT Imagery
   - a. Working with California's Cotton Pest Control Board, Select a Test Area
   - b. Acquire mid-spring LANDSAT data
   - c. Map all cotton fields in the test area
   - d. Instruct CDFA personnel in use of the LANDSAT-based techniques

2. Green Fuel Moisture Estimation Using LANDSAT data
   - a. Working with U.S. Forest Service personnel select Test Site
   - b. Collect ground data simultaneous with LANDSAT passes from May Through August
   - c. Compare results and prepare feasibility report

3. Remote Sensing of Perched Water and Soil Salinity
   - a. Complete the User Needs Survey
   - b. Perform an Operational Demonstration
   - c. Analyze results in terms of accuracy & cost effectiveness
   - d. Prepare Procedural Manual

4. Watershed Runoff Predictions Using LANDSAT Digital Data
   - a. Complete LANDSAT mapping of 17 quadrangles
   - b. Test mapping accuracy, and analyze for cost effectiveness
   - c. Prepare Procedural Manual

5. Applications of Remote Sensing In Ventura County
   - a. Complete User Needs Survey
   - b. Select demonstration project and area
   - c. Conduct the demonstration project

MILESTONE CHART FOR ACTIVITIES PROPOSED BY THE REMOTE SENSING GROUP ON THE RIVERSIDE CAMPUS
1 May, 1979 through 30 April, 1980

ACTIVITY

I. <u>Develop an Avocado Production Information System</u>.

A. Make a Feasibility Study

1. Select a Sample Survey Area
2. Acquire Landsat and Aerial Imagery
3. Interpret each type of imagery for number, variety, bearing, size, condition, and spreading size of each tree and area of each orchard
4. Evaluate Imagery Requirements and Overall Feasibility

B. Develop and Test the System

1. Determine need for ancillary data
2. Develop and test a system that uses imagery plus ancillary data
3. Evaluate Statewide Usefulness of the System

II. <u>Develop a Means for the General User Better to Employ Landsat Imagery</u>.

A. Select Test Areas

B. Obtain EDIPS Image Products from the EROS Data Center

C. Further Enhance and Test the Usefulness of These Image Products for Various User Purposes