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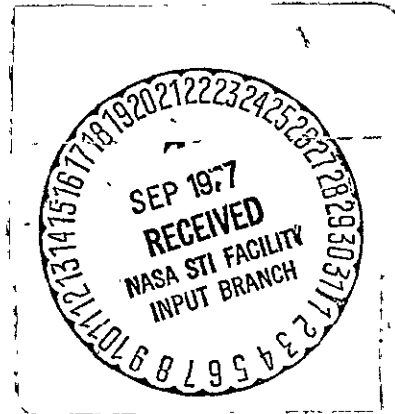
AN INTEGRATED STUDY OF EARTH RESOURCES
IN THE STATE OF CALIFORNIA
USING REMOTE SENSING TECHNIQUES

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A report of work done by scientists
of 4 campuses of the University of
California (Davis, Berkeley, Santa
Barbara and Riverside) under NASA
Grant NGL 05-003-404



Semi-Annual Progress Report
31 May 1977
Space Sciences Laboratory
Series 18, Issue 44

UNIVERSITY OF CALIFORNIA, BERKELEY

AN INTEGRATED STUDY OF EARTH RESOURCES
IN THE STATE OF CALIFORNIA
USING REMOTE SENSING TECHNIQUES

Principal Investigator

Robert N. Colwell *RC*

A report of work done by scientists
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Chapter 1

Introduction

Robert N. Colwell

In two respects the present Progress Report marks a significant transition stage with respect to our NASA-funded multi-campus studies on applications of remote sensing to the state of California:

(1) With this report we are bringing to an end, or nearly so, our remote sensing studies that pertain specifically to water resources. As a corollary we have arrived at the near-final iteration of our various Procedural Manuals that deal with applications of remote sensing to the inventory and management of water resources; and

(2) During the coming one-year period, as we near the time of termination of this NASA grant, we intend to concentrate on the preparation of procedural manuals that deal with applications of remote sensing to the inventory and management of an area's entire "complex" of earth resources, including its timber, forage, agricultural crops, soils, water, minerals, fish, wildlife, and recreational potential.

In keeping with the above, our present Progress Report consists of (1) a concise chapter-by-chapter account of research that our group has performed since 1 May 1976 and (2) based on this research, a final or near-final iteration of several Procedural Manuals, each of which deals with some specific way in which remote sensing can be used advantageously by the managers of water resources.

In conformity with our NASA-approved plan, these Procedural Manuals will continue to be subjected to user agency reaction. Furthermore, the finalized versions will be prepared: (1) in both abridged and unabridged versions, the latter providing much more complete step-wise descriptions and documentation than the former and (2) in degrees of aggregation ranging from a single aspect per manual to all aspects. There will be, for example, three separate Procedural Manuals relative to aspects of water-supply estimation by remote sensing--those dealing, respectively, with snow areal extent, snow water content, and evapotranspiration. These in turn will be compiled (with suitable integration to avoid repetition) into a single volume dealing with all aspects of the use of remote sensing in the estimation of water supply. Finally the integrated water supply volume will be further integrated with similar Procedural Manuals dealing with one aspect or another of remote sensing in relation to the estimation of water demand. Thus, the rather sizable overall document will be for use of those concerned with all aspects of water resource management (both the supply and the demand aspects) while each

of its various subdivisions, when made to stand alone, will better serve the needs of those concerned with only one limited aspect or another of this management problem.

A major part of the rationale for our having concentrated our remote sensing research on California's water resources for the past several years resides in the following facts:

(1) From the economic standpoint, water is the most important resource obtainable from California's vast wildland areas, i.e., from the areas in which, because of difficulty of access on the ground, remote sensing is most needed.

(2) Since the supply of water that is present in California's wildland areas tends to fluctuate far more from season-to-season and year-to-year than does the supply of the other resources found there, the importance of remote sensing as an aid to the making of frequent and periodic inventories (i.e., to the "monitoring") of California's water supply becomes even greater.

(3) Virtually all of California's most important industry, viz., agriculture, is very heavily dependent upon water. In fact, the water required to irrigate California's agricultural crops presently constitutes more than 80 percent of California's total water demand--the rest coming primarily from various industrial, commercial, and domestic uses. Furthermore, just as the supply of this water can vary dramatically from season-to-season and year-to-year, so can the demand for it. Consequently, in view of the vastness of California's agricultural lands, and the frequency with which the water resource manager needs current, accurate information on the water demands that are being imposed by those lands, remote sensing constitutes a means of great potential importance for the inventory and monitoring of water demand.*

(4) Not only in California, but also in many other parts of the world, water is becoming an increasingly critical resource in relation to the economic well-being of mankind. It is probable that remote sensing techniques of the type which we have been developing for the inventory and monitoring of California's water resources could be applied, with only slight modification, to other parts of the world as well.

*Documentation as to the great concern that currently exists relative to the adequacy of California's water resources, and therefore of the concern that exists relative to the adequacy of the information pertaining to the supply of and demand for those resources, is provided in the brief analysis which comprises Special Study No. 2 in Chapter 7 of the present Progress Report.

By way of further placing in proper perspective our present emphasis on water resources, the following additional points are considered highly relevant:

(1) California receives an annual average of 200 million acre-feet of precipitation.

(2) Because most of this precipitation occurs in the winter months and most runoff occurs in areas with low demand for water, the state of California has built large scale systems, as under the California Water Plan, for the purpose of storing water and eventually of transporting it from areas of surplus to areas of scarcity.

(3) A group with which we have been working very closely in connection with our water-related studies, viz., the California Department of Water Resources (DWR) is charged with the "control, protection, conservation, and distribution of California's water in order to meet present and future needs for all beneficial purposes in all areas of the state".

(4) The DWR carries out this responsibility through a statewide planning program which, in part, includes periodic reassessment of existing and future supplies of, demands for water. This periodic reassessment gives special consideration to local water resources, water uses, and the magnitude and timing of the need for additional water supplies that cannot be supplied locally.

(5) To help satisfy certain of its informational needs, the DWR has been performing a continuing survey on a 5- to 10-year cycle to monitor land use changes over the state that will be indicative of changes in water demand.

(6) Because of both the survey costs (an estimated \$150,000 per year) and the manpower efforts involved, only a portion of the state is surveyed during a given year. Hence, at any given time water resource data applicable to the various portions of the area of concern have differing degrees of currency, the information having been collected in some areas only recently and in others as much as 5 to 10 years previously. The shifting time base applicable to information from the various components makes it very difficult to compile figures that will reflect water demand throughout the entire state for any given point in time.

(7) Similar problems exist in California with respect to the estimation of water supply. Specifically, the vastness and inaccessibility of California's wildland areas (from whence comes most of California's water supply) necessitate the basing of water supply estimates on very limited amounts of sample data.

(8) Even before the advent of our present studies, some remote sensing was used in the DWR data collection effort. For example, conventional aerial photography was acquired, in any given year and only on a one-date basis, for each of the counties that were scheduled for an updating

of information relative to water demand. From interpretation of the aerial photography and the use of supplemental field inspection, the DWR has been able to estimate with moderately high accuracy the acreage of irrigated land in that county as of the date of photography. However, for want of multi-date photography during the growing season, DWR has not been able to determine either (a) individual types of crops (or crop groupings) that are of significance because of differing demands for irrigation water, or (b) areas in which, through a practice known as "multi-cropping", a given area is made to produce two or more crops in succession in the same growing season, thereby imposing in most instances increased water demands per acre per season.

In view of the foregoing it was considered probable that the repetitive monitoring capabilities offered by the Landsat I and Landsat II vehicles would provide a practical source of information that could become a valuable supplement to the DWR surveys that have just been described. For example, DWR has long recognized the need to develop an operationally feasible process by which it could use information derived from the analysis of Landsat imagery, together with supporting large scale aerial photography and ground data, to obtain irrigated acreage statistics on a regional basis (i.e., statewide). The methods which have been developed by University of California participants under the present NASA grant are now in the process of being demonstrated/tested in a survey of ten California counties (13,745,000 acres).

The foregoing provides only one of several examples that might be cited to document the fact that our team of remote sensing scientists is aware of the need to work closely with potential users of remote sensing-derived information in order to maximize the usefulness of such information in the management of California's resources.

The approach that has just been described is being used as we broaden our studies so as to include the entire earth resource complex, area-by-area, in selected parts of California. Specifically (and with respect to the preparation of the more comprehensive Procedural Manuals that will result from our broadened studies), we recently have had discussions with various resource managers including (1) California's Regional Forester of the U.S. Forest Service; (2) the Supervisors of various U.S. National Forests in California; (3) their counterparts in California's State government; and (4) those concerned with resource management for representative county governments and private industrial groups. As a result of these discussions we have concluded that (1) in some instances it would be preferable from the intended user's standpoint for any given Procedural Manual to deal with remote sensing as applied to only a single resource because the management objective, quite simply, is to obtain maximum production or benefit from that single resource, even at the expense of receiving reduced production or benefits from other resources that pervade the same area and (2) in other instances it would be preferable for the Procedural Manual to deal with remote sensing as applied to the inventory and management of multiple resources or, indeed, to the entire "resource complex". In instances of this second type the policy which

the resource manager has been told to implement is one that recognizes the "trade-offs" that necessarily result when efforts are made to favor one resource over another. Hence, he has the nontrivial task of managing the entire property that has been entrusted to him in such a way as to provide an optimum "mix" of resource products. Reduced to its ridiculous extreme, this is the policy of attempting to provide that which, many years ago, the first Chief of the U.S. Forest Service termed: "the greatest good for the greatest number". The concept would become considerably less ridiculous, however, if an integrated inventory were to be made with suitable rapidity and at suitably frequent intervals and providing suitably accurate information as to how much of each of the previously-mentioned components of the resource complex are present in each portion of the area that is to be managed. It, therefore, will be our objective, as we produce this second type of remote sensing-oriented Procedural Manual, to present a step-wise procedure, complicated though it necessarily will be, for inventorying an area's entire resource complex. Consistent with NASA's wishes, that effort will be made (during the one-year period beginning on 1 May 1977) primarily by three components of our multi-campus integrated team: (1) the Geography Remote Sensing Unit on the Santa Barbara campus; (2) the Geosciences Remote Sensing Group on the Riverside campus; and (3) the Remote Sensing Research Program on the Berkeley campus. During that same period our Social Sciences Group also will be assisting in the preparation of the relevant manuals. By mutual agreement, the remote sensing team at Davis, under the leadership of Dr. Ralph Algazi, will not contribute to the preparation of Procedural Manuals during the one-year period that begins on 1 May 1977. Instead his grant-funded efforts will be entirely in support of the ASVT that is jointly administered by NASA Goddard and the U.S. Army Corps of Engineers dealing with remote sensing as an aid to the estimation of water supply.

CHAPTER 2

WATER SUPPLY STUDIES BY THE DAVIS CAMPUS GROUP

Co-Investigator: Ralph Algazi

Contributors: A. Bhumiratana
J. Stewart
R. Romberger
G. Ford
M. Suk

CHAPTER 2

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Chapter 2

Water Supply Studies

By the Davis Group

R. Algazi, Co-Investigator

Contributors: A Bhumiratana, J. Stewart, B. Romberger,
G. Ford, M. Suk

I. Introduction and Overview

In the past three years, the research performed under this grant has focused on the application of remote sensing techniques to the study of water resources. Our group has studied some of the problems concerned with the supply of water in California. Hydrologic models have been implemented and analyzed, and studies have been conducted to determine by remote sensing some of the physical parameters which characterize the state of watersheds and the evolution of snowpacks. In addition to this systems engineering and modeling work, we have continued our technical work on digital image processing techniques for remote sensing applications.

In this report, we discuss the results of the research conducted during the past year, with an emphasis on the work performed since our May 1976 Annual Report. Significant results have been obtained in the following areas:

1. Implementation and sensitivity analysis of a watershed model and determination of hydrologic parameters amenable to remote sensing inputs.
2. Development of techniques for snowmelt runoff prediction based on digital processing of satellite images.
3. Basic studies of image processing techniques pertinent to remote sensing applications.

To facilitate the reading and understanding of this report, we have used appendices to explain the details of some of the image processing algorithms. This allows proper emphasis in the body of the report on the utility and significance of these procedures in achieving the grant objectives.

II. Implementation and Analysis of Hydrologic Models

During the past two years, we have conducted a study of hydrologic models which are intended to be used as operational tools to study the response of a watershed to various hydrologic, climatologic and meteorologic occurrences and to assess the effect of alternative land use patterns and hydraulic projects on this response. The hydrologic models of interest to us are basically of two types. The first type is intended to model the existing conditions on a watershed. Historical records of precipitation and runoff are typically used to calibrate these models. These models can be used by watershed managers to make timely and pertinent analyses regarding project operations decisions, such as the control of reservoir releases. The second type of hydrologic model is intended to model anticipated or proposed changes in the characteristics of a watershed, such as residential or urban development and the construction of water retention or diversion structures. Our work to date has been concerned with a study of models of the first type, although some discussion of elements of models of the second type is given in section IV of this report.

We began our work on hydrologic models by reviewing the technical literature, and presented a discussion of our findings in the May 1975 Annual Report. Our subsequent work has been influenced by the work of

Ambaruch and Simmons [1] on the use of remote sensing in the Kentucky Watershed Model. Their work suggested that a quantitative assessment of the potential of remote sensing in watershed modeling be based on a study of the sensitivity of the output response of the model to variations in the input and internal model parameters.

We proceeded to conduct a sensitivity analysis of a streamflow model developed by Burnash, Ferral, and McGuire [2] for the River Forecast Center (RFC), operated jointly by the National Weather Service and the California Department of Water Resources. It was found that this analysis could not be carried out analytically, since some of the model parameters are determined by optimization procedures which are not amenable to analytical study. Due to this problem, the sensitivity analysis was performed by computer simulation. The RFC model, made available to us by Burnash and Ferral, was implemented on two computers on the Davis campus in March 1975:

The RFC model consists of a main program known as the soil moisture model, and a major subroutine known as the snow submodel which generates equivalent precipitation from snowmelt for use in the soil moisture model. The soil moisture model has been implemented at Davis, and simulation results have been generated for the Middle Fork of the Feather River, using historic data on precipitation and runoff from 1962 to 1969.

To support our ultimate objective of determining the utility of the use of remote sensing data as an input for this model, we pursued the following specific objectives:

1. Analysis of the model: To acquire, by simulation and analytic study, some insight into the behavior of the hydrologic model.
2. Sensitivity study: To study the effect of variations in the

dynamic inputs and internal parameters of the model on the predicted runoff. Emphasis is placed on those parameters which can possibly be acquired by remote sensing.

3. Simulation: To use parameters and inputs acquired by remote sensing in the model and to determine the effect of these parameters on the predicted runoff.

Parts 1 and 2 above have been completed for the soil moisture model, and a comprehensive discussion of the results was presented in the May 1976 Annual Report. In the sensitivity analysis, the effect on monthly volume runoff of variations in the parameters representing precipitation (rainfall and snowmelt), evapotranspiration, lower zone and upper zone tension water capacity, the percent imperviousness of the watershed, and the percent of the watershed in riparian vegetation, streams and lakes was studied. The most sensitive and critical parameters were found to be precipitation during the entire year, and evapotranspiration, principally for the spring regime of the model. From this result, we can conclude that precipitation and evapotranspiration are the most important parameters to acquire by remote sensing techniques. Since snowmelt is a component of precipitation, the determination of snowmelt by remote sensing is also an important task.

Model simulations incorporating information acquired by remote sensing are currently in progress. A cooperative study of the effect of acquisition of evapotranspiration by remote sensing will be made by our group and the Titus group of the Remote Sensing Research Project (RSRP) in Berkeley. The Titus group has developed a technique for the estimation of evapotranspiration from remotely sensed data. They will apply this technique to the Middle Fork of the Feather River for the Spring season of 1975. Our

group will use their estimated evapotranspiration parameters as an input to the RFC model to simulate the Spring 1975 conditions. Problems with this approach have recently been encountered, and must be resolved during the coming year. In order to perform the desired simulations, it is necessary to acquire daily volume runoff data for the Middle Fork at Merrimac and daily precipitation data for five stations within the watershed. The runoff data and raw precipitation data are available from the California Department of Water Resources. However, in order to run the simulation, the raw precipitation data must be preprocessed using the snow submodel. R. L. Ferral of the River Forecast Center has indicated that the work entailed in this preprocessing is substantial, and that his organization does not plan to do this work in the immediate future. In addition, he stated that the snow submodel program has not been adequately documented, so that it would not be possible for our group to do the precipitation preprocessing. A meeting with personnel from the River Forecast Center is planned for early 1977 to attempt to resolve these problems.

We are presently developing a model for the prediction of snowmelt runoff prediction which has a strong reliance on data acquired by remote sensing. At the present time, we do not anticipate incorporating our snow model with the RFC model. Rather, we intend to develop an independent snowmelt model which will demonstrate the feasibility of the use of remote sensing in the prediction of snowmelt runoff. Our work in this area is discussed in greater detail in the following section.

III. Snowmelt Runoff Prediction

Our work with hydrologic models primarily concerns the development of dynamic models for the prediction of runoff due to snowmelt, in which satellite data is the principal dynamic input. On the basis of previous research in this area, the following physical quantities are of primary interest in the modeling of basinwide snowmelt: the temperature, albedo, water content, and the elevation, slope, aspect and areal extent of the snow; the spatial distribution of precipitation; and the properties of the vegetal canopy. It is well known that these parameters vary substantially across the snow covered area within a major watershed and that they can change rapidly with time. For these reasons, we have undertaken a study to incorporate satellite data into a physically based, spatially distributed model of snowmelt for basinwide runoff prediction.

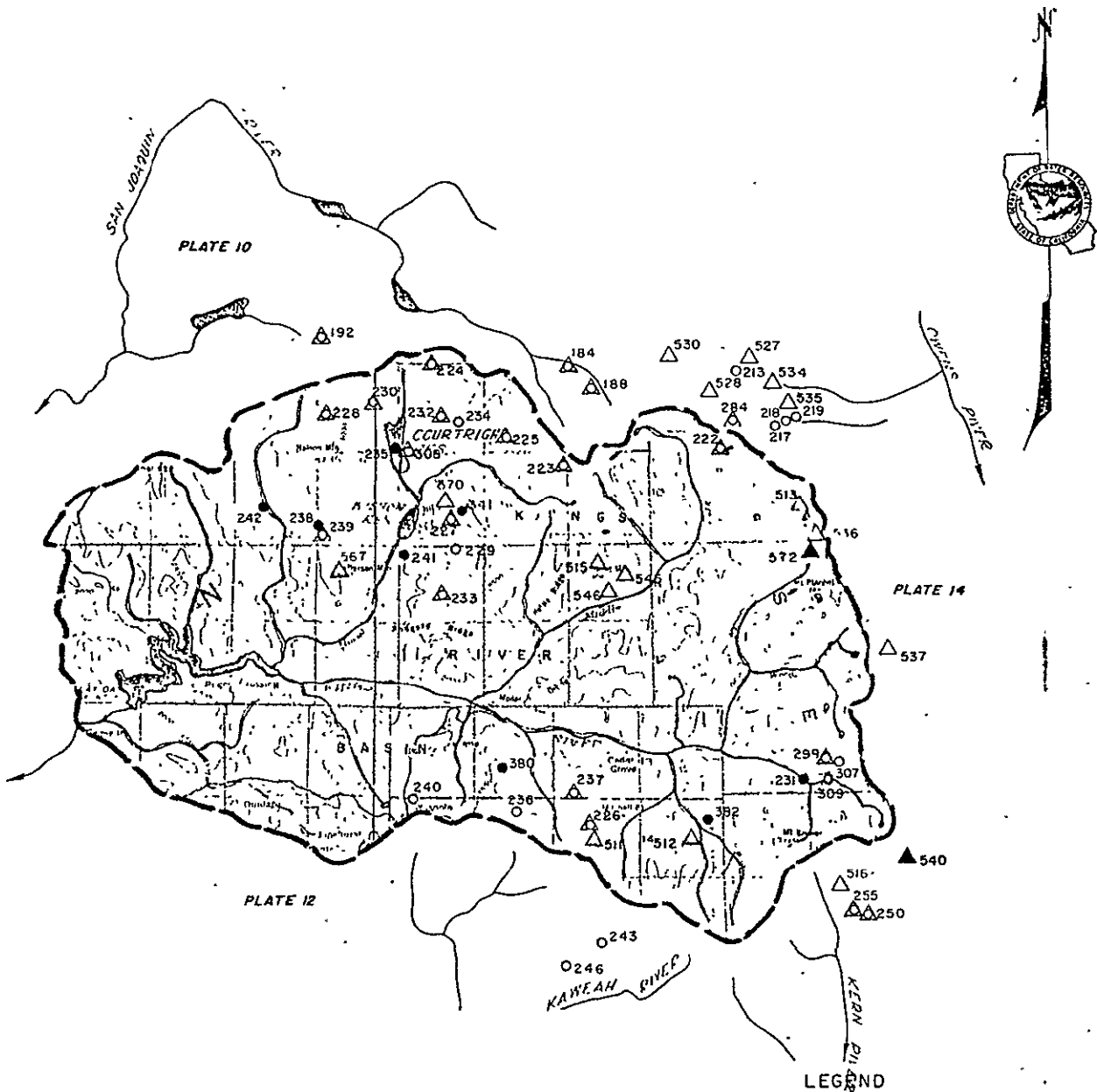
Since the snowpack evolves rapidly, and we wish to develop a dynamic model of snowmelt runoff, we have chosen to use the daily coverage provided by the NOAA satellites as our principal remote sensing data source. In addition to the daily coverage, the NOAA satellites provide data in a thermal infrared band (10.5 to 12.5 μm) as well as in a visible band (0.5 to 0.7 μm). However, we will not restrict the input data solely to remote sensing sources. Other easily obtained data will be incorporated, including: LANDSAT images, digitized elevation data, temperature and precipitation records from ground stations within the watershed, snow survey data and daily volume runoff data.

Our approach to modeling the snowmelt is to first apply pattern recognition clustering analysis to the spatially distributed data to partition the watershed into regions which are homogeneous in terms of the available

remotely sensed parameters. Submodels will then be developed to predict the localized snowmelt runoff on each of these regions. Standard hydrologic techniques of streamflow routing and combining will be applied to the localized runoff in order to predict the basinwide snowmelt runoff.

The model will be developed and tested on the Kings River basin of the southern Sierra Nevada range. This basin was selected because it is typical of the Sierra Nevada watersheds. It is a diverse watershed, ranging in elevation from about 500 feet at the outlet below Pine Flat Lake on the west to over 14,000 feet along the crest of the Sierras on the eastern edge of the watershed. The Kings River has three forks, the North, Middle, and South, and flow has been impaired only on the North Fork at Courtright and Wishon Reservoirs and on the main channel at Pine Flat Lake which is below the confluence of the three forks. A map of the watershed is shown in figure 1.

We chose to study the spring 1975 snowmelt season because of the availability of NOAA satellite data for this period. Coincidentally, the precipitation for winter 1974-1975 for the Kings River region was very close to the historical average values, so our study is for a near normal water year. We acquired all usable data collected by the NOAA-3 and NOAA-4 satellites over California, both in the visible band and in the thermal infrared band, from April 1, 1975 to July 7, 1975. We have data for 24 dates, but the data for the 9 dates in April are missing every third line of the image data because some of the user agencies were unable to handle the full data rates prior to early May 1975, and every third line was deleted in order to reduce the data load.



- LEGEND
- EXISTING SNOW COURSE
 - ABANDONED SNOW COURSE
 - △ AERIAL SNOW DEPTH MARKER
 - △ AERIAL SNOW DEPTH MARKER ON SNOW COURSE
 - RIVER BASIN

STATE OF CALIFORNIA
 THE RESOURCES AGENCY OF CALIFORNIA
 DEPARTMENT OF WATER RESOURCES
 DIVISION OF RESOURCES DEVELOPMENT
 CALIFORNIA COOPERATIVE SNOW SURVEYS
 SNOW COURSE LOCATIONS

KINGS RIVER BASIN

1970

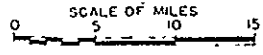


Figure 1. Kings River Watershed.

We have attempted to obtain all of the ground truth data which is available for the Kings River basin for the first half of 1975. Charles H. Howard, an Associate Water Resources Engineer with California DWR has provided us with a wealth of hydrologic data, including: daily temperatures for Grant Grove and Balch Power House; daily water equivalent of the snow pack as measured by snow sensors at State Lakes, Mitchell Meadow and West Woodchuck Meadow; monthly snow survey data for 22 snow courses; and daily unimpaired flow by Pre-Project Piedra, below Pine Flat Lake. A plot of the daily water equivalent of the snow pack is shown in figure 2, and a plot of the unimpaired flow is shown in figure 3.

Digital terrain tapes prepared by the Department of Defense, Defense Mapping Agency, from the USGS 1:250,000-scale topographic quadrangle map series were obtained from the National Cartographic Information Center for the Mariposa, California, and Fresno, California quadrangles. The data on these tapes has been converted into digital image format, and has been placed in registration with the NOAA satellite images, as will be discussed later in this report.

We have also obtained a computer-compatible tape (CCT) of the LANDSAT 2 image for September 1, 1975. Both the cloud cover and the snow cover are negligible on this date, and the imagery covers the entire extent of the Kings River basin. This imagery will be analyzed to determine the vegetative cover within the watershed.

NOAA Satellite Image Geometric Correction

In order to analyze the available data, and to convert it into a format which is suitable for input to a snowmelt model, we have been working to establish a file of spatial and temporal data consisting of albedo,

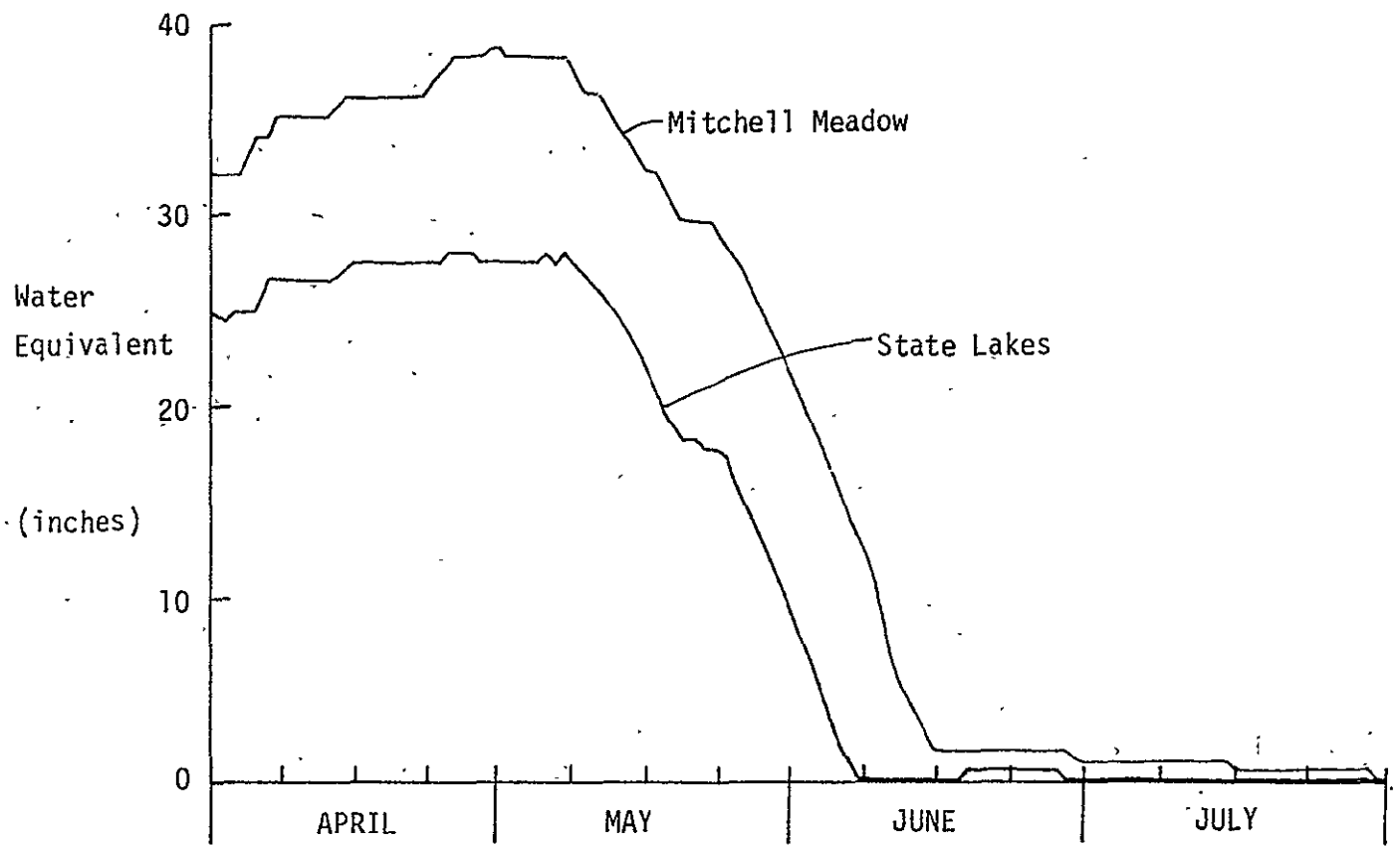


Figure 2. Daily Water Equivalent of Snow Pack

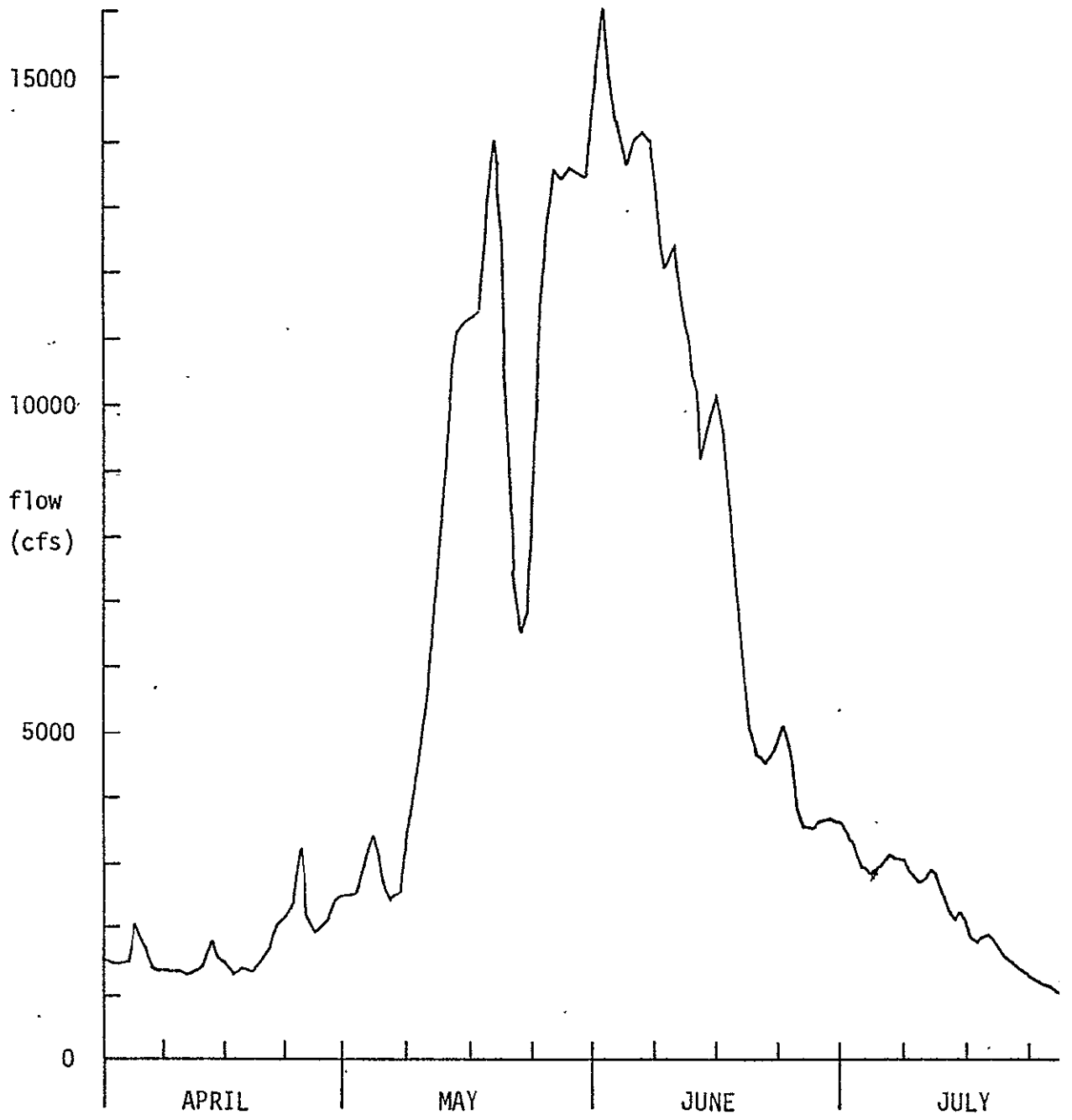


Figure 3. Unimpaired Daily Average Flow at Pre-Project Piedra

temperature, and elevation. For each date for which we have NOAA data, we want to be able to determine the albedo, temperature and elevation of any point within the watershed. With this capability, we can study the dynamic behavior of the snowpack. To establish this file, we must be able to achieve multitemporal registration of the NOAA images.

In order to obtain multitemporal registration, the geometric distortion present in the images must be removed. This distortion is due to a number of sources, including the scanning motion and orbital characteristics of the satellite, and the curvature and motion of the earth. This distortion varies from day to day due to the variation in location of the satellite with respect to a given point on the ground at the time the image is acquired. Thus, geometric correction is a crucial issue in our attempts to employ this form of remote sensing data.

A general discussion of techniques for geometric correction of satellite images is given in section IV of this report; however, a summary of the techniques applied to the NOAA images will be given here, and the details of these techniques are given in the appendices.

A two step geometric correction procedure is applied to the NOAA images. An example of a raw data image of south-central California on May 16, 1975 is shown in figure 4. A comparison of this image with a map of the region clearly demonstrates the distortions in this image, due primarily to the panoramic distortion caused by the earth's curvature and the skew distortion caused by the earth's rotation. This primary distortion is removed by a nonlinear resampling algorithm which is based on a model describing the distortion which was developed by Legeckis and Pritchard [3]. In this algorithm, which is discussed in detail in Appendix A, two-point interpolation resampling is applied along each image scan line

Figure 4. Uncorrected NOAA-4 Visible Image .
for May 16, 1975 .

independently. The resulting images still possess a variable degree of rotation, which is a function of the satellite position at the time of image acquisition, and other residual distortions, which were not accounted for in the correction algorithm. In the second step of the geometric correction procedure, the residual distortion is corrected by transforming the image using a biquadratic mapping function. Ground control points (GCPs) are used as external reference information to determine the proper mapping function. A GCP is a physical feature which is easily detectable in the image and easily located on a map. In this work, the GCPs used are water-land interfaces, such as the shorelines of lakes, the coastline near Monterey Bay, and features of major rivers. The locations of as many as 125 GCPs are determined from the partially corrected image and from USGS 1:250,000 scale topographic maps. The coefficients of the mapping function are then selected to minimize the squared distance between the GCPs in the image and the transformed GCPs from the maps. The image is then transformed, and examples of the results for the images of May 16 and May 24, 1975 are shown in figures 5 and 6. Details of this procedure are given in Appendix B.

An analysis of the remaining mean-squared errors of the GCPs indicates that the geometric correction procedure is correct to within one pixel in the output image. A summary of the results obtained for the four separate dates which we have worked with is shown in the table below:

<u>Date</u>	<u>GCPs</u>	<u>MSE</u>
May 16	124	0.740
May 24	111	0.798
May 28	120	0.823
May 29	103	0.508

While the results above show that the geometric correction procedure is effective, we have found that it is not entirely adequate due to the fact that it is very time-consuming. Determining the locations of over 100 GCPs in a 512x512 image is a very tedious task, even though we are able to do this by moving a cursor across a video display of the image. Our analysis of the procedure indicates that by eliminating some of the unreliable GCPs, we should be able to correct the image to nearly one pixel by using only 30 GCP's. However, this would still be a tedious procedure to apply to over 20 images, so we are currently developing an alternative approach to the geometric problem.

Development of a New Geometric Correction Algorithm

In our new approach, we still apply the algorithm to correct for panoramic and skew distortion. We then will calculate the amount of rotation in the image from a knowledge of the satellite orbital parameters. A simple bilinear transformation can then be applied to remove this rotation. The resulting image will only possess minor residual distortions. At this point one of the images which has been corrected using the previously described procedure will be selected as a reference image in determining the transformation to be applied to remove the residual errors. We will compute cross-correlation matrices between the reference image and the partially corrected image on several small, selected regions which have high contrast features. The locations of the maximum value of each of these cross-correlation matrices will be used as a virtual control point in the determination of the coefficients of a biquadratic transformation.

Figure 5. Geometrically Corrected NOAA-4 Image
for May 16, 1975

Figure 6. Geometrically Corrected NOAA-4 Image
for May 24, 1975

Correction of Radiometric Errors in NOAA Thermal Images

In addition to geometric correction, it is necessary to correct the errors in the thermal infrared image which are due to a drift in the sensitivity of the sensors. These random errors appear as horizontal banding or striping in the image. We have developed a digital filtering algorithm to remove these errors. A NOAA calibration algorithm is then applied to convert the numerical thermal image values into temperature. Details of our work to correct the early NOAA procedure have been discussed in earlier reports.

The final error which must be corrected is a random mis-registration of the thermal and visible images which is due to causes unknown to us. To correct this error, we first align the images as close as possible by eye, then we select regions of the image which contain high contrast features and compute the cross-correlation between the two images over these regions. The maximum cross-correlation determines the amount of horizontal and vertical translation required. We are able to register the two images to within one pixel with this procedure.

Elevation Data Correction

The elevation data on the digital terrain tapes which were mentioned previously also had to be corrected in order to put them in registration with the NOAA images. The terrain data is taken from a universal transverse mercator (UTM) grid, in which degrees longitude and latitude are given uniform spacing. However, the satellite data was corrected to have uniform distance spacing, so it was necessary to apply a map-to-map transformation to the elevation image. The resulting image is shown in figure 7,

with a corrected NOAA visible image for May 24, 1975 covering the same area shown in figure 8 for comparison.

Future Work on Kings River Modeling

We plan to continue our work to simplify the procedure for geometric correction. When this is complete, we will apply the correction procedure to as many of our available NOAA images as is practical.

We will continue our work on the development of a snowmelt runoff model for the Kings River basin. Trial runs of this model are planned for late spring or summer 1977.

IV. DIGITAL IMAGE PROCESSING TECHNIQUES DEVELOPMENT

Our efforts in the specific technical field of digital processing have followed two parallel goals: to pursue vigorously the specific areas of work in which we feel we can make a valuable contribution and to incorporate into our facility the algorithms and techniques developed by others which seem to have the most merit in applications.

A. Geometric Correction of Satellite Images

As discussed in section III, remote sensing data acquired by satellite sensors are affected by geometric distortions that, if uncorrected, diminish the accuracy of the information extracted and thereby reduce the utility of the data. The raw data image is an array of digital data which represents a geometrically distorted, two-dimensional perspective projection of some portion of the Earth's surface. The desired image is a geometrically corrected map projection of the same ground area.

The principal geometric errors associated with the data received from a satellite are the following:

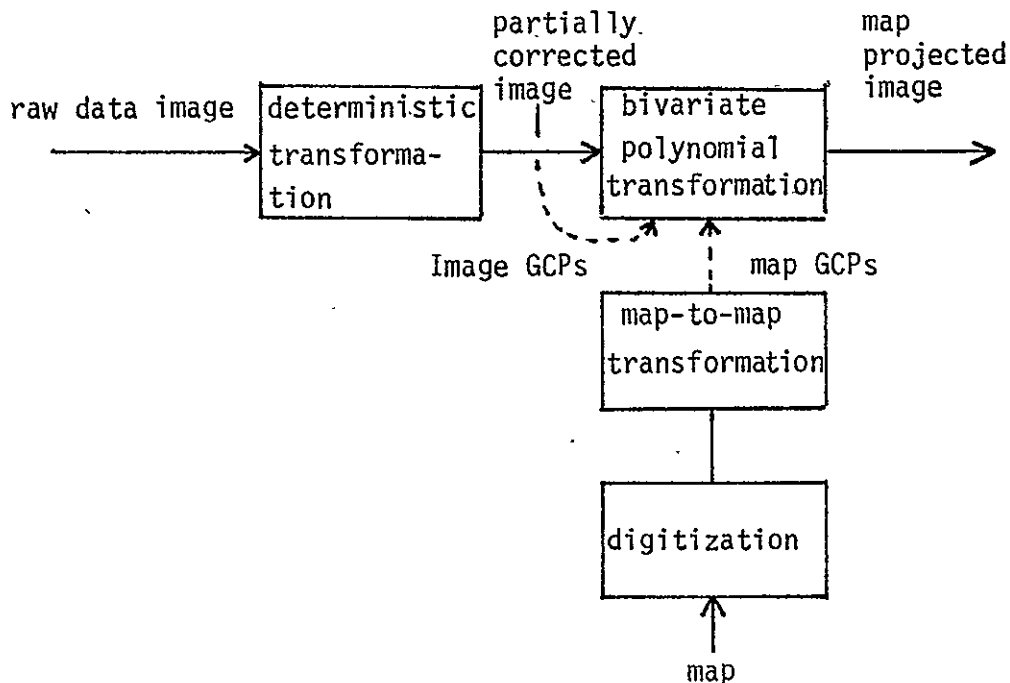
Figure 7. Digital Elevation Image

Figure 8. Portion of Geometrically Corrected
NOAA-4 Image for May 24, 1975

- (1) Panoramic distortion - Data samples are taken at equi-angular intervals of the scanning mirror motion, which means that the data does not come from regular intervals along the ground. This produces a nonlinear stretching of the image along scan lines.
- (2) Earth rotation - During the image acquisition, the earth rotates beneath the sensor. This causes both along-scan and cross-scan distortion.
- (3) Scan skew - During a line scan, the satellite moves along a ground track. Thus the ground swath swept out by the sensor is not normal to the ground track but is slightly skewed, which produces cross-scan distortion.
- (4) Velocity - If the satellite velocity varies, the spacing of image samples on the ground will vary, causing a cross-scan scale variation.
- (5) Altitude - Due to the non-circular nature of the satellite orbit, and the non-spherical nature of the Earth's surface, the spacecraft altitude of the satellite varies, causing scale changes in the image data.
- (6) Attitude - If the attitude of the satellite varies from the nominal values, geometric distortions will result.
- (7) Mirror velocity - If the scanning mirror rotates at other than the nominal constant angular rate, along-scan geometric distortion will occur.

Geometric correction procedures are applied to the distorted received images to transform them to a desired map projection. Most of these procedures are composed of two major steps, and require the use of external

reference information obtained from maps. An overview of the procedure is shown in block diagram form below:



In the first step, a model is developed to describe the known image distortion as accurately as is possible. A deterministic correction transformation is then synthesized from the model, utilizing the satellite orbital parameters to adjust the transformation. An example of a deterministic correction procedure developed for NOAA satellite data is given in Appendix A. The deterministic correction produces a partially corrected image which contains residual distortions due to random errors, or to deterministic errors which were not accounted for in the deterministic transformation.

In the second step of the generalized geometric correction procedure, external reference information is used to characterize a bivariate polynomial image transformation which is used to transform the partially corrected image to the desired map projection. Ground control points (GCPs) are used to

obtain the external information. A GCP is a physical feature which is easily detected in the image and easily located on a map. The most reliable GCPs are land-water interfaces, but airports, highway intersections, geological features, or agricultural field boundaries can also be used. The locations of these GCPs must be determined in the partially corrected image (dotted line labeled image GCPs in the figure above). The actual locations of the GCPs must be determined from a map (or several maps). This is typically accomplished by first digitizing the GCP locations on the map using a digitizing table or a graphics tablet. This establishes the GCP locations in the coordinate system of the digitizing instrument. It is then necessary to perform a map-to-map transformation on this data to transform it to the desired coordinate system of the map projected image. This transformation generally consists of scaling and translation, but can also entail a transformation from one mapping system to another. The outputs of the map-to-map transformation are the map GCP's. The coefficients of the bivariate polynomial transformation are then selected so as to minimize the sum of the squared errors between the image GCPs and the transformed map GCPs. A network of grid points in the map projection coordinate system is mapped into the coordinate system of the partially corrected image. After determining the location of the output pixels in the input image, the image is resampled using a bilinear interpolation method which uses four neighboring input values to compute the output intensity by two-dimensional interpolation.

We are actively trying to refine and improve on this procedure. Our first step is the development of interactive software for use with a graphics tablet and a minicomputer which will allow us to digitize GCPs from maps, and then to analyze the effect each GCP has on the resulting

transformation. With this software, we will easily be able to eliminate those GCPs which appear to have been unreliably located in either the image or the map. Secondly, we are developing procedures which will eliminate the need for the tedious acquisition of GCPs. Using a reference image which has been geometrically corrected, we will select small, high contrast regions in the image and compute a cross-correlation matrix between the reference image and a partially corrected image. The location of the maximum of the cross-correlation matrix will be used as a virtual GCP. The virtual GCP should be more accurate than the previously obtained GCPs, and will lead to a better correction transformation.

B. Acquisition of Ground Truth Information

In support of our work involving the use of remote sensing data in hydrologic modeling, we frequently need to acquire information from maps. Examples of the data required are: locations of ground control points, watershed boundaries, and boundaries of contiguous land use regions.

In order to meet this requirement we are developing software to allow interactive digitization of map information, using a graphics tablet and terminal interfaced to a minicomputer. The interactive capability will allow us to detect and correct errors during the process of digitization, which will provide improved accuracy.

C. Land-Use Classification

For the development of hydrologic models which are intended for use in analyzing proposed or anticipated changes in watershed characteristic, important information which can be acquired by remote sensing is the classification of existing land use.

We are presently exploring procedures for determining land use which are based on the efficient use of satellite image data and ground truth.

We have specifically focused on the well-developed methodologies for the classification of land use by remote sensing which are based on the efficient use of satellite image data and ground truth information.

A general underlying concern is to consider the suitability of the procedures used to the equipment and capabilities available to the Corps of Engineers. On these grounds, highly interactive methods requiring high quality image displays are not suitable. Thus, we have found that maximum likelihood classification, a supervised technique, is not adequate, due to the requirements for selection of training fields which are representative of the land uses in the watersheds of interest. The emphasis in our work has shifted to clustering, an unsupervised technique, which seems more likely to provide accurate land use classification results with a limited amount of interaction. The clustering approach has been applied to the Trail Creek watershed near Athens, Georgia, resulting in a substantial improvement in land use classification accuracy as compared to maximum likelihood. The clustering approach has also been applied to the Castro Valley, California watershed providing us with preliminary land use classification.

The following is a summary of the work completed to date:

1. Use of clustering for land use classification.
2. Karhunen-Loeve transformation or principal component analysis of LANDSAT data.
3. Incorporation of spatial information or texture into classification algorithms.
4. Outline of a tentative operational procedure for land use classification.
5. Classification results for the Trail Creek watershed.
6. Ground truth for the Castro Valley watershed.
7. Preliminary classification results for the Castro Valley watershed.

Examples of land use classification using the clustering algorithm are shown in Figure 9, where pictorial results are given for Trail Creek and Castro Valley.

D. Improvement of Processing Capability

In the past year, a digital image processing facility has been acquired by the Department of Electrical Engineering at UC Davis. The facility is currently operational, and since March 1977, all of our image processing work has been conducted at the Davis facility.

A block diagram of the facility is shown in figure 10. The major hardware elements are as follows:

1. The digital processor is a DEC PDP 11T55 Fast Fortran Laboratory System. This extremely fast minicomputer system contains 128,000 words (16 bit) of memory and a fast asynchronous floating point processor. DEC peripherals include a DECwriter and two RK-05 disks with a total storage of 4.8 million 8-bit bytes.
2. The primary interactive terminal is a Tektronix 4014 graphics terminal with supporting Tekplot software.
3. The graphics input device is a Tektronix 9054 X-Y digitizing tablet, measuring 30" x 40", with a resolution of 0.01".
4. The tape drive is a Kennedy 9300, 9 track 125 IPS, dual density 800/1600 BPI drive. The capability for handling 1600 BPI tapes is unique on the UC Davis campus.
5. The card reader is a Documentation 2000, which reads 285 cards per minute.
6. Printed and graphics output is provided by a Versatec 1200A printer-plotter, with the Versaplot 2 software package. This device prints on 11" wide paper at a density of 200 dots per inch.
7. The image display system is an International Imaging System (I²S)

model 70, which has a powerful video rate processing capability. A full color 256 x 256 image can be refreshed digitally, and three binary graphics overlays are available. The display device is a high quality 19" Conrac color television monitor.

8. Photographic output products will be generated using a black and white precision, high resolution recording cathode ray tube with a 70 mm camera. This unit is being modified to allow the photography of 1024 x 1024 full color images by the use of sequential filters.
9. A 300 megabyte disk, presently under procurement, will be used for mass storage of data and images.
10. Image digitizing will be accomplished by an image scanner. A 512 x 512 unit will be built at the earliest possible time.

Work is nearly complete on the development of a software picture processing system which is compatible with the DEC operating system RSX-11M. The basic objective of this system is to facilitate interactive usage. The second objective of the system is that it is easy to use. A user is able to sit at the console and type in the commands that tell the system what parameters to use. The syntax is easy to understand without being overly restrictive or hard to expand.

Secondary user objectives met by the system:

1. Parameters with commonly used values have default values so that they do not have to be entered every time.
2. Parameters with restricted values are checked for validity.
3. Results (such as max. or min.) from one step are usable in further steps without requiring the user to remember and enter them.
4. The user is able to interrogate the system as to what programs are available, what data is presently accessible, what values parameters

have and what parameters are required for each program.

5. Once the user determines a procedure, he is able to set up a series of commands for the system to execute without his intervention at every step.
6. The system handles data storage space allocation.

A third objective of the system is that new processing programs can be added easily. This involves a procedure for telling the system what new programs have been added, what its parameters are and their restrictions, how to set up data files or where to find input files, and what comments to give the user if he requests information on the program or its parameters

A fourth objective is that the system be easy to implement. A balance is being established between features wanted and difficulty of implementation. The system is designed in such a way to make check-out convenient, but is also flexible enough to make modifications and additions fairly easy.

The system is nearly complete, with minor modifications required to provide a compatible two-user environment.

V. PUBLICATIONS AND TECHNICAL PRESENTATIONS

1. B. J. Fino and V. R. Algazi. "Unified Matrix Treatment of the Fast Walsh-Hadamard Transform" IEEE Trans. on Comp., vol. C-25, no. 11, pp. 1142-1146, Nov. 1976.
2. V. R. Algazi, "Remote Sensing", A technical presentation at the 3rd Infocorp Assoc. Meeting (USACE Automatic Data Processing Conference), Davis, Calif., Aug. 17-19, 1976.
3. V. R. Algazi, "Image Processing in the Application of Remote Sensing to Hydrology". Invited presentation at the US-Japan Seminar on Image Processing in Remote Sensing, College Park, Md., Nov. 1-5, 1976.

4. V. R. Algazi, "The Psycho-physics of Vision and Their Relation to Picture Quality and Coding Limitations", Acta Electronica, vol. 19, no. 3, pp. 225-232; 1976.
5. V. R. Algazi and M. Suk, "Satellite Land Use Acquisition and Application to Hydrologic Planning Models", Eleventh International Symposium on Remote Sensing of the Environment, 1977.
6. G. E. Ford, "Sliding Mean Edge Estimation", submitted to IEEE Proceedings.

VI. PROPOSED AND CONTINUING WORK FOR 1977

The work under this multicampus University of California grant is being phased out over the coming year. By agreement with Dr. R. N. Colwell and the NASA monitor the work on our portion of the grant will be principally concentrated on support work in digital image processing for the ASVT program co-sponsored by NASA and the Corps of Engineers. Hence 1 and 2 below represent the phase out work on the "Integrated Study" grant. Item 3 is being continued until May 1978.

1. Simulation work on RFC hydrologic model using evapotranspiration parameters acquired by remote sensing, in cooperation with RSRP, Berkeley.
2. Basic work on the use of NOAA data as an input to a snowmelt runoff model:
 - . data correction
 - . geometric correction
 - . development of distributed snowmelt model
 - . statistic prediction of runoff
 - . trial simulations of model

3. Digital image processing work in support of our work on hydrologic modeling:

- . geometric correction
- . digitization of map information
- . land use classification

Part of the budget requested in the period May 1, 1977 to May 1, 1978 will be used in the acquisition of computer peripherals for our work in the operational application of remote sensing in hydrology.

VII. REFERENCES

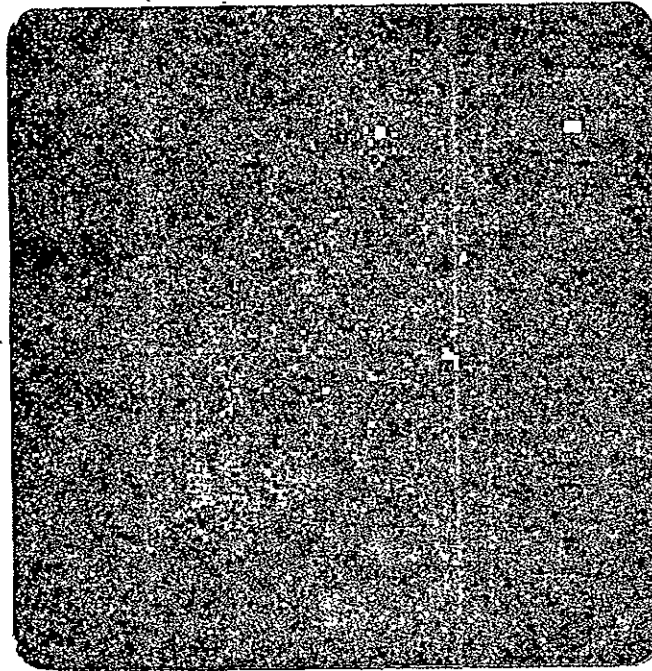
1. R. Ambaruch and J. W. Simmons, "Developments in Applications of Remote Sensing to Hydrology Through Continuous Simulation", Remote Sensing of Earth Resources, vol. II, Proc. of the 2nd Annual Remote Sensing Conference, Tullahoma, Tennessee, March 1973, pp. 1287-1306.
2. R. J. C. Burnash, R. L. Ferral, and R. A. McGuire, "A Generalized Streamflow Simulation System", River Forecast Center, Sacramento, California, March 1973.
3. R. Legeckis and J. Pritchard, "Algorithm for Correcting the VHRR Imagery For Geometric Distortions Due to the Earth's Curvature and Rotation", NOAA Technical Memorandum, Washington D.C., January 1976.

The following notes also are considered highly relevant:

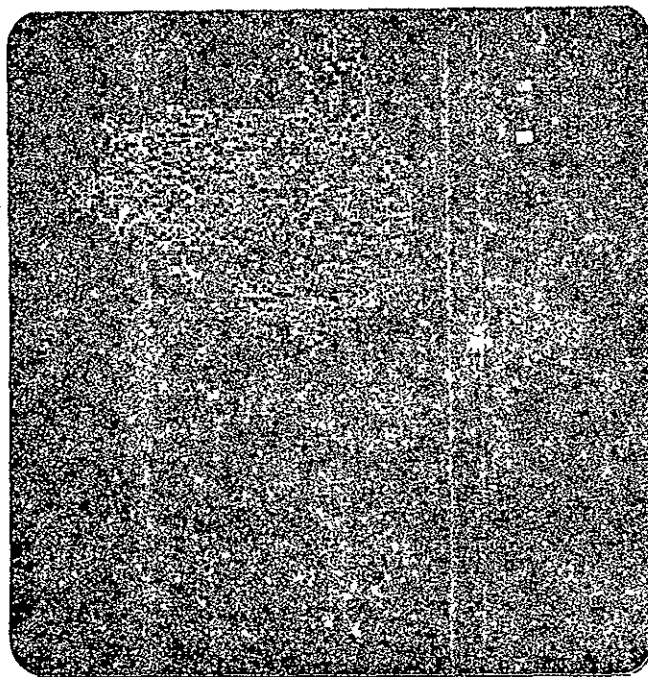
1. The digital processor is a DEC, PDP 11T55 Fast Fortran Laboratory System. This extremely fast minicomputer includes 32,768 words (16 bit) of memory, a fast asynchronous Floating Point Processor, a DECwriter, and 2 RK 05 disks with a total storage of 4.8 million 8-bit bytes.
2. A 285 card per minute card reader.
3. One Kennedy Model 9300, 9 track 125 IPS, Dual Density 800/1600 BPI tape drive. The 1600 BPI density is unique on campus for this very fast digital tape drive.
4. A Tektronix 9054 X-Y digitizing tablet. The size is 30" x 40" and the resolution is .01".
5. A large disk (not acquired yet because of lack of funds).
6. Printer-Plotter. Versatec 1200A, 11" wide and 200 dots/inch. Versaplot 1 software package.
7. Image display system. Model 70 manufactured by International Imaging System (I²S). This display system includes powerful video rate processing capability. A 256 x 256 full color image is refreshed digitally. Three overlays are available.
8. Color television monitor. A high quality 19" Conrac color monitor.
9. High resolution CRT. A black and white precision recording cathode ray tube with a 70 mm camera. This unit will be modified to allow the photography of 1024 x 1024 full color images by the use of sequential filters.
10. Image scanner. Not available. A 512 x 512 unit will be built at the earliest possible time.

A Tektronix 4014 graphics terminal with supporting software will also be connected to the PDP 11/55.

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(a) Trail Creek, Georgia



(b) Castro Valley, California

Figure 1. Land Use Classification by Clustering

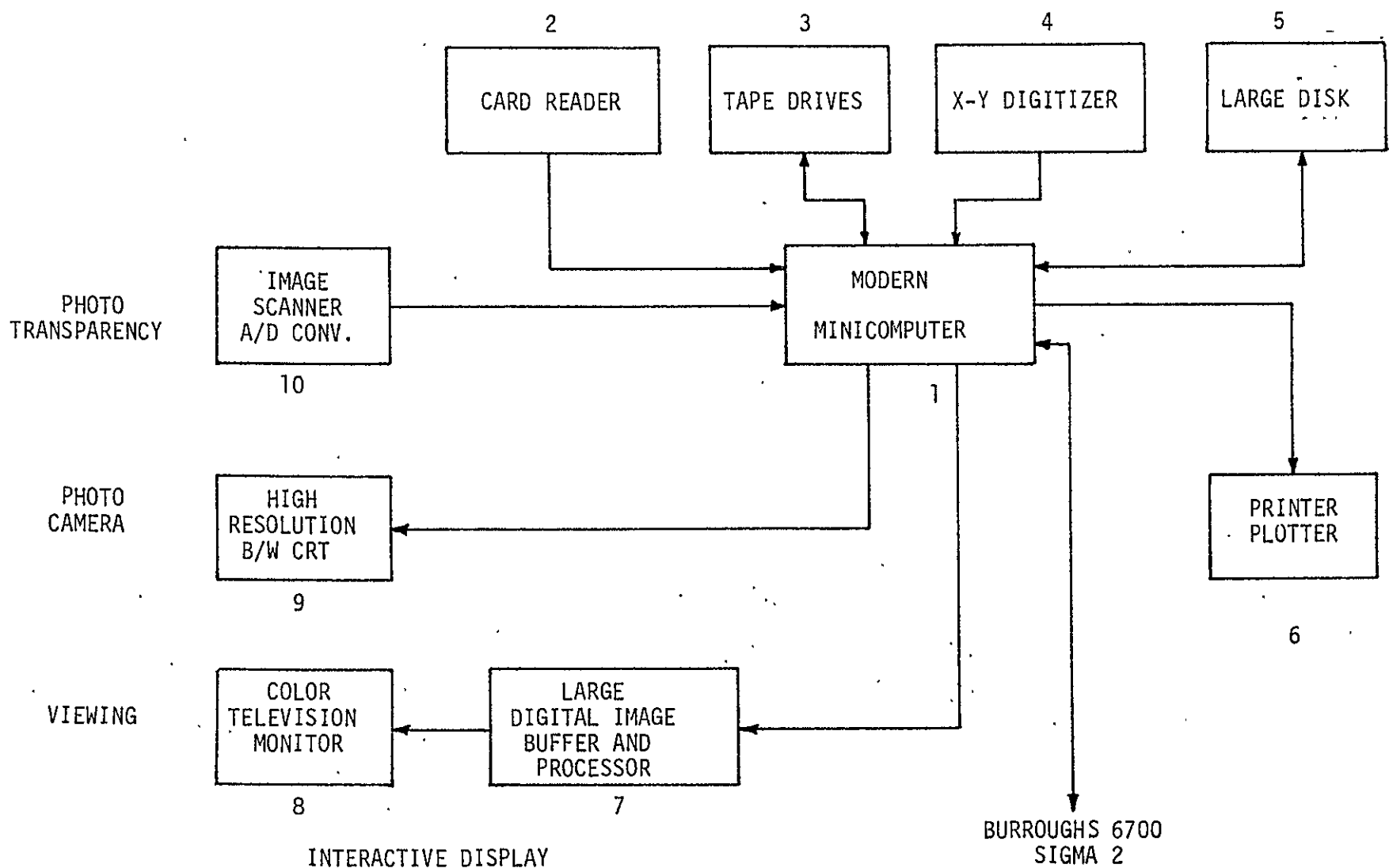


Figure 10. DIGITAL IMAGE PROCESSING FACILITY

APPENDIX A

Deterministic Geometric Correction Algorithm for NOAA Satellite Data

The principal geometric distortions in the NOAA Very High Resolution Radiometer (VHRR) images are due to the fact that the line scans are made along the curved and rotating Earth's surface. As a result, the distance between samples as well as the area of the scene in the VHRR field of view varies as the distance from the nadir increases. Although other variables contribute to the geometric distortion of the images, the principal distortions can be eliminated by correcting the errors due to the curvature and rotation of the Earth.

Radiometer Characteristics

The radiometer, as described by Schwalb [A1], is a two-channel scanning instrument sensitive to energy in the visible spectrum (0.5 to 0.7 μ m) and the thermal infrared spectrum (10.5 to 12.5 μ m). The scanning instrument is designed to operate on a spacecraft with a sun-synchronous orbit having a nominal altitude of 1501 km. Energy is gathered by an elliptical scan mirror which is set at an angle of 45° to the scan axis and rotates at 400 revolutions per minute. The reflected energy is focused by a Cassegraini-type optical system and is detected by a silicon photo-voltaic detector in the visible range and a thermistor bolometer in the infrared range.

The NOAA-3 and NOAA-4 satellites are operated in polar orbits. Over the western portion of the U.S., the satellite moves toward the southwest, in an orbit having an inclination angle (Q) of 78° at the equator, as shown in figure A-1.

The scan mirror of the radiometer rotates at a constant angular velocity and the visible and infrared detectors are sampled at a uniform rate(s) of 106,666 samples per second, so the acquired data is the same as would be

obtained from a device having uniform angular sampling as shown in figure A-2.

Assumptions

In order to simplify the geometric correction procedure, the following assumptions are made:

1. The Earth is a sphere with radius (R) of 6371 km which rotates on its north-south axis with a constant period (T) of 24 hours.
2. The following satellite parameters are assumed constant:
 - orbital angle of inclination of the equator, $Q = 78^\circ$
 - orbital period, $P = \begin{cases} 116.1 \text{ min for NOAA-3} \\ 115.0 \text{ min for NOAA-4} \end{cases}$
 - data sampling rate, $S = 106,666$ samples per second
 - angular scan rate, $W = 400$ revolutions per minute

Correction for Panoramic Distortion

Panoramic distortion appears in the VHRR images as a contraction of the Earth's features at increasing distance from the nadir. To remove this distortion, an algorithm must be applied to resample the original data so that the new sample points correspond to equi-distant spacing on the ground. The panoramic correction procedure discussed here is based on an algorithm developed by Legeckis and Pritchard [A2].

First refer to figure A-3 to determine the relationship between the radiometer scan angle (α) and the geocentric viewing angle (ϕ). It can be shown that

$$\tan(\alpha) = \frac{x}{h_0 + \Delta h} = \frac{R \sin(\phi)}{h_0 + R - R \cos(\phi)} = \frac{\sin(\phi)}{\frac{h_0 + R}{R} - \cos(\phi)}$$

or

$$\alpha = \tan^{-1} \left[\frac{\sin(\phi)}{\frac{h_0 + R}{R} - \cos(\phi)} \right] \quad (A-1)$$

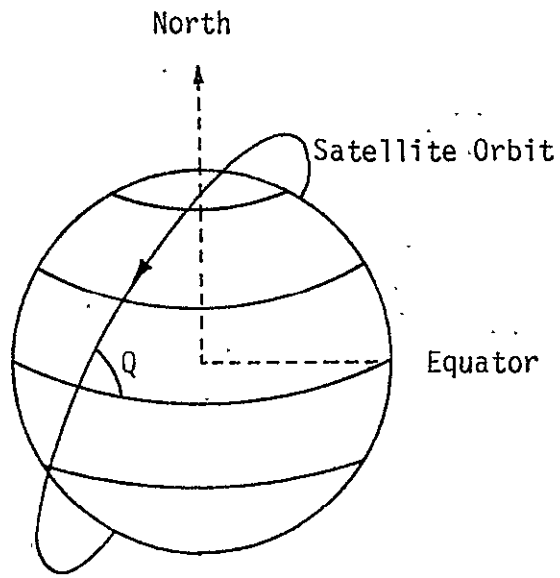


Figure A-1

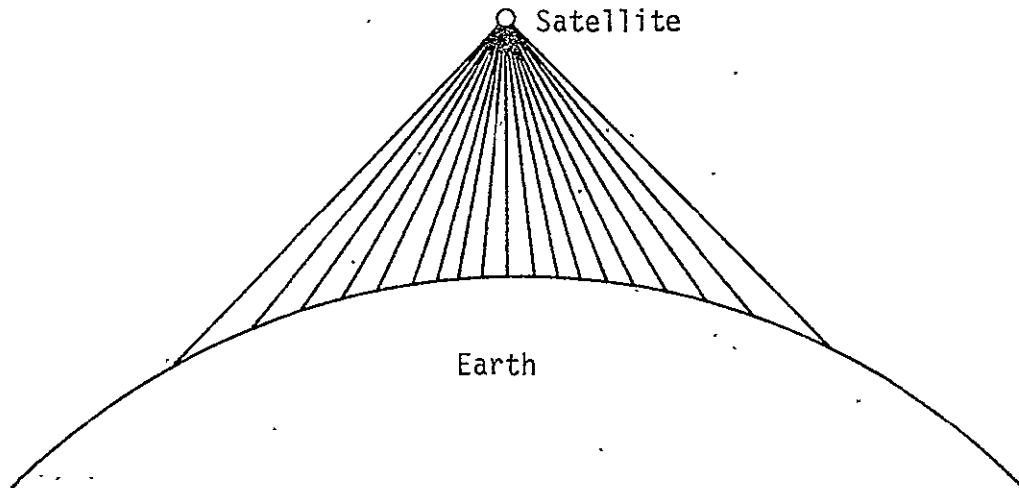


Figure A-2

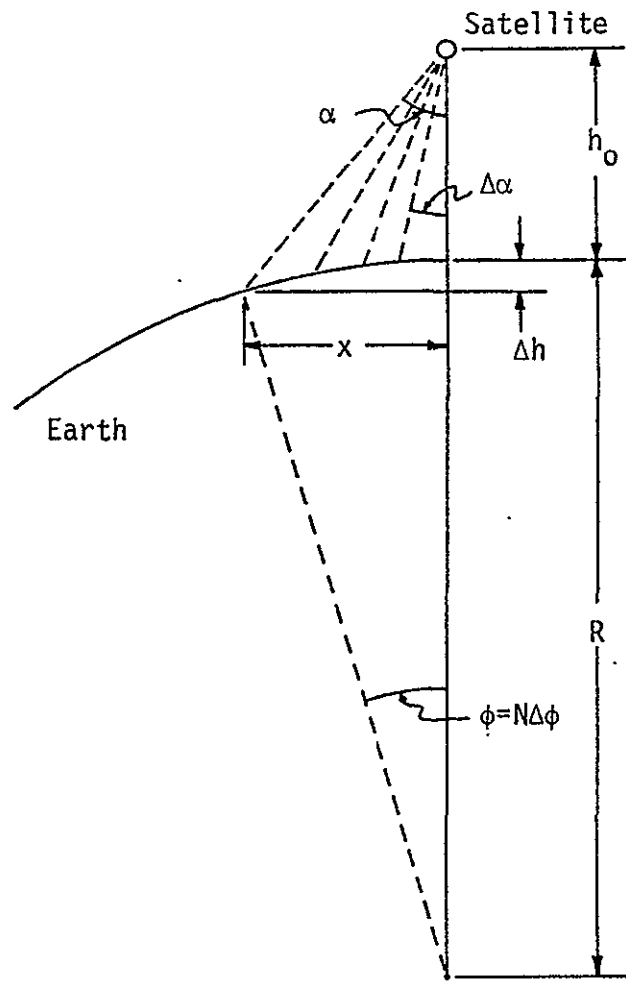


Figure A-3

θ = Latitude of satellite sub-point

$$R' = R \cos \theta$$

ϵ = angle between instantaneous intersection of the orbital plane and latitudinal plane.

$$= \cos^{-1}(\cos Q / \cos \theta)$$

$$V = 2 R \cos \theta / T$$

$$V_F = V \cos \epsilon$$

$$V_S = V \sin \epsilon$$

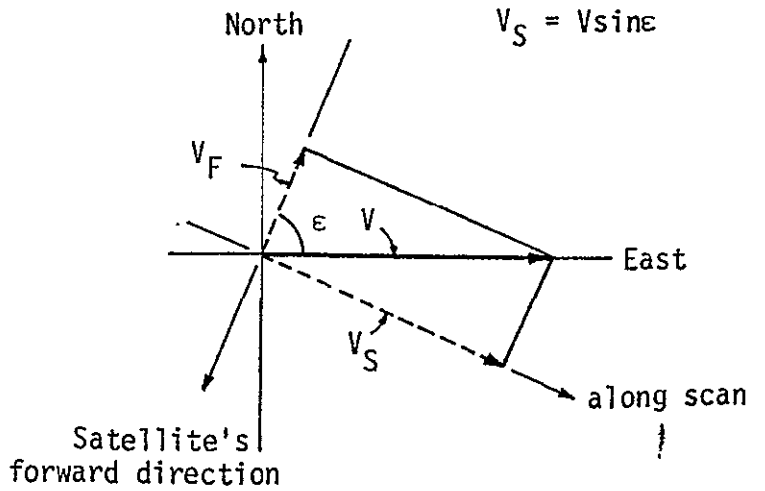
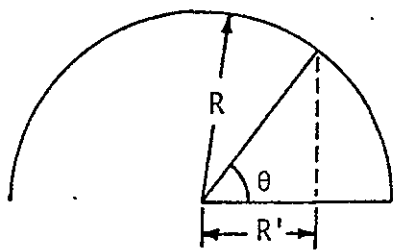


Figure A-4

where h_0 is the satellite altitude at the time of image acquisition.

The detector signals are sampled at uniform angular increments $\Delta\alpha$.

Thus,

$$\alpha = I \Delta\alpha = I \frac{2\pi W}{S} \quad (A-2)$$

where I is the original sample number counted from the center of the scan line. We want to resample the original data so that the new samples (indexed by N) represent the reflected energy at equidistant points along the ground track of the scan line. Since from figure A-2, it can be seen that the scanning is symmetric about the nadir, it is only necessary to derive the algorithm for one half of the line scan.

If D is the desired distance between samples then:

$$D = R \Delta\phi$$

and

$$\phi = N \Delta\phi = \frac{ND}{R}$$

From equations (A-1) and (A-2), we have:

$$I = \frac{S}{2\pi W} \cdot \tan^{-1} \frac{\sin(ND/R)}{\frac{h_0+R}{R} - \cos(ND/R)} \quad (A-3)$$

We wish to select the horizontal spacing (D) between sample points to be equal to the vertical spacing (L) between lines. To determine L , we must take into account the forward motion of the satellite and the rotation of the Earth, as follows:

$$\begin{aligned} L &\triangleq \text{ground distance between scan lines in km} \\ &= (\text{ground speed of forward motion}) \times (\text{scan period}) \\ &= (\text{ground speed due to satellite} + \text{ground speed due to Earth's rotation}) \times (\text{scan period}) \end{aligned}$$

The ground speed of the satellite (V_0) is given by:

$$V_0 = \frac{2\pi R}{P} \quad (A-4)$$

The three angles which are used to compute the components of the ground speed due to Earth motion are the orbital inclination angle Q , the latitude of the satellite sub-point θ , and the angle ϵ between an instantaneous orbital plane and a latitudinal plane. It can be shown that these angles are related by:

$$\cos \epsilon = \frac{\cos Q}{\cos \theta} \quad (A-5)$$

Figure A-4 shows the two components of Earth rotational velocity (V), consisting of one along the scan (V_S), and another along the forward direction of motion (V_F). The magnitude of the rotational velocity is given by:

$$V = \frac{2\pi R \cos \phi}{T} \quad (A-6)$$

Thus, the ground speed due to Earth's rotation is:

$$\begin{aligned} V_F &= V \cos \epsilon \\ &= \frac{2\pi R \cos \theta \cos \epsilon}{T} \\ &= \frac{2\pi R \cos Q}{T} \end{aligned} \quad (A-7)$$

From (A-4) and (A-7), we can determine L :

$$\begin{aligned} L &= \left[\frac{2\pi R}{P} + \frac{2\pi R \cos Q}{T} \right] \cdot \frac{1}{w} \\ &= \frac{2R}{w} \left[\frac{1}{P} + \frac{\cos Q}{T} \right] \end{aligned} \quad (A-8)$$

Letting $D = L$, by substituting (A-8) into (A-3) we have:

$$I = k \tan^{-1} \left[\frac{R \sin(N\Delta\phi)}{(h_0 + R) - R \cos(N\Delta\phi)} \right] \quad (A-9)$$

where

$$k = \frac{S}{2\pi W}$$

$$\Delta\phi = \frac{2\pi}{W} \left(\frac{1}{P} + \frac{\cos Q}{T} \right)$$

$$N = 0, 1, 2, \dots$$

For a given value of N , we compute I from equation (A-9). Since this I is not necessarily an integer, we compute the new radiometric sample N by linear interpolation between the original radiometric values of the integer sample numbers which bracket I .

Correction for Earth's Rotation

Because of the rotation of the Earth and the inclination of the satellite's orbit, the subsatellite point of every scan line of the radiometer is displaced westward. The amount of displacement depends on the latitude, inclination of the satellite orbit and the instantaneous angle of intersection of orbital plane and the latitudinal plane. This effect introduces skew distortion in the resulting image.

Referring to figure A-4 and equations (A-5) and (A-6), we see that the drift velocity in the direction of the scanning motion is given by:

$$\begin{aligned} V_s &= V \sin \epsilon \\ &= \frac{2\pi R \cos\theta \sin\epsilon}{T} \\ &= \frac{2\pi R (\cos^2\theta - \cos^2Q)^{1/2}}{T} \end{aligned}$$

From figure A-4 we see that $x = ND$ is the distance from the subsatellite point to the new sampling point N. The drift can be compensated for by adding the drift distance for m lines, $m\Delta x$, to the distance x if the new sampling point is on the right of the subsatellite point and subtracting it if it is on the left. Thus, equation (A-3) becomes:

$$I = \frac{s}{2\pi w} \tan^{-1} \left[\frac{\sin\left(\frac{ND \pm m \Delta x}{R}\right)}{\frac{h_0 + R}{R} - \cos\left(\frac{ND \pm m \Delta x}{R}\right)} \right] \quad (A-11)$$

substituting equations (A-8) and (A-10) into (A-11), we have:

$$I = k \tan^{-1} \frac{\sin(N \Delta \phi \pm m \Delta \beta)}{\frac{h_0 + R}{R} - \cos(N \Delta \phi \pm m \Delta \beta)} \quad (A-12)$$

where

$$k = \frac{s}{2\pi w}$$

$$\Delta \phi = \frac{2\pi}{w} \left(\frac{1}{p} + \frac{\cos Q}{T} \right)$$

$$\Delta \beta = \frac{2\pi}{w} (\cos^2 \theta - \cos^2 Q)^{1/2}$$

It can be shown that $m\Delta\beta$ is small compared to $N\Delta\phi$, and that I can be accurately approximated by the first two terms of its Taylor's series expansion:

$$I = k \tan^{-1} \left[\frac{\sin(N \Delta \phi)}{\frac{h_0 + R}{R} - \cos(N \Delta \phi)} \right] \pm \frac{m \cdot k \cdot \Delta \beta \left[\left(\frac{h_0 + R}{R} \right) \cos(N \Delta \phi) - 1 \right]}{\left(\frac{h_0 + R}{R} \right)^2 - 2 \left(\frac{h_0 + R}{R} \right) \cos(N \Delta \phi) + 1} \quad (A-13)$$

where k , $\Delta\phi$, $\Delta\beta$, m , and N are defined above. Note that the sign of the second term on the right of equation (A-13) is positive if the new sample is

on the right side of the subsatellite point, otherwise it is negative.

Equation (A-13) serves as the basis for the algorithm for the correction of panoramic distortion and Earth rotation distortion. However, before it can be applied to an image, two parameters must be determined: the altitude of the satellite (h_0) and the latitude of the satellite sub-point (θ) at the time of image acquisition.

In early trials of the correction algorithm, we found that the algorithm was very sensitive to changes in the altitude of the satellite. It was necessary to use the altitude of the satellite at the time of image acquisition instead of using the nominal value for this parameter. Russell Koffler of NOAA-NESS supplied us with NOAA-4 orbital ephemeris data which gives the altitude at each minute during an orbit.

The latitude of the satellite sub-point at the time of image acquisition varies from day to day. We found that it was not adequate to use a nominal value for this parameter. In fact, this parameter varies during image acquisition, since the satellite is moving during the time the image is being sensed. However, we found that accurate distortion correction could be obtained by using a latitude value corresponding to the satellite location at the center of the image.

It is necessary to calculate the latitude from reference data in the image, as this information is not available from the ephemeris data. We have developed an algorithm for calculating this parameter which is based on a NOAA Technical Memorandum by Ruff and Gruber [A3].

We first select a reference point in the center of the original image which is easily detected in the image, and which has a known latitude (θ_r). In our work, we chose the intersection of the Middle Fork and the South Fork

of the Kings River as our reference point. We then determine the sample number (I_r) of this reference point in the image, measured from the center of the image, with positive to the left, or west on the image.

The satellite nadir angle (α) for this reference point is given by:

$$\alpha = I_r \frac{2\pi W}{S} \quad (A-14)$$

the satellite zenith angle (z) is:

$$z = \sin^{-1} \left[\frac{R + h_0}{R} \sin \alpha \right] \quad (A-15)$$

From equations (A-14) and (A-15), we can calculate the geocentric viewing angle ϕ :

$$\phi = z - \alpha \quad (A-16)$$

the satellite latitude is then computed from the following expression:

$$\theta = \sin^{-1} \left[\frac{\sin \theta_r - \cos Q \sin \phi}{\cos \phi} \right] \quad (A-17)$$

The reader is directed to the paper by Ruff and Gruber [A3] for the details of the derivations of these equations.

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a Point Viewed Perpendicular to the Satellite Velocity Vector (Side Scan)", NOAA Technical Memorandum NESS 65, Washington, D.C., March 1975

APPENDIX B

Least-Square Geometric Correction Algorithm

Images which have been geometrically corrected using deterministic algorithms such as is described in Appendix A will still contain residual distortions due to random errors or to deterministic errors which were not accounted for in the deterministic correction. In the second step of a geometric correction procedure, a least-squares transformation is applied to correct the residual errors. In the procedure which we employ, external reference information is used to characterize a bivariate polynomial image transformation which is used to transform the partially corrected image to the desired map projection.

Using image coordinates (x_i, y_i) and map coordinates (x_m, y_m) , the transformation is the following:

$$\begin{aligned}x_i &= a_0 + a_1 x_m + a_2 y_m + a_3 x_m^2 + a_4 y_m^2 + a_5 x_m y_m \\y_i &= b_0 + b_1 x_m + b_2 y_m + b_3 x_m^2 + b_4 y_m^2 + b_5 x_m y_m\end{aligned}$$

To determine the coefficients a_0, \dots, a_5 and b_0, \dots, b_5 , locations of over 100 ground control points (GCPs) are determined on both the partially corrected image and on the appropriate USGS 1:250,000 scale maps. The coefficients are chosen to minimize the sum of the squared errors in the image coordinate system between the image GCPs and the transformed map GCPs.

The problem of calculating the coefficients can be seen to be a problem of multiple regression, and a variety of techniques are available for its solution. Let (x_{ij}, y_{ij}) be the coordinates of the j th GCP in the image, and (x_{mj}, y_{mj}) be the corresponding coordinates in the map. Define the following parameters:

$$\begin{aligned} R_j &= x_{ij} \\ Z_{1j} &= x_{mj} \\ Z_{2j} &= y_{mj} \\ Z_{3j} &= x_{mj}^2 \\ Z_{4j} &= y_{mj}^2 \\ Z_{5j} &= x_{mj} y_{mj} \end{aligned}$$

then subtract the arithmetic mean from each of these parameters:

$$\begin{aligned} r_j &= (R_j - \bar{R}) \quad \text{where} \quad \bar{R} = \sum_{j=1}^N R_j \\ z_{kj} &= (Z_{kj} - \bar{Z}_k) \quad \text{where} \quad \bar{Z}_k = \sum_{j=1}^N Z_{kj} \end{aligned}$$

and where N is the number of GCPs.

The desired coefficients a_0, \dots , as are given by the following:

$$\begin{bmatrix} a_1 \\ a_2 \\ a_3 \\ a_4 \\ a_5 \end{bmatrix} = \begin{bmatrix} T_{11} & T_{12} & T_{13} & T_{14} & T_{15} \\ T_{21} & T_{22} & T_{23} & T_{24} & T_{25} \\ T_{31} & T_{32} & T_{33} & T_{34} & T_{35} \\ T_{41} & T_{42} & T_{43} & T_{44} & T_{45} \\ T_{51} & T_{52} & T_{53} & T_{54} & T_{55} \end{bmatrix}^{-1} \begin{bmatrix} S_1 \\ S_2 \\ S_3 \\ S_4 \\ S_5 \end{bmatrix}$$

$$a_0 = \bar{R} - a_1 \bar{Z}_1 - a_2 \bar{Z}_2 - a_3 \bar{Z}_3 - a_4 \bar{Z}_4 - a_5 \bar{Z}_5$$

$$\text{where } T_{k\ell} = \sum_{j=1}^N z_{kj} z_{\ell j}$$

$$\text{and } S_k = \sum_{j=1}^N r_j z_{kj}$$

The equations for the coefficients b_0, \dots, b_5 are very similar, and will not be given here.

For the image transformation to be correct, the locations of the GCPs must be determined very accurately and carefully. In order to do this, we display 256x256 sections of the 512x512 image on a video monitor and use a cursor to locate the GCPs. When we have located all of the points which are not under a cloud cover for that date, we compute the transform coefficients and transform the map GCPs to the partially corrected image. This allows us to observe the errors in GCP locations, and we then refine our image GCP locations if necessary. This avoids errors in GCP selection such as choosing the wrong feature in the image as the desired GCP. The transform coefficients are then recomputed.

This algorithm has been applied to images for four dates, and in each case, the coefficients for the square terms of the transformation were much smaller than those for the linear terms. This indicates that most of the highly nonlinear distortions have been removed by the deterministic correction algorithm.

Having now acquired the desired transformation, the positions of the output picture elements on the input image are determined. The image is then resampled, using the bilinear interpolation, in which the four neighboring input values are used to compute the output intensity by

two-dimensional interpolation. A discussion of the resampling procedure can be found elsewhere [B-1, B-2].

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CHAPTER 3

WATER SUPPLY STUDIES BY THE
BERKELEY CAMPUS RSRP GROUP

Co-Investigator: Siamak Khorram

Project Scientist: Edwin F. Katibah

CHAPTER 3

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Chapter 3

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3.000 INTRODUCTION

During the present reporting period most of the work that has been performed by the Remote Sensing Research Program (RSRP) personnel at the Berkeley Campus has continued to deal with water supply studies. The focus of these studies is on the development of remote sensing-aided procedures to provide cost-effective, timely, and satisfactorily accurate estimates of various important components of hydrologic models. Specifically, procedures are being developed for estimating the areal extent of snow, the water content of snow, the amount of solar radiation, and the loss of water to the atmosphere by evapotranspiration. The values obtained for these components by means of remote sensing will be used as inputs to each of the two state-of-the-art water yield forecast models currently being operated by the California Department of Water Resources (DWR). These are (1) the California Cooperative Snow Survey's (CCSS) model, and (2) the model of the federal-state River Forecast Center (RFC). The RSRP effort is being currently conducted in close coordination with that of other NASA Grant participants, particularly the efforts of the Algazi group on the Davis campus as described in Chapter 2 of this progress report. This cooperative effort involves an analysis of the sensitivity of the RFC runoff forecast model to its input components, particularly the model response that results from using a remote sensing-aided evapotranspiration estimate as one of the major input parameters.

This work, to be completed with the preparation of procedural manuals, describes the step-wise process which might best be followed by managers of water resources in using remote sensing as an aid to water resources inventory, development and management. Therefore, it is considered appropriate in this progress report to briefly summarize our findings to date relative to the preparation of procedural manuals. Most of the work that is about to be presented has been brought to completion during the present reporting period.

As it is presently seen, the work is placed in proper context by first briefly explaining some of the work which our group has previously done on Spanish Creek Watershed (475 km²) for some parts and entire Feather River Watershed in other parts. Then we will describe our research activities during the present reporting period and discuss the remaining future research. This report will then be concluded with various procedural manuals. These procedural manuals include a complete version of Snow Areal Extent Estimation, a version of Snow Water Content Estimation, and Outlines of Solar Radiation Estimation and Estimation of Water Loss to the Atmosphere.

3.100 SUMMARY OF WORK DONE ON SPANISH CREEK WATERSHED
AND FEATHER RIVER WATERSHED

In this section the procedure for estimating areal extent of snowcover is discussed at the beginning. The results of snow areal extent will then be used in a technique developed for snow water content estimation. The last part of this section will cover the methodology developed for evapo^l transpiration and solar radiation estimations.

3.101 Methodology for Estimating Areal Extent of Snowcover

From the late forties to date, many studies have included use of aerial photography to measure the areal extent of snowcover (Parsons and Castle, 1959; Finnegan, 1962; Leaf, 1969). However, it was not until the early 1960's that one could attain a synoptic view of large geographical areas through earth orbiting satellites. Today, a wide variety of satellites are collecting massive amounts of data that could be utilized to map the snow areal extent in a repetitive mode over the large watersheds. Imagery obtained from Landsat-1 has provided the raw data for this study. The method used to estimate areal extent of snow at the Remote Sensing Research Program (RSRP) is based upon the analysis of imagery defined by artificial units (grids) with environmental considerations (Katibah, 1975). This procedure allows the image analyst to make decisions in discrete units of the imagery as to the areal extent of snow based upon factors affecting the snowpack.

Three cloud free dates in spring 1973, April 4, May 10, and May 28, covering the Feather River Watershed were used for this snowcover inventory. Landsat imagery in the form of simulated color infrared enhancements of bands 4, 5, and 7 was utilized for the interpretation procedures (Katibah, 1973). On these three dates random transects were flown across the watershed using a 35 mm camera to acquire large scale photography required as an aid in determining the actual snow condition on the ground.

To estimate the areal extent of snow, the Landsat-1 images were gridded with image sample units (ISU's), each equalling approximately 400 hectares. These image sample units were then transferred to the large scale photography where applicable. The image sample units on the aerial photography were divided into five classes containing from 0 to 100% snowcover.

The gridded Landsat color enhanced images were then interpreted, sample unit-by sample unit, and coded using the following method to account for vegetative cover and density and to some degree, aspect and elevation. Scale-matched simulated color infrared enhancements of Landsat-1 imagery were produced for April 4, 1973; May 10, 1973; May 28, 1973 and also for August 31, 1972 in reflection print form. The April and May dates represent the snowpack and were gridded, while the August 1972 date, representing a cloud free summer image, was not gridded. The purpose of the August date

was to provide a clear aerial view of actual ground relationships of vegetation/terrain features. The August date was superimposed with each of the snowpack dates using a mirror stereoscope. Using this technique the image analyst could observe what conditions actually occurred on the ground in the image sample unit he was interpreting for snowpack.

The large scale photographs were used to calibrate the Landsat data where applicable. The sample unit-by-sample unit interpretation of the Landsat imagery, was then used to find the estimate for the areal extent of snowcover in the watershed. Summations of each of the individual snowcover classes were used to estimate the areal snowcover of each image sample unit on the ground. By addition of these totals the areal extent of snowcover for the entire area was estimated.

This estimation of the areal extent of snow was based only on the Landsat interpretation results. To correct this estimate, the image sample units where snow areal extent "ground truth" was obtained (from large scale aerial photography) were compared with the same image sample units on the Landsat imagery. The relationship between the snow areal extent values on the corresponding Landsat and "ground truth" sample units is the basis for the application of the ratio estimator statistical technique (Cochran, 1963). This technique not only provides a correction for the original interpretation estimate, but also allows for an estimate of the precision of this estimate through the application of confidence intervals. The 95% confidence intervals around the areal extent of snow estimates were then calculated.

3.102 Methodology for Snow Water Content Estimation

The rate at which the snowcover depletes is an index which is inversely related to the snow water equivalent and snowmelt runoff (Rango and Salomonson, 1975; Khorram, et al., 1976). The procedure used in this study is designed to generate an estimate of watershed-wide snow water content and an associated statement of precision. This system employs a stratified double sampling technique based on Cochran, 1963 and Raj, 1968 and uses both ground snow course and Landsat data. Its objective is to combine snow water content information for the whole watershed, as obtained inexpensively from Landsat data, with that gained from a much smaller and more expensive sample of ground-based measurements at snow courses. This method is described below:

Black-and-white Landsat imagery for April 4, May 10, and May 28, 1973 covering the Feather River Watershed (7,800 km²) was obtained and transformed into a simulated infrared color composite. In the color combining process, an ISU grid was randomly placed over each image so as to cover the watershed of interest. ISU's in this study represented areas of about 400 hectares.

Estimates of snow areal extent by Landsat ISU for previous year(s) or current snow build-up dates were made. Each ISU was interpreted manually

as to its average snow areal extent cover class according to a snow environment-specific technique (Khorram, et al., 1976). Estimates of snow areal extent by ISU for Landsat snow season date were then calculated.

This snow areal extent data was transformed to snow water content data. Snow water content index was estimated from the following first order, time-specific model:

$$X_i = \sum_{j=1}^J (M_{ij})(G_j) K_i$$

where X_i = estimated snow water content for image sample unit i ,

M_{ij} = snowcover midclass point based on photo interpretation; expressed on a scale of 0.00 to 1.00 for image sample unit i on the j th Landsat snow season date.

G_j = weight assigned (0.00-1.00) to a past M_{ij} according to the date of a current estimate,

K_i = the number of times out of j that sample unit i has greater than zero percent snowcover, and

J = total number of snow season dates considered.

To insure reasonably high correlation between X_i and corresponding ground snow water content values, there usually should be at least three snow season dates considered ($j \geq 3$). Normally, one or two dates of Landsat imagery would be required during the early snow accumulation season. Occasionally, j may be only two, such as when the first date consists of an April 1 snow water content map based on past year's Landsat data. In all cases the sample unit grids on all dates must be in common register with respect to a base date grid location.

All the image sample units were stratified into Landsat snow water content index classes. The number of ground sample units (GSU's) by stratum or snow courses required to achieve the allowable error criteria for the basin snow water content estimate was then calculated. The number of required ground samples may be determined (Thomas and Sharp, 1975) for individual strata according to the snow survey direct cost budget for the watershed of interest and according to the following stratum-specific statistics: relative stratum size, Landsat snow water content variability, Landsat-to-ground correlation, and Landsat-to-ground sample unit cost ratio. This study employed six snow water index strata, with water content index values ranging from less than 0.1 to over 8. Such stratification was used to control the coefficient of variation of the overall basin snow water content estimate.

The GSU's were allocated among snow water content strata with equal probability within strata in accordance with stratified random sampling requirements. Table I summarizes the number of image and ground sample units required in each of six snow water content strata, given a cost per ISU of 15¢ and a cost per GSU of \$150.

The final product was the watershed-wide estimate of snow water content according to a summation of strata-wide snow water content index data, comparing each stratum to the corresponding sample of ground snow water content measurements.

3.103 Methodology for Watershed-Wide Estimation of Evapotranspiration

Evaporation may be defined as the transfer of water vapor from a non-vegetative surface on the earth into the atmosphere. Evapotranspiration is the combined evaporation from all surfaces and the transpiration of plants. Except for the omission of a negligible amount of water used in the metabolic activities, evapotranspiration is the same as the "consumptive use" of the plants. The fact that the rate of evapotranspiration from a partially wet surface is greatly affected by the nature of the ground leads to the concept of potential evapotranspiration. Penman (1948) defines potential evapotranspiration as "the amount of water transpired in unit time by a short green crop, completely shading the ground, of uniform height and never short in water."

A multistage, multiphase sample design is utilized to estimate watershed evapotranspiration water losses. Basically, there are three increasingly resolved levels of information, each of which is sampled. The first level is composed of satellite and topographic data. Vegetation, terrain, and meteorological types of information are defined for a convenient base resolution element, in this case a small group of Landsat pixels. The appropriate evapotranspiration equations, defined as Level I models, are able to perform adequately on this "least resolved" information available from the first data level.

After an estimate of evapotranspiration has been made for each basin resolution element, the resolution elements (here 4 x 4 or 5 x 5 blocks of pixels) are grouped into primary sampling units (PSU's). Based upon the variability among PSU's a sample of these units will be selected within each stratum for further sampling. Within each PSU selected, a series of secondary sampling units (SSU's) will be defined and photographed at large scale with light aircraft. The photographic SSU data along with nearby snow course and ground station calibrated meteorological satellite data will provide the second level of information resolution. Thus Level II evapotranspiration models employing more data types and more refined data will be used to generate evapotranspiration estimates for each SSU. A sample of two of the SSU's per PSU selected will then be randomly chosen for further analysis on the ground. For each of these SSU's selected, detailed ground measurements will be made of vegetation canopy geometry, color, etc. as well as of soil and litter-organic debris conditions. The detailed data from this third level of information will then drive Level III evapotranspiration prediction

models. Since estimates of evapotranspiration will be for the entire ground area of the SSU photo plot, this third stage unit (TSU) will actually comprise a double sample of the SSU's.

The full watershed estimate of evapotranspiration can then be developed by first using the ground based evapotranspiration estimate to calibrate the SSU estimate derived from photo data. The calibrated SSU estimates can then be expanded to the PSU stage by utilizing the SSU selection weights developed earlier. Finally, PSU evapotranspiration estimates can be expanded, each over the appropriate stratum, and then to the entire watershed by applying the PSU selection weights (proportion of evapotranspiration in the given PSU relative to all other PSU's in the watershed) originally calculated. In this way, a cost-effective combination of an increasingly smaller sample of more precise and more expensive information levels can be utilized to give basin-wide watershed estimates.

The multistage equation that will be used to combine data from Levels I, II, and III in order to generate an estimate of watershed-wide evapotranspiration is:

$$ET = \frac{1}{n} \sum_{i=1}^n \frac{1}{P_i} \left[\frac{1}{n_i} \sum_{j \in \{D\}} \frac{A_i}{a} \times \frac{Y_{ij}}{P_{ij}} \right], \text{ in which}$$

$$P_i = \frac{ET_i}{\sum_{i=1}^n ET_i} \quad \text{and} \quad P_{ij} = \frac{ET_{ij}}{\sum_{j \in \{D\}} ET_{ij}}, \text{ where}$$

- n = number of PSU's sampled (5)
- P_i = probability of selection of the *i*th PSU
- n_i = number of SSU's selected within *i*th PSU (2)
- $j \in \{D\}$ = the set of SSU's selected in each sampled PSU
- A_i = area of the section within which SSU is located
- a = area of SSU
- Y_{ij} = ground ET estimation for the *j*th SSU of the *i*th PSU
- P_{ij} = probability of selection of *j*th SSU for ground measurement within *i*th PSU
- ET = average evapotranspiration estimate for the entire watershed

This sampling technique allows the estimate of ET based on each level of modeling and if a user does not require high accuracy on ET estimates he/she can use the Level I models results independently or calibrated with Level II models results without having to use Level III models at all. Sampling theory allows a variance for each estimate. Therefore a confidence interval with specified probability may be associated with the estimates.

The required input data for this evapotranspiration estimation system is composed of physiographic data of the watershed and climatic data. Physiographic data include latitude, longitude, elevation, slope, aspect, and vegetation/terrain data. Climatic data include temperature, humidity, precipitation, wind movement, cloud cover, solar radiation, and some standard meteorological constants.

Recommended Level I ET Models:

Empirical and semiempirical formulas are applied in this level. The input for these models is provided primarily from Landsat, Environmental (meteorological) satellites, ground meteorological stations, and digital topographic data. The variables to be derived from these data for the above models are surface temperature, net solar radiation, relative humidity, precipitation, and cloud cover. The watershed values of net solar radiation are calculated based on a model developed by the author (Khorram, 1976). The models based on the following equations are being considered for this level: Jensen and Haise Equation (1963), Hargreaves Equation (1956), and Blaney-Criddle Equation (1950). Based on climatic conditions and models performances one of these equations is selected to represent the Level I models (Khorram, 1974 a, b).

Recommended Level II ET Models:

The basis for the evapotranspiration models to be applied to the second level of information resolution is that of energy conservation. For this level, the energy-balance method will be combined with other methods for consideration of vegetation canopy effects. The objective of the model applied at Level II will be to capitalize on vegetation canopy, geometry-composition, and other surface data available from aerial photography to provide improved evapotranspiration estimates for the appropriate photo SSU's (Khorram, 1975). The following models are being examined for application: Priestly and Taylor Model (1972), McNaughton and Black Model (1970), Modified Slatyer and McIlroy Model (1961), and Linacre Model (1967). Based on climatic conditions and models performances one or two of these equations are selected to represent the models in this level (Khorram, 1976).

Recommended Level III ET Models:

The third information resolution level in this remote sensing-aided evapotranspiration estimation system will allow application of the practical as well as the most sophisticated models. The approach will be to select and develop those evapotranspiration estimation equations which are most rational and physical in terms of the actual processes involved. A combination of empirical, energy-balance, and aerodynamic methods will be examined for this level. This model is to be developed in the future.

3.104 Methodology for Solar Radiation Estimation

Total incoming solar radiation ($I + H$) is defined as the direct (I) and diffused (H) shortwave radiation reaching the ground through the

atmosphere. Some of this incident radiation is reflected back to the atmosphere (R), which is called reflected radiation, and the rest is absorbed by objects on the earth's surface. Part of the absorbed radiation is dissipated to the atmosphere as longwave radiation (G). In turn, a portion of this dissipated longwave radiation is absorbed by the clouds and atmosphere particles and part of it is returned to the ground (A). This returned longwave radiation from the atmosphere to the ground (A) is called atmospheric radiation. The difference between upgoing (G) and atmospheric (A) longwave radiation may be defined as the net longwave radiation. Net radiation (Q_n), as it is shown in the following equation, is the sum of net shortwave radiation (I+H-R) and net longwave radiation (-G+A).

$$Q_n = (I+H-R) + (A-G)$$

A multistage sampling technique similar to evapotranspiration sample design has been employed to provide the input variable values to the solar radiation estimation model. These input variables are temperature, cloud cover, and albedo.

The net radiation flux Q_n may be calculated from the equation:

$$Q_n = (1-\alpha) Q_s - |Q_{nL}|, \text{ where}$$

- Q_n = net solar radiation
- α = albedo
- Q_s = total incoming solar radiation based on solar constant, declination angle, slope, aspect, latitude, and altitude
- $(1-\alpha) Q_s$ = net shortwave radiation, and
- Q_{nL} = net longwave radiation, based on temperature, cloud cover, atmospheric turbidity, and advective thermal energy.

Climatic variables utilized in this system are composed of temperature, cloud cover, daylength, total incoming radiation, and albedo. The values of daylength can be obtained from standard meteorological tables. Albedo can be estimated from Landsat and/or NOAA satellite data. The values of temperature can be estimated from NOAA satellite, thermal data, or from spatial interpolation of ground station point temperature data, or precisely from thermal aerial imagery. Cloud cover data may be estimated from NOAA satellites or GOES data. The values for total incoming radiation are estimated either by the model developed in this system or, less precisely, by values obtained from standard meteorological data.

3.105 Summary of Results

The results of snow areal extent, snow water content, evapotranspiration, and solar radiation are discussed respectively.

The estimates for the areal extent of snow and their confidence intervals for April 4, May 10, and May 28 are shown in Table II. The appropriate statistical parameters such as standard deviations and population ratio estimator values are also presented in Table II. Additional Chi-square tests indicated that on all the dates the experimental set-up was adequate at 2.5 percent significance level.

The results of Landsat-aided snow water content estimates, based on Spanish Creek Watershed data are shown in Table III. This data is used to represent Feather River Basin values due to the similarity in snow water content class distribution between the two basins for the snow season dates investigated. The correlation coefficients between the average ground-based and Landsat-based values of snow water content indices are 0.85 and 0.77, respectively. Since more than two dates will be available in most operational snow water content estimation situations, a conservative value of 0.80 was selected as the correlation coefficient to be used in the sample size analysis.

A side-by-side comparison of an operational and this Landsat-aided snow water content estimation system was facilitated by a blending of statistical and economic theory. This comparison, using 1974 data, was based on analysis of over 2,200 image sample units at 15¢ each and 26 ground sample units at \$150 each. The analysis indicated a decided advantage for the Landsat-aided method (Sharp and Thomas, 1975).

Level I evapotranspiration models have been applied to Spanish Creek Watershed (SCW) for August 1972. The results are different in terms of accuracy depending on the model used. The model based on the Jensen and Haise equation has yielded satisfactory results. The available ground meteorological stations within the Spanish Creek Watershed are shown in Table IV. All the input parameters for ET models are based on these ground meteorological stations. Currently, we are developing methodologies to obtain the main input parameters (i.e., temperature, cloud cover, etc.) from Landsat and NOAA satellites.

The areal distribution of the mean monthly temperature in °F and relative humidity in percent over the Spanish Creek Watershed were used as inputs to ET models. Watershed-wide distribution of average monthly consumptive use (potential ET) estimates based on the Blaney-Criddle equation is shown in Figure 1. This method has been developed primarily for agricultural crops and the results appear to be higher than expected. Based on the Hargreaves equation, the average free water surface evaporation map of August 1972 was calculated and the results seem to be higher than the expected values. Daily potential evapotranspiration estimates of August 14, 1972, based on the Jensen and Haise model, are shown in Figure 2. The results of the Jensen and Haise model seem to be closer to the values initially expected than the Blaney-Criddle and Hargreaves methods. Based on the performance of the Level I evapotranspiration models it can be concluded that the Hargreaves model may not be directly applicable to the forested watersheds without major modifications.

The results of ET Level I models utilizing solar radiation and temperature data on the main variables (i.e., the models of Jensen and Haise) are more applicable to the watershed diversified evaporative surfaces present in the Spanish Creek Watershed. Nevertheless, slight modifications based on the ground measurements of evapotranspiration values may be required depending on the accuracy desired.

Based on the manual interpretation of Landsat data the vegetation map of the Spanish Creek Watershed (SCW) is completed. An albedo index has been assigned to each vegetation/terrain type; using these indices, the albedo map of the SCW is prepared and electronically displayed.

The watershed-wide elevation zones based on digitization of U.S. Geological Survey topographic maps and computer interpolation between the sample points are calculated. Slope and aspect maps of SCW are prepared based on the methodology developed by RSRP utilizing elevation data.

The net shortwave, net longwave, and net solar radiation maps of the watershed for a selected day have been produced. The values of net solar radiation, as an example, are shown in Figure 3.

Table I. Required Image and Ground Sample Units for all the Snow Water Content Strata.

Landsat Snow Water Content Stratum	1	2	3	4	5	6
Index Range (mm)	<0.10	.614	<1.00	<3.00	5.00	283
No. of Landsat ISU's Examined in Watershed	503	614	205	393	220	283
No. of ISU's Visited on Ground	0	3	1	7	4	11

Table II. Summary of Results, Areal Extent of Snow Estimation (in hectares)
Along with the Confidence Intervals.

Date of Landsat imagery	April 4, 1973	May 10, 1973	May 28, 1973
Landsat-1 estimate of the areal extent of snow	515,820	205,768	60,516
Estimate of the true areal extent of snow	507,309	195,644	57,847
Standard deviation of the areal extent of snow estimate	21,100.6	14,526	17,126
Population ratio estimator	9835	0.9509	0.9559
Total number of hectares inventoried	887,200	813,014	798,340
Total number of image sample units inventoried	2,218	2,050	2,013
Confidence intervals (95%)	$465,234 \leq Y_R \leq 549,384$	$176,601 \leq Y_R \leq 234,935$	$26,075 \leq Y_R \leq 94,958$

Table III. Landsat-based Snow Water Content Statistics Based on Spanish Creek Watershed Data for April 4, May 10, and May 28, 1973.

Stratum Index (h)	Landsat-1 Snow Water Content Estimate Range	Average Snow Water Content Index per Image Sample Unit $X_h = \frac{\sum_{i=1}^{I_h} X_{hi}}{I_h}$	Standard Deviation for X_{hi}	Coefficient of Variation	Total Snow Water Content Index $X_h = \sum_{i=1}^{I_h} X_{hi}$	Stratum Weight Based on Snow Water Content $W_h = \frac{X_h}{\sum_{i=1}^6 X_h}$	Number of Image Sample Units for the Spanish Creek Watershed	Number of Image Sample Units for the Feather River Watershed
1	0.00-0.10	0.0000	0.0000	0.00	0.00	0.0000	32	503
2	0.10-0.35	0.1833	0.1194	65.14	7.15	0.0304	39	614
3	0.35-1.00	0.7808	0.1883	24.12	10.15	0.0432	13	205
4	1.00-3.00	2.0480	0.4404	21.50	51.20	0.2178	25	393
5	3.00-5.00	3.9557	0.4525	11.44	55.38	0.2356	14	220
6	5.00	6.1750	0.9672	15.66	111.15	0.4729	18	283
							N*=141	N=2,218

Table IV. Available Data from Ground Meteorological Stations
in the Spanish Creek Watershed Region.

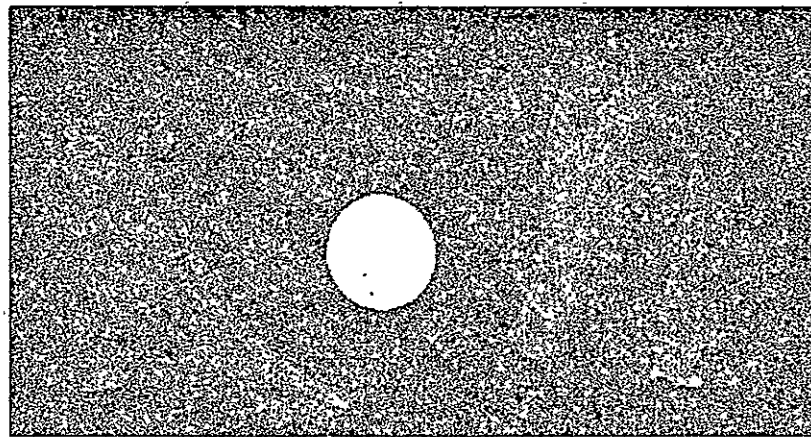
Station	Long.	Lat.	UTM(x10 ³) X	Y	Dates of Data
Quincy	120°57'	39°55'	675.63	4422.57	72*, 75 [†] & 75 ^{††}
Greenville	120°56'	40°08'	675.19	4445.11	72* & 75 [†]
Boulder Creek	120°37'	40°12'	703.25	4442.34	72* & 75 [†]
Mohawk	120°38'	39°47'	702.62	4406.53	72* & 75 [†]
Camel Peak	121°06'	39°43'	662.84	4398.22	72* & 75 [†]
Smith Peak	120°32'	39°52'	711.32	4415.75	72* & 75 [†]

* = Wet bulb temperature, dry bulb temperature, daily temperature, relative humidity, precipitation, and wind speed and direction.

† = Daily average temperature, relative humidity, precipitation, and wind speed and direction.

†† = Wet bulb temperature, dry bulb temperature, daily average temperature, evaporation, precipitation, cloud cover, and day length.

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8: ET 1 MODEL, BC, SCW, AUG. 72

Figure 1. Areal distribution of average monthly evaporation in inches of water for August 1972, Spanish Creek Watershed, based on the Blaney-Criddle equation. Light purple = 16.13, Dark purple = 16.30, Darker purple = 16.47, Orange = 16.50, Yellow = 16.65, Gray = 16.87, Green = 17.00, Blue-Green = 17.45, Dark Blue = 17.67, Saturated blue = 17.85, White = 18.08.

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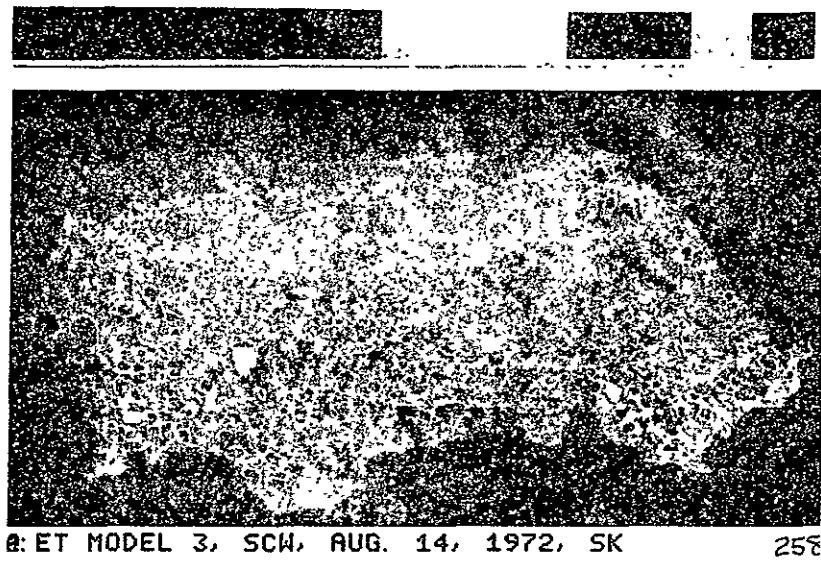
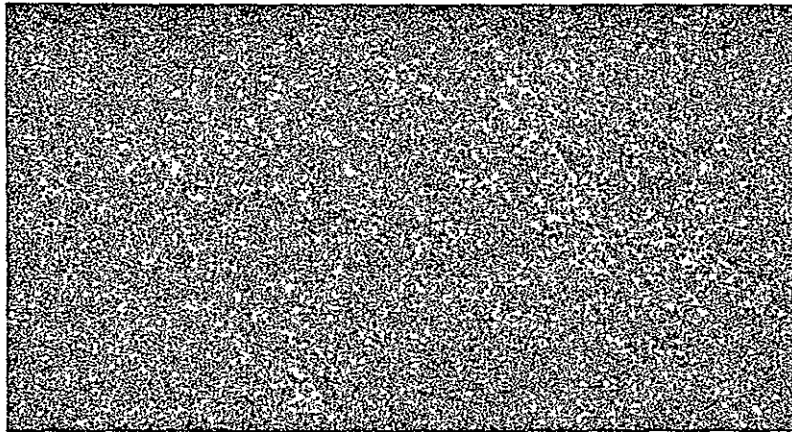


Figure 2. Areal distribution of daily potential evapotranspiration estimates in inches for August 14, 1972, over the Spanish Creek Watershed, based on the Jensen and Haise equation. Red = 0.1-0.28, Orange = 0.28, Yellow = 0.29, Brown = 0.30, Green = 0.31, Green-blue = 0.31, Blue-Green = 0.32, Blue = 0.33-0.38.



NET SOLAR RAD., SCW, AUG 14, 72, SK

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Figure 3. Electronically displayed map of solar radiation in ly/day for August 14, 1972 over the Spanish Creek Watershed.

Blue = 20-439
Green-blue = 440-459
Blue-green = 460-469
Bluish-green = 470-479
Green = 480-489

Brown = 490-499
Yellow = 500-509
Orange = 510-519
Red = 520-620

3.200 CONTINUED RESEARCH SINCE MAY 1976

3.210 Watershed Analysis

3.211 Watershed Boundary Determination

Determination of the watershed boundary on the Landsat digital data is necessary to:

1. Accurately determine the water input and output for the watershed.
2. Minimize computer expenses by keeping the area that is to be analyzed to the smallest possible dimensions.
3. Provide an accurate and meaningful summation of computer generated data for the watershed.
4. Provide useful visual presentation and hard copy of the results.

The location of the watershed boundary is done in conjunction with the geometric transformation of the Landsat digital data. The watershed boundary is carefully determined and annotated on the same U.S.G.S. 1:120,000 topographic series maps as are used in locating the control points. The watershed boundary is digitized at the same time as the control points. This gives a geometric description of the watershed boundary relative to the control points (see Figure 4).

The digitized boundary can now be incorporated to the Landsat digital data using the transformation equation previously generated.

3.212 Geometric Correction

The Landsat digital data, as we received it from the EROS Data Center, contained a certain amount of spatial distortion as compared with map projections commonly in use. In order to rectify this data, it was necessary to lay out a network of geometric controls over the specific Landsat scenes. A transformation equation was then generated to convert the Landsat data to its planimetric position. This geometric rectification of Landsat digital data is a necessary step to facilitate further analysis and to enhance the appearance of visual results.

Much of the topographic data used in this evapotranspiration research is derived from United States Geological Survey Topographic Series maps, based on the transverse mercator projection system. This data includes elevation, slope, aspect, and watershed boundaries. Other necessary data, such as location of the ground meteorological stations within and around the watershed, must be determined. Watershed-wide distribution of data collected at these stations must be comparable (location-wise) to the Landsat digital data and its manipulations. The final products of the

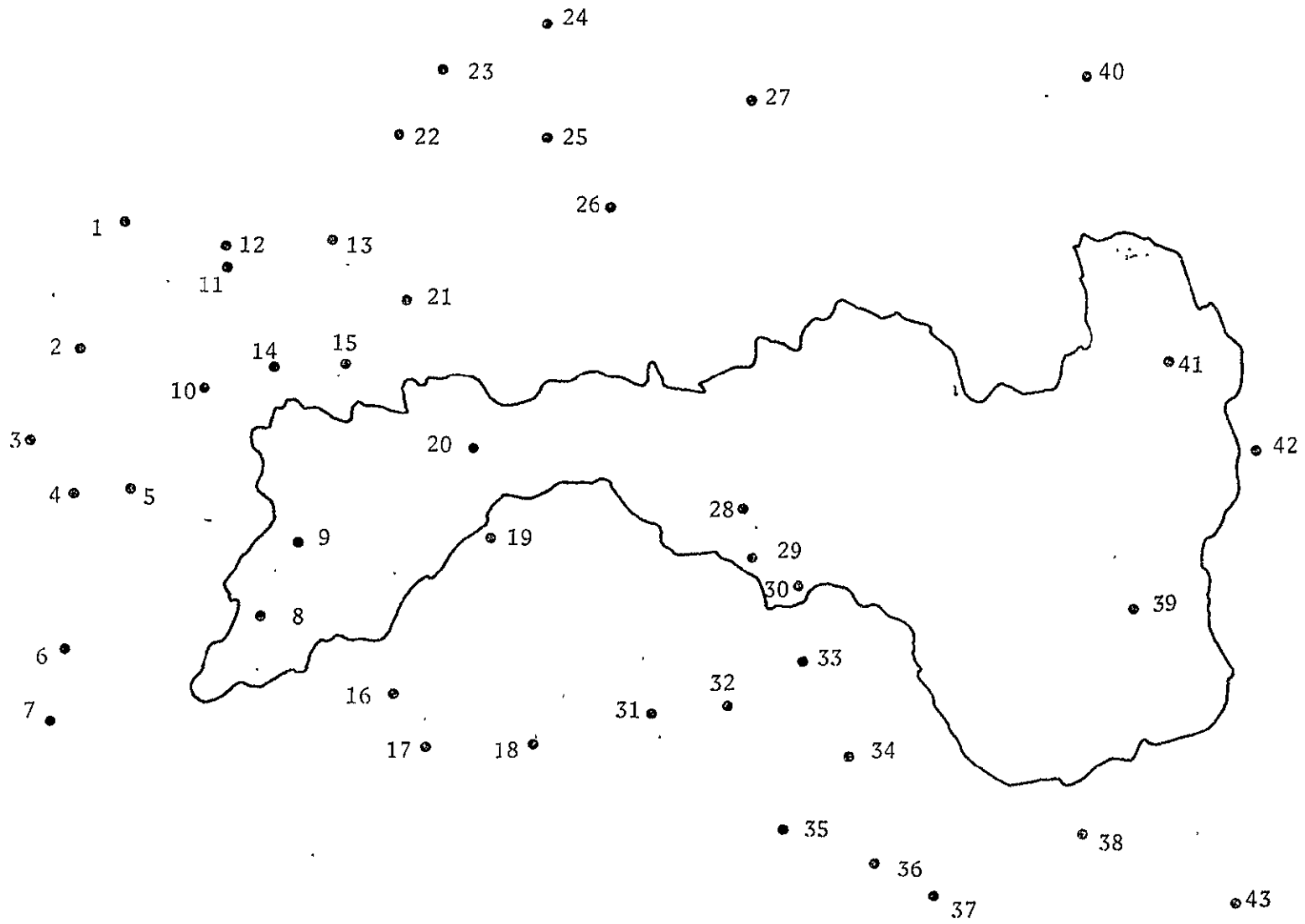


Figure 4. Boundary limits and location of control points within the watershed covering the Middle Fork of the Feather River.

research effort must all be of common appearance, as far as the boundary of the research area is concerned. This makes it necessary to correct the Landsat data to the map projections used by the other data sources, in this case the transverse mercator projection system.

A total of 43 control points were located in and around the Middle Fork of the Feather River Watershed. These points were related directly to river courses or water bodies. Control points located along river courses were located at major river/stream intersections and on bends in the rivers. Dams on lakes and reservoirs provided for the most accurate control point location available due to the almost vertical displacement of apparent lake (or reservoir) shorelines. Control points were located both on the Landsat digital data and on U.S. Geological Survey 1:250,000 topographic series maps. These control points were first located on the topographic maps. Then they were identified on the Landsat digital data, and displayed in a simulated infrared color enhancement form on a color television monitor. A variable x, y cursor on the color television monitor allowed each control point to be identified in terms of its nearest Landsat picture element (pixel). Locations of the control points based on the U.S.G.S. topographic maps were digitized to provide their coordinate information. This coordinate system was then statistically related to the x, y coordinate values for the control points as located on the Landsat digital data. A linear regression model was then generated to give the transformation equation necessary to geometrically relocate the Landsat digital data to the transverse mercator map projection data.

3.213 Vegetation/Terrain Analysis

Knowledge of the spatial distribution of vegetation/terrain features in the Middle Fork of the Feather River Watershed is necessary for generation of albedo indices. Albedo is used directly as an input to the shortwave radiation model, which ultimately is used in the watershed-wide calculation of evapotranspiration.

The albedo or reflection is the ratio of the reflected to the incident radiation, usually expressed as a percentage. The values of albedo for the total range of solar radiation and in some cases for the visible electromagnetic range only are shown in Table V. The figures given in this table illustrate what can be observed directly from an airplane. The sea appears darkest, relative to white strips of surf and sand dunes. Woods show up darker than fields, and snow covered areas are light. One can see here how the absorption capacity for incident solar radiation varies and how this affects the whole heat economy and therefore evaporation and evapotranspiration. Albedo is influenced not only by the nature of a surface, but also by its moisture content at any time, i.e., wet surfaces appear darker than dry surfaces.

The procedure used to develop the vegetation/terrain distribution for the Middle Fork of the Feather River is based upon the computer-aided classification of Landsat-1 digital data. Basically this classification involves

the selection of training statistics based on the unsupervised initial classification test sites located throughout the watershed and surrounding areas. Those training statistics, relating to specific vegetation/terrain classes, are then used to derive the final, watershed-wide classification.

Sixteen classes of vegetation/terrain features were selected for consideration in the classification. The initial, unsupervised classifications of the test sites were then organized into the appropriate vegetation/terrain classes. The vegetation/terrain classes used for this are as follows:

- Red fir forest
- Mixed conifer forest
- Eastside timberland-chaparral complex
- Mixed hardwood forest
- Riparian hardwoods
- Foothill pine-oak woodland
- Brush-chaparral complex
- Sagebrush
- Grassland-meadow
- Marshland
- Agriculture/rangeland
- Water
- Urban
- Exposed soil
- Exposed bedrock
- Serpentine-vegetation complex

In order to determine how closely these vegetation/terrain types could be identified on the Landsat digital data, ten test sites were selected in and around the Middle Fork of the Feather River Watershed. These sites were selected from 1:120,000 scale high-altitude aerial photography of the watershed area, as acquired by the NASA Earth Resources Program. Each of the sites is approximately 10,000 acres in size (100 x 100 Landsat picture elements). The sites are distributed throughout the watershed as shown in Figure 5. All the test sites were identified on the Landsat digital data, and on 1:30,000 to 1:120,000 scale Infrared Ektachrome aerial photography. A computer compatible tape of the ten sites was made from the Landsat digital data. The ten 100 x 100 pixel sites on the computer compatible test were clustered using unsupervised classification techniques according to an algorithm in a computer program known as ISOCLAS.

ISOCLAS applies a modified version of the clustering algorithm known as ISODATA to multispectral scanner data. The acronym ISODATA stands for Iterative Self-Organizing Data Analysis Technique (A). As its name implies, the algorithm is arrived at through an iterative procedure which groups similar "objects" into sets called clusters. The algorithm was originally developed by Hall and Ball (1965 and 1967) of the Stanford Research Institute. A clustering technique based on ISODATA and suitable for use in processing multispectral scanner data was developed by Kan and Holley (1972). To distinguish between the original and revised programs, the multispectral scanner version became known as ISOCLAS.

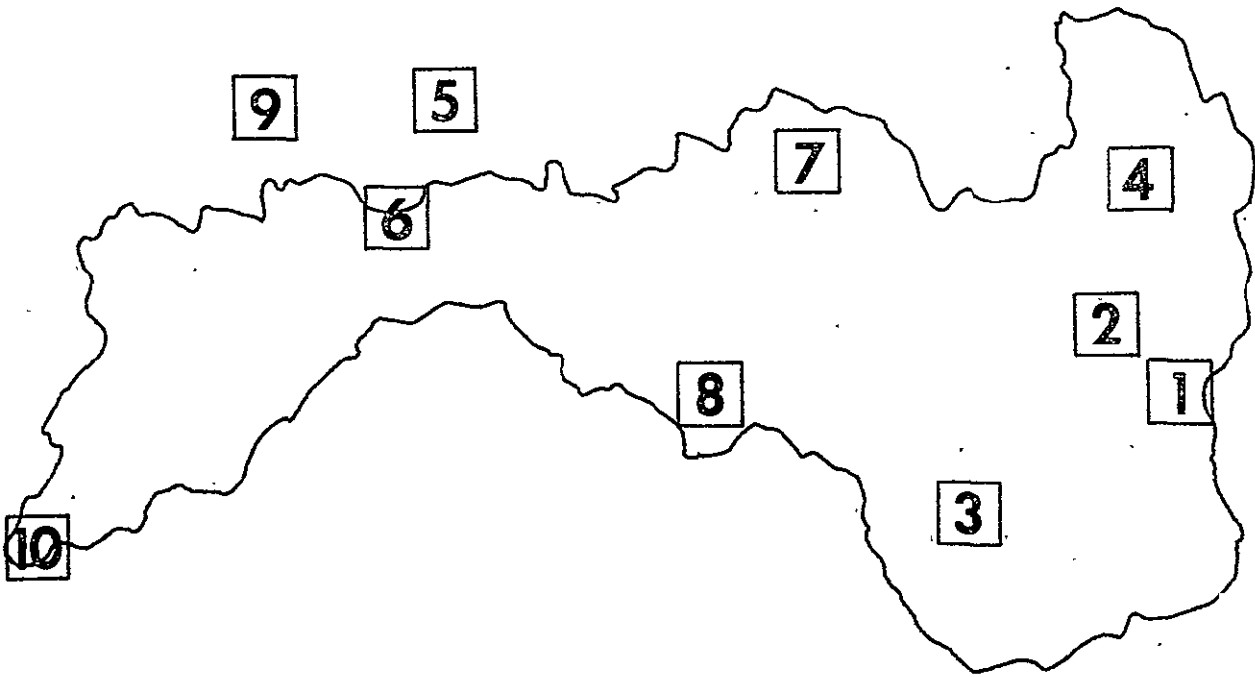


Figure 5. Distribution of Landsat test sites throughout the Middle Fork of the Feather River Watershed and surrounding area.

- Area 1 Sierra Valley Mountains
- Area 2 Sierra Valley Area 1
- Area 3 Sierra Valley Area 2
- Area 4 Franchman Reservoir Area
- Area 5 Quincy/American Valley
- Area 6 Serpentine Area
- Area 7 Davis Lake Area
- Area 8 Gold Lake Area
- Area 9 Silver Lake Area
- Area 10 Middle Fork /Lake Oroville

This procedure will, ideally, separate all of the data into distinct groups or clusters, the center of each cluster being represented by its mean. The process is initiated by assigning each data point to the nearest estimated cluster center (absolute distance is calculated to each cluster mean). After all of the data has been assigned, new means are calculated and tests are made to see if clusters should be split or combined. A cluster is split if the standard deviation of the cluster exceeds a specific threshold value. Two clusters are combined if the distance between cluster centers is smaller than the specified threshold. A cluster is deleted if it has fewer than some specified number of points. The data is reassigned, after each split or combining iteration, to the new clusters and the process continues until the desired number of iterations has been obtained.

Since ISOCLAS is used in this case as a training device for the watershed-wide image classification of vegetation and terrain features, two approaches were evaluated on the initial ISOCLAS runs. In the first approach, all ten test sites were considered to be a portion of the same population of picture element reflectance values. The program was instructed to go through twelve iterations to reach no more than forty separate clusters. In this algorithm, the same minimum distance was sought between the cluster means. Also the same maximum (threshold) standard deviation was sought among the picture element reflectance values that make up each cluster. Consequently, clusters found in one test could be absolutely related to clusters found in other test sites without any intermediate statistical manipulation. The advantage of using this technique relies on the established statistical relationship between clusters in each test site. Instructions to the image classification program, which will ultimately analyze the watershed for vegetation/terrain classes, are relatively simple and straightforward. Similar (but not exactly the same) vegetation/terrain groups, easily identified on the aerial photography, were grouped into single clusters, due to the limitations of the number of classes available in the program. Although only fifty clusters are possible using this technique, it was estimated that approximately one hundred clusters would be needed to adequately characterize the entire range of vegetation/terrain classes found in the watershed when all test sites were analyzed in this fashion. A still more detailed classification might have been desirable, but was considered to be out of the scope of this project.

In order to minimize the restrictions which the ISOCLAS routine placed on the absolute number of clusters available, each test site was analyzed independently. The ISOCLAS program was again instructed to consider twelve iterations of no more than forty classes. However, using this approach it was possible to have up to forty clusters for each test site. It was found that, while not perfect, this technique represented the desired vegetation/terrain classes much more accurately than in the previous technique. Confusion in vegetation/terrain classes still existed, however, but generally in features with similar reflectance values. The fact that some vegetation/terrain classes were confused in the ISOCLAS clusters even though they were distinct on the aerial photography, probably can be attributed to the differences in texture of different features. This texture consideration is a function to which the ISOCLAS analysis is not sensitive.

One of the test site blocks taken on September 9, 1975, in color infrared small-scale aerial photography (original scale, 1:120,000) is shown in Figure 6. This site, located on the eastern edge of the Middle Fork of the Feather River Watershed in the Sierra Valley region, is composed of the following six vegetation/terrain classes:

1. Bare soil
2. High density eastside conifer
3. Low density eastside conifer
4. Brush/chaparral
5. Sagebrush
6. Sagebrush/bare soil

The ISOCLAS routine was instructed to differentiate amongst up to forty clusters for this test site. However, the natural appearance of the picture element values for this site limited the area to nineteen "natural" clusters. Two of these clusters were from within an area that was affected by a bad data line introduced by the ISOCLAS program, thereby leaving only seventeen clusters. These seventeen clusters appear to represent the vegetation/terrain classes found on the aerial photography fairly well, with no major confusion classes. Displaying the ISOCLAS results in such a way so that the clusters are easily interpreted presents a minor problem. Organizing the clusters so that they will represent actual, visible ground vegetation/terrain classes is difficult when this type of display is used. In order to display the ISOCLAS clusters in a more meaningful manner, ratios of the band 7-to-band 5 reflection mean values of each cluster were determined. These values were then ranked and a color was assigned to each value (Clark, 1946). The ratioing method is based on the fact that vegetation in various forms and in different conditions (especially in the healthy condition) reflects relatively large amounts of near-infrared (band 7) energy compared to visible red wavelength (band 5) energy. Thus, the higher band 7/band 5 ratios are likely to indicate vegetation. Of course, different plant species have different band 7/band 5 ratios; therefore, it was found possible to assign spectrally ordered colors to the numerically ranked band 7/band 5 ratios. Other terrain features, such as bare soil, bare ground, and water tend to have their own unique ratios, thus making it relatively easy to identify them. Table V is a listing of the nineteen clusters found in this test site with their associated band 7/band 5 ranked mean ratio values and the corresponding assigned colors. The band 7/band 5 ratio-ranked display presents a more meaningful representation of the ISOCLAS clusters than the display utilizing the random assignment of colors to the clusters (see Figure 7).

The final assignment of specific ISOCLAS clusters to vegetation/terrain classes is the result of associating the band 7/band 5 ratio television display results with the high-altitude aerial photography and the computer printout of the ISOCLAS clusters. Specifically, areas represented on the 7/5 ratio display which can be accurately identified on the aerial photography as a specific vegetation/terrain class are located on the computer printout.

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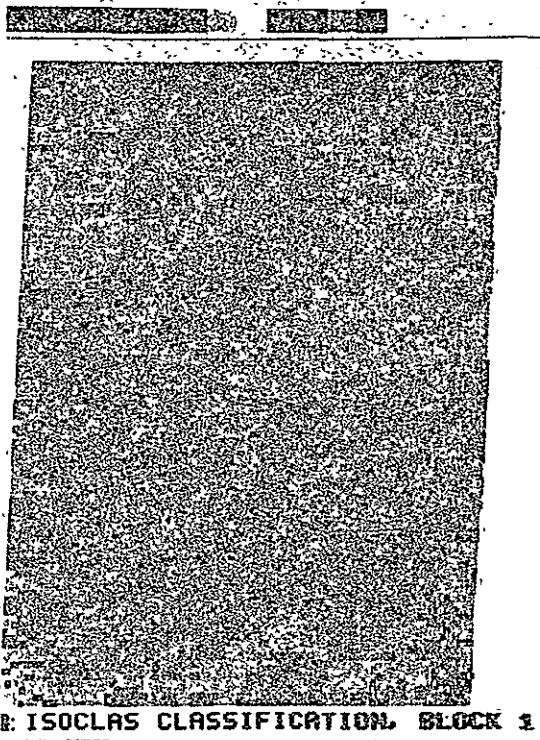
Figure 6. Small scale aerial photograph of ISOCLAS block 1 taken by U2 aircraft on September 9, 1975.

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Figure 7. Band 7 to band 5 ratio display of ISOCLAS block 1 based on Landsat data.

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B: ISOCAS CLASSIFICATION, BLOCK 1

Figure 8. Classified ISOCAS display of block 1 based on Landsat data.

Identification Key:

<u>Color</u>	<u>Vegetation/Terrain Type</u>
Brown	Bare Soil
Red	High Density Eastside Conifer
Green	Low Density Eastside Conifer
Yellow	Brush
Dark Blue	Sagebrush
Light Blue	Sagebrush/Bare Soil

Table V. Band 7/Band 5 Ratios and Color Assignments for ISOCLAS Block 1

<u>Band 7/Band 5 Ratio*</u>	<u>Numerical Order</u>	<u>Cluster</u>	<u>Color Assignment Group</u>
2.4534	1	5	Lavenders & Reds
2.1284	2	7	
2.0276	3	9	
1.6127	4	12	
1.5688	5	10	Browns & Oranges
1.3381	6	3	
1.2037	7	1	
1.1812	8	16	
1.1751	9	17	Yellows
1.1751	10	6	
1.1484	11	2	
1.1236	12	8	Greens
1.1032	13	4	
1.0960	14	13	
1.0844	15	14	Blues
1.0592	16	15	
1.0396	17	11	
-----	18	--	Black
-----	19	--	

*The actual equation for the Band 7/Band 5 ratio is:

$2 \times (\text{Band 7 mean scene brightness value of cluster } n) \div (\text{Band 5 mean of scene brightness value of cluster } n)$ where n goes from 1 to 17 inclusive.

Table VI. List of Band 7/5 Ratios and Clusters Identified on ISOCLAS Block 1 for each Vegetation/Terrain Class.

<u>Vegetation/Terrain Class</u>	<u>Cluster</u>	<u>Band 7/Band 5 Ratio</u>
High density eastside conifer	5	2.4534
	7	2.1284
Low density eastside conifer	9	2.0276
Brush/Chaparral	10	1.5688
Sagebrush/Bare Soil	12	1.6127
	2	1.1484
	4	1.1032
	8	1.1236
	16	1.1812
Sagebrush	1	1.2037
	3	1.3381
	6	1.1751
Bare Soil	11	1.0396
	13	1.0960
	14	1.0844
	15	1.0592

The computer printout is organized on an x and y format with a separate character representing each cluster. All clusters found within the area identified from the coordinates are then placed within the vegetation/terrain class previously identified. This procedure is done until all clusters have been assigned to a specific vegetation/terrain class. Table VI lists the 7/5 ratios and clusters for each vegetation/terrain type identified in the ISOCLAS block "1" test site.

By use of the analysis method shown in Table V, it is possible to facilitate the identification of vegetation/terrain classes in which some classification confusion exists.

The ISOCLAS statistical summaries for each cluster form the basis for the training of a classification routine which will ultimately place every picture element into its predetermined vegetation/terrain class. While the 7/5 ratio method provides useful information for cluster distribution, it cannot be expected to decide, statistically, to group clusters into vegetation/terrain classes. The development of a method for measuring class (or cluster) separability is extremely important due to the individual clustering performed by ISOCLAS on each of the ten test sites. A methodology for the determination of class separability based on the Scheffé method of multiple comparison has been applied to this analysis (Thomas and Vasick, 1975). Statistical analysis using the Scheffé method allows significance probabilities to be calculated for all cluster pairs. These probabilities are displayed in matrix form. Class pairs with significance probabilities below specific threshold values are considered to be separable for classification purposes. Thus individual clusters can be statistically compared to other clusters within a vegetation/terrain group and all other clusters in the vegetation/terrain classes. Table VII represents an example of the Scheffé multiple comparison test run on all clusters determined to fall into the brush and related vegetation/terrain class. Cluster pairs determined to be separable are designated by the symbol "0". Cluster pairs determined to not be separable are designated by the symbol "+". The significance level for the particular application of the Scheffé multiple comparison test was set at $\alpha = .10$. Clusters from various vegetation/terrain groups (i.e., those falling in some broad band of classification; for example, the coniferous forest vegetation/terrain group may include red fir, mixed conifer, eastside pine, pure fir, etc.) are systematically compared to one another until unique sets of clusters are found which represent all desired vegetation/terrain classes and are all separable using the Scheffé test. The statistical description of each cluster selected in terms of mean, standard deviation, and covariance are then used to drive a discriminant analysis routine called CALSCAN. CALSCAN is a maximum likelihood classifier based on the Purdue University image classification program, LARSYSAA. The CALSCAN program utilizes the ISOCLAS cluster training statistics to classify each picture element within the available population into a specific vegetation/terrain class (Figures 9 and 10).

The vegetation/terrain classification performed by the maximum likelihood classifier was then converted into areal distribution of albedo (Figure 11) using a technique documented in our portion of the May 1975 Grant Report

Table VII. Sheffé multiple comparison test for brush and brush related vegetation types. "0" indicates no confusion while "+" indicates confusion between class pairs at a significance level of .10

	Class 1	Class 2	Class 3	Class 4	Class 5	Class 6	Class 7	Class 8	Class 9	Class 10	Class 11	Class 12	Class 13	Class 14	Class 15
Class 1	/	+	0	0	0	0	0	+	0	+	0	0	0	+	+
Class 2	+	/	+	+	+	+	+	+	+	+	+	0	0	+	+
Class 3	0	+	/	0	+	+	+	0	0	0	+	+	+	+	0
Class 4	0	+	0	/	+	0	0	+	+	0	+	0	0	0	+
Class 5	0	+	+	+	/	+	+	0	+	0	+	+	0	+	+
Class 6	0	+	+	0	+	/	+	0	0	+	0	+	+	+	0
Class 7	0	+	+	0	+	+	/	0	0	0	+	+	0	0	0
Class 8	+	+	0	+	0	0	0	/	+	+	0	0	0	+	+
Class 9	0	+	0	+	+	0	0	+	/	0	+	0	0	+	+
Class 10	+	+	0	0	0	+	0	+	0	/	0	0	+	+	+
Class 11	0	+	+	+	+	0	+	0	+	0	/	0	0	+	+
Class 12	0	0	+	0	+	+	+	0	0	0	0	/	0	0	0
Class 13	0	0	+	0	0	+	0	0	0	+	0	0	/	+	0
Class 14	+	+	+	0	+	+	0	+	+	+	+	0	+	/	+
Class 15	+	+	0	+	+	0	0	+	+	+	+	0	0	+	/

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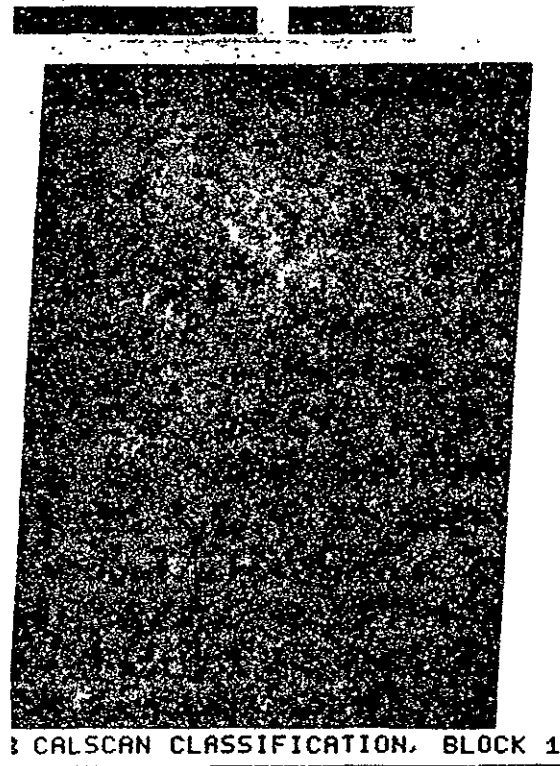


Figure 9. CALSCAN discriminant analysis classification of block 1. The statistical training for this classification was derived from the ISOCLAS classification and applied to the Landsat raw digital data.

Identification Key:

<u>Color</u>	<u>Vegetation/Terrain Type</u>
Lavender	Sagebrush
Purple	Sagebrush/Bare Soil
Off White	Bare Soil
Yellow	Mesic Grassland
Red	Mixed Conifer
Dark Green	Brush
Light Green	Xeric Brush

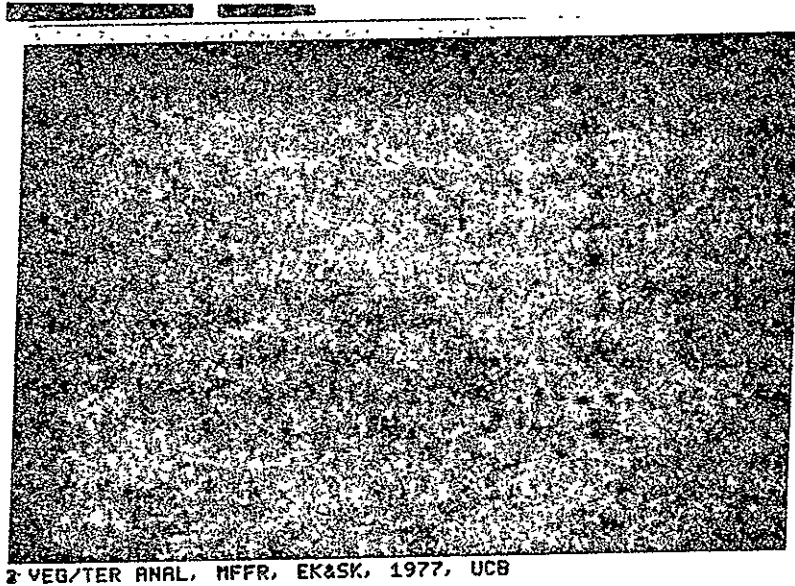


Figure 10. CALSCAN discriminant analysis vegetation/terrain classification of the Middle Fork of the Feather River Watershed.

Identification Key:

<u>Color</u>	<u>Vegetation/Terrain Type</u>
Lavender	Sagebrush
Purple	Sagebrush/Bare Soil
Off White	Bare Soil
White	Rock
Orange	Agricultural
Yellow	Marsh/Mesic Grassland
Red	Mixed Conifer
Orange/Red	Red Fir
Light Blue	Riparian Hardwoods
Blue/Green	Mesic Brush
Dark Green	Brush
Light Green	Oakwood/Xeric Brush
Dark Blue	Water

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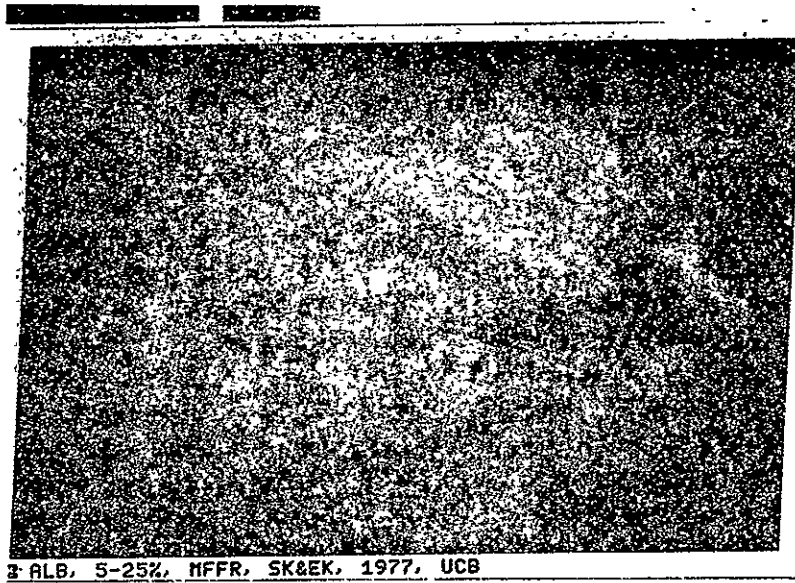


Figure 11. Areal distribution of Albedo for the Middle Fork of the Feather River Watershed based on the vegetation/terrain classification.

Identification Key:

<u>Color</u>	<u>Albedo (%)</u>
White	5
Dark Blue	9
Purple/Blue	10
Yellow	11
Light Green	12
Green	13
Dark Green	14
Light Blue	15
Orange	18
Red	22
Brown	25

(Khorram, 1975). The albedo calculation is then used in the shortwave radiation model, necessary for the calculating of evapotranspiration in the Middle Fork of the Feather River Watershed.

3.214 Topographic Analysis

Topographic characteristics of the watershed are one of the major factors effecting the amount of solar radiation and consequently vegetation density and composition, evaporation, and evapotranspiration.

Of the tremendous quantity of radiant energy emitted by the sun, only a very small portion is intercepted by the earth and its atmosphere. This small portion is the ultimate source of the earth's energy. This amount of incident radiation is known as the solar constant which is defined as the intensity of solar radiation received on a unit area of a plane normal to the incident radiation at the outer limit of the earth's atmosphere with the earth at its mean distance from the sun.

The portion of the solar radiation which actually reaches the earth's surface depends upon the transparency of the atmosphere. Some of the incident solar radiation is reflected, some scattered, and some absorbed by the atmosphere. In the absence of clouds these amounts are relatively small and quite constant. The atmospheric transmission coefficient varies from about 80 percent at the time of the winter solstice to about 85 percent at the time of the summer solstice.

By far the largest variations (in the portion of solar radiation transmitted by the atmosphere) are caused by clouds. Similar to the cloud effects, the environmental conditions such as a forest canopy exert a powerful controlling influence on net allwave radiation exchange in hydrologic processes. However, the forest canopy has a different effect than that of clouds, particularly with respect to shortwave radiation. While both the clouds and trees restrict the transmission of insolation, clouds are highly reflective, while the forest canopy absorbs much of the insolation. Consequently, the forest canopy tends to be warmed and in turn gives up a portion of the energy for evapotranspiration.

It is this portion of the solar radiation which is used for evapotranspiration that is of interest for the water yield prediction models. The values for solar radiation in turn are site-specific and consider the effects of elevation, slope, aspect, albedo, latitude, and cloud cover (Khorram, et al, 1976).

The elevation, slope, and aspect maps are constructed from the elevation countour data on U.S. Geological Survey topographic maps, 15' series. The procedure involves the orientation of each Landsat picture element in the watershed. Each picture element (pixel) is defined in terms of x, y and z coordinate dimensions. The x and y coordinates locate the center of the pixel while the z coordinate defines the elevation (average).. Each pixel can be "titled" and/or rotated. The tilt and rotation functions are considered to be the slope and aspect of the pixel, respectively.

The first step in the watershed elevation, slope, and aspect calculation involves the selection of control points on the U.S. Geological Survey topographic maps. Control points are located on the ridgetops (including the watershed boundary) and in the valley bottoms (generally along stream courses). Control points are selected at ridge intersections and midway (approximately) down ridges running into valleys. Subsequently, control points are also located at stream intersections and midway up streams from their headwaters (Figure 12).

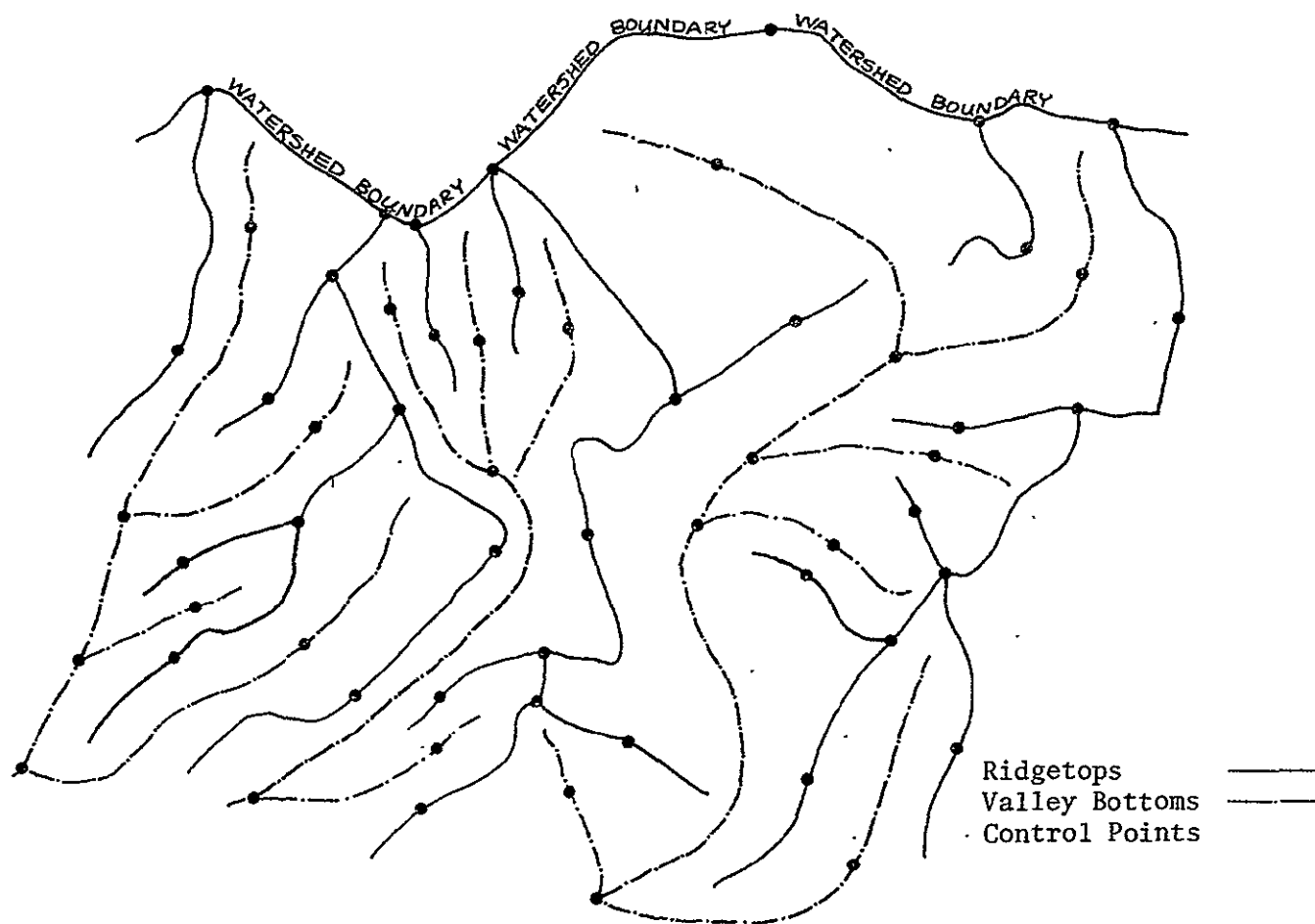


Figure 12. Location of Control Points on Ridge Tops and Valley Bottoms. Note the location of occasional control points along long stretches of ridge tops and valley bottoms.

The control points are described in terms of Universal Transverse Mercator grid units (x and y coordinates) and elevation (z coordinate).

The control points are then used to drive the elevation-determining algorithm,

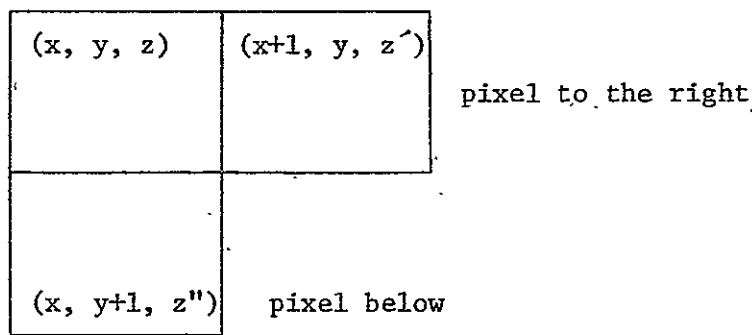
$$E(x,y) = \frac{\sum_{i=1}^n \frac{E_i}{(\Delta_i)^2}}{\sum_{i=1}^n \frac{1}{(\Delta_i)^2}}$$

where: Δ_i = the distance from (x,y) to control point i,
 E_i = the elevation of control point i,
 n = the number of control points within range of (x,y)
 $E(x,y)$ = the elevation of point (x,y).

which uses the x,y,z coordinates of the control points to assign a z coordinate (elevation) to each Landsat pixel. The actual z coordinate represents a zone of elevation per pixel rather than an absolute value.

Determination of a "normal" vector is necessary for pixel slope and aspect calculation. This "normal" vector is a directional variable that originates in the center of each pixel and locates a direction that is 90 degrees to the surface of the pixel. This vector is expressed in triple coordinates (n_x, n_y, n_z), where the center of the pixel is considered to be the origin (0, 0, 0), and the triple coordinates are the coordinates in three dimensions (x, y, z).

For determining slope and aspect, the "normal" vector for a pixel is computed by using the pixel's position relative to the pixels to the right and below. The "normal" vector, \vec{n} , is then the cross product of the two vectors in x (the pixel to the right) and y (the pixel below) directions.



Using the vector's cross-product formula, the normal vector is

$$\vec{n} = (x + 1, y, z - z') \times (x, y + 1, z'' - z)$$

$$= \left\{ \begin{aligned} & [(x + 1)(y+1) - xy] - [(x+1)(z''-z) - x(z - z')], \\ & [(x + 1)(z'' - z) - x(z - z')] \\ & [(x + 1)(y+1) - xy] \end{aligned} \right\}$$

Once the "normal" vector, \vec{n} , is computed, the slope is calculable since it is the angle between the normal vector and the vertical vector (0, 0, 1), θ , subtracted from $\frac{\pi}{2}$ in radians. Therefore

$$\theta = \arccos \left(\frac{n_z}{\|\vec{n}\|} \right) \quad \text{and}$$

$$\text{slope} = \frac{\pi}{2} - \theta \quad \text{in radians, where}$$

$$\|\vec{n}\| = \sqrt{n_x^2 + n_y^2 + n_z^2}$$

then slope is converted to percent.

The aspect is determined from the (x,y) projection of the normal vector. The degrees away from true North will determine the aspect,

$$\phi = \arctan \left(\frac{n_y}{n_x} \right), \text{ where}$$

ϕ is the angle from the x-axis in radians.

This is then converted to degrees and added to 90 degrees to give the aspect in degrees from the true North direction.

3.215 Climatic Data Collection

Climatic data required for use in the remote sensing-aided evapotranspiration estimation system is not fully available within the watershed covering the Middle Fork of the Feather River. The number of meteorological stations in this catchment is limited. Also, data pertaining to only a few types of climatic parameters has been taken at each station. A similar problem existed within the Spanish Creek Watershed, and the personnel of the Remote Sensing Research Program, with the cooperation of several U.S. Forest Service employees working on the Plumas National Forest, collected additional climatic data for that area. This data was composed of "Weather Bureau Class A" evaporation pan data and evaporimeter data. Evaporimeters were designed by RSRP personnel with the cooperation of the California Department of Water Resources at Red Bluff. Both the evaporation pan and the evaporimeter data are collected simultaneously. This additional data was collected at each of four localities on the Plumas National Forest, viz., Mohawk, Mount Hough, Quincy, and the U.C. Forest summer camp at Meadow Valley.

Since the date for application of ET models for the new watershed (MFFR) is 1975, to correspond to the analysis date of the RFC hydrologic model by the Algazi group at U.C. Davis, there cannot at this late date be any pan evaporation and evaporimeter data collected for this new watershed. According to the sensitivity analysis of the RFC model by the U.C. Davis group, the runoff variation is most sensitive to evapotranspiration in the springtime. Therefore, the spring of 1975 will be the first candidate time during which to incorporate ET information into our water yield forecast model. This eliminates the use of some of the climatic data collected by the Forest Service ranger stations during the fire season (middle of May to middle of October).

Table VIII. Existing Ground Meteorological Stations Within and Around the Watershed Covering the Middle Fork of the Feather River.

<u>Station Name</u>	<u>Latitude (N)</u>	<u>Longitude (W)</u>	<u>Elevation (Feet)</u>
Brush Creek	39°41'	121°21'	3560
Bucks Creek Pump House Challenge	39°55'	121°20'	1760
Forbestown			2900
Greenville Ranger Station	40°08'	120°56'	3560
Mohawk Ranger Station	39°47'	120°38'	4370
Oroville Ranger Station	39°32'	121°34'	300
Plumas Creek State Park	39°45'	120°42'	5165
Portola	39°48'	120°28'	4850
Quincy	39°55'	120°57'	3408
Sagehen Creek	39°26'	120°14'	6337
Sierra City	39°34'	120°38'	4150
Sierraville Ranger Station	39°45'	120°22'	4975
Vinton	39°49'	120°11'	4950
Woodleaf Oroleve	39°31'	121°11'	3340

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Table IX. Available Ground Meteorological Station Data Within the Middle Fork of the Feather River Watershed for 1975.

<u>Meteorological Stations</u>	<u>Temperature</u>	<u>Precipitation</u>	<u>Relative Humidity</u>
Brush Creek		yes	
Bucks Creek Pump House		yes	
Challenge Ranger Station	yes	yes	yes
Forbestown	yes	yes	
Greenville Ranger Station		yes	yes
Mohawk Ranger Station	yes	yes	
Oroville Ranger Station	yes	yes	yes
Plumas Creek Ranger Station	yes	yes	
Portola	yes	yes	
Quincy	yes	yes	yes
Sagehen Creek		yes	
Sierra City	yes	yes	
Sierraville Ranger Station	yes	yes	
Vinton	yes	yes	
Woodleaf Oroleve		yes	

Within the MEFR there are only 14 meteorological stations which are listed in Table VIII. The data types collected in these stations include temperature (dry bulb, wet bulb, max., min.), humidity, wind, precipitation, and cloud cover.

This data is collected by USDC Environmental Data Service (National Climatic Center), Plumas National Forest, and the California Department of Water Resources. Table IX summarizes all the data sources, including data type, used in ET models.

3.220 Snow Quantification

In previous progress reports prepared by personnel of our Remote Sensing Research Program, techniques were described for using remote sensing as an aid in estimating (1) areal extent of snow, and (2) snow water content. (These techniques have been summarized in the preceding sections of the present report.) These two techniques together comprise the snow quantification research that our group currently is completing. Because both of these techniques have demonstrated their ability to characterize efficiently the resource parameters which they were designed to estimate, procedural manuals are now being compiled for each technique.

Since application of the "areal extent of snow" technique is the first step in the snow water content estimation procedure, the two systems are linked through information and data gathering requirements. To help the potential user of such snow quantification systems, refinement of both techniques and the preparation of procedural manuals constituted the primary research objectives of our group for the May 1976 to May 1977 reporting period. It was determined that the most significant single improvement in areal extent of snow estimation (and hence in snow water content estimation) could be achieved by optimizing the basic estimation elements, i.e., the image sample units (ISU's).

3.230 Evapotranspiration and Solar Radiation

The methodology developed by the Remote Sensing Research Program for evapotranspiration estimation utilizes some watershed physiographic data as well as data with respect to climatic variables. The physiographic data consists of vegetation type, ground cover, and elevation. The climatic data consists of temperature, humidity, wind, precipitation, solar radiation, and a few standard meteorological constants. The specific climatic data required for use in ET models varies with the level of modeling. Level I ET models use solar radiation, temperature, humidity, and precipitation as the main variables. Level II and III ET models utilize the required input variables for Level I as well as a psychrometric constant, the ratio of saturation vapor pressure to temperature, canopy resistance, aerodynamic resistance, and atmospheric conductance. All ET models and their required input data are described in the May 1976 NASA Grant report.

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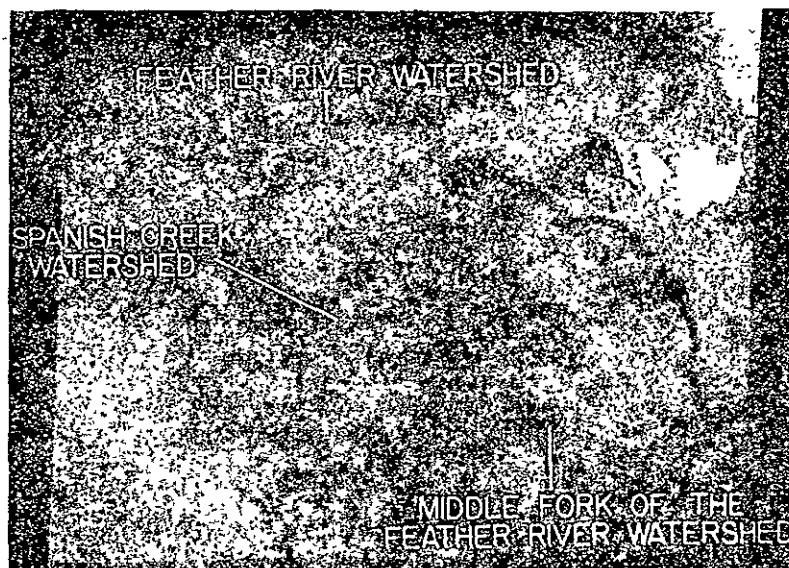


Figure 13. Boundary limits of Spanish Creek Watershed (old one), Feather River Watershed, and the watershed covering Middle Fork of Feather River (new one).

Solar radiation is one of the major input components for all three levels of ET models and is the ultimate source of the earth's energy as well as being the driving force for all of the hydrological processes. Therefore, the ability to better estimate solar radiation could produce significant improvements in our ability for site-specific estimation of both water supply and vegetation water demand (consumptive use). The RSRP group has developed a remote sensing-aided technique and model for estimating solar radiation. The climatic input variables to the model include temperature, cloud cover and albedo. The estimates are site-specific as a function of slope, aspect, latitude, day length, elevation, and vegetation type. Based on such information a net solar radiation map has been produced of the Spanish Creek Watershed. The primary results are in general agreement with values reported in the literature for similar areas in the same latitude but are, of course, more specific in terms of site, time and accuracy.

Some of the evapotranspiration estimation models have been tested in the previously mentioned Spanish Creek Watershed (SCW). The physiographic characteristics of the SCW have been determined and the areal distribution of input parameters for both solar radiation and Level I ET models have been documented.

Performance evaluation of ET models could be obtained by two means: (1) by comparing results obtained when using the models with corresponding measured values of actual and/or potential evapotranspiration made on the ground; and (2) by evaluating the results from runoff forecast models as obtained when remote sensing-aided estimates of ET were used as a direct input. In our research, because of the lack of measured evapotranspiration data on the ground, the second method is being used for evaluating the results and the California River Forecast Center (RFC) hydrologic model (sometimes referred to as the Sacramento Model) is being used for this evaluation. This study is being carried on in coordination with U.C. Davis (Algazi) group. As explained in Chapter 2, that group has been involved for several years with the sensitivity analysis of RFC models not for the Spanish Creek Watershed, but for the Middle Fork of the Feather River Watershed (MFFR). Consequently, it became apparent that, in order to maximize the integration between our research efforts and those of the U.C. Davis group, all of our evapotranspiration models that had been developed for the Spanish Creek Watershed should be reapplied to the Middle Fork of the Feather River. This has led to two problems: (1) determining the physiographic characteristics of the MFFR watershed; and (2) collecting the necessary input climatic data for that watershed. Much of the RSRP evapotranspiration research in the last few months has involved working on reapplication of the methodology developed for the Spanish Creek Watershed for our new watershed.

The new watershed (MFFR) is much larger than the old one, with greater diversity in vegetation type, elevation difference, and slope and aspect. The boundaries of both the Middle Fork and Spanish Creek Watersheds and their locations with reference to the entire Feather River Watershed are shown in Figure 13.

3.300 SUMMARY/CONCLUSIONS

The methodology that has been developed by personnel of our RSRP for a remote sensing-aided system to estimate the various components of a water-yield model will give timely, relatively accurate, and cost-effective estimates over snow-covered areas on a watershed-by-watershed basis. These components are snow areal extent, snow water content, water loss to the atmosphere (evapotranspiration) and solar radiation. The system employs a basic two stage, two phase sample of three information resolution levels to estimate the quantity of the above-mentioned components of the water-yield model. The input data for this system requiring spatial information is provided by Landsat, by environmental (meteorological) satellites, by high- and low-flight aerial photography, and by ground observation.

The general concept of multistage sampling has been used successfully by RSRP in several other remote sensing research experiments involving manual and automatic data analysis. The design of this project facilitates the performance of valid statistical analyses. This is extremely important so that future results from different approaches can be analyzed with respect to one another and to prior research. Confidence intervals have been applied to all estimates discussed herein, thus providing figures relative to the accuracy of results.

Sources of input data for RSRP research on water resources include the entire spectrum of environmental data gathering systems currently operating. Satellite information sources include Landsat and NOAA. The primary photographic data base consists of large to medium scale photography obtained by our group. Ground data is collected with the cooperation of both federal and state agencies such as U.S. Geological Survey, National Climatic Center, U.S. Forest Service, California Division of Forestry, and California Department of Water Resources.

In the case of snow areal extent estimation, we have completed the manual analysis. One of the advantages of our technique versus conventional methods is that ours not only corrects the interpreter's snow areal extent classification to plot/ground values based on testing results, but also minimizes variation in final classification results between interpreters. Thus, a consistent result can be expected even though areal extent of snow estimation is performed on different areas by different interpreters. Also, the double sampling method, which in effect calibrates the more coarsely resolved Landsat-based estimates, provides a good data bank for more accurate estimation of parameters of interest.

Based on the results obtained when using the remote sensing-based techniques described above, it can be concluded that there is a substantial advantage in terms of both cost-effectiveness and precision to be gained through their use, as compared to other, conventional methods. Further

investigations in automatic analysis of the areal extent of snow as well as further refinement of the corresponding manual interpretation technique are needed, in order to allow the user to make an intelligent choice as to the level of sophistication that he desires or can afford. The complete version of a procedural manual for a remote sensing-aided system for snow areal extent estimation is described in Appendix I.

From the results obtained in our snow water content study to date, it can be shown that a potential cost and/or precision advantage is to be gained in this area, also, by use of remote sensing-aided methodology. Our method utilizes data obtained through conventional ground measurement of snow courses integrated into a double sampling framework with Landsat-derived data. Further investigations on optimizing image sample unit size and on the use of automatic analysis techniques probably would improve the precision of the snow water content estimates.

Level I and Level II evapotranspiration estimation models have been developed. Level I models are based on the first information level and utilize solar radiation, temperature, and humidity as the main input variables. Level II models are based on energy-balance and Level III models are based on energy-balance, and on aerodynamic and canopy resistances. Level I ET models have been applied to the Spanish Creek Watershed with satisfactory results. The results of ET models will be directly applied to the operational hydrologic model (known as the Federal-State River Forecast Center Model) that currently is being used by the California Department of Water Resources. Comparison of simulated runoff values after and before using ET results as an input will provide the information necessary for evaluation of ET models. As a result of our coordination with the U.C. Davis NASA-Grant participants, (Algazi, et al.) the Middle Fork of the Feather River Watershed was chosen as a test area on which to apply hydrologic data for the spring of 1975. Currently, RSRP personnel are applying to this new watershed the ET estimation models which they previously had developed for the Spanish Creek Watershed.

Solar radiation is the major source of energy for hydrological processes. Specifically, the quantity of net radiation constitutes the key parameter in hydrological modeling. A remote sensing-aided system developed by RSRP for solar radiation estimation is designed to give time- and location-specific estimates on a watershed or subwatershed basis. This system utilizes some constant physiographic data and some climatic variables. Our methodology, as applied to Spanish Creek Watershed, has provided very satisfactory results. Solar radiation results, therefore, are being used as one of the major inputs in our evapotranspiration models.

In summary, our investigations have shown that remote sensing can cost-effectively provide much major input data required for hydrologic models. In several specific instances we have shown that the use of our methods can help water resources managers by making available to them better water resource

inventories and more accurate water-yield predictions, thereby permitting them to devise and implement better management practices. Based on such experience, as we near the end of our research on remote sensing as applied to water supply, we are preparing and refining various Procedural Manuals, as described in Appendices I, II, III, and IV.

3.400 CONTINUED RSRP RESEARCH ON WATER SUPPLY

The following continuing aspects of our work in the estimation of snow areal extent, snow water content, solar radiation, and evapotranspiration are summarized below:

1. Our concluding efforts to document both the nature and the performance of state-of-the-art water-yield forecast models will soon be completed. This effort, carried out in coordination with the U.C. Davis NASA-Grant participants has been found to be necessary to fully evaluate both snow quantification and water loss estimation procedures utilizing remote sensing techniques. Both the Federal-State River Forecast Center Model (RFC model) and the snow quantification models used by the California Cooperative Snow Survey (CCSS) continue to be examined. Performance documentation continues for the CCSS models and performance for the RFC model will be stated concisely in our next report within the context of the forecast assumptions and model inputs.
2. Development and application of water-yield forecast models will be continued. This work includes refinement of sample design and technique development for estimation of snow water content, solar radiation, and evapotranspiration.
3. Concluding investigations will be made relative to the application of evapotranspiration and solar radiation models to our new watershed covering (as it does in order to better integrate our final tests with those of the Algazi group at Davis) the Middle Fork of the Feather River (MFFR). The models will continue to be examined, based on data acquired during the spring of 1975. Our concluding work on this MFFS watershed (MFFR) can be outlined as below, and in recognition of the fact that several of the listed activities already have been completed or nearly so:
 - a. Topographic analysis (elevation, slope, and aspect maps)
 - b. Completion of existing climatic data collection
 - c. Application of solar radiation models
 - d. Completion of ground data collection
 - e. Application of Level I evapotranspiration
 - f. Modification and application of Level II evapotranspiration models and development of Level III ET models
 - g. Performance of sensitivity analyses for different inputs in ET and color radiation models.
4. Sensitivity analyses will be completed for critical parameters in water supply models. In conjunction with the Algazi group, RSRP is developing water parameter (water loss) estimates to be included in current RFC and CCSS hydrologic models. The performance

change in the models with and without these remote sensing-aided estimates, and based on the U.C. Davis system will be determined. Feedback on model performance will allow modification of the remote sensing-aided water parameter estimation sampling design and methodology so as to improve hydrologic model performance.

5. We soon will complete our evaluation of the cost of information-gathering using conventional and remote sensing-aided methods. This effort continues especially in the context of the RFC Sacramento River Model and the CCSS volumetric model. Cost data on semiautomatic/automatic remote sensing-aided estimation of basin, snow areal extent, snow water content, evapotranspiration, and solar radiation needs to be evaluated to a greater extent than has been possible up to the present time.
6. Development of an automatic (computerized) system for watershed-wide integration and interpolation of point data will be furthered. This system, when fully developed, would estimate the distribution of point data (i.e., precipitation) over the watershed of interest.
7. In light of progress made on the foregoing, we will prepare:
 - a. A final documentation of assumptions, structure, information levels, advantages, and limitations of remote sensing-aided systems for snow quantification and evapotranspiration estimation, and
 - b. A final version (insofar as our efforts under the present grant will permit) of procedural manuals on remote sensing as an aid for watershed-wide estimation of four factors of vital importance in estimating water supply in snow-covered areas, viz. snow areal extent, snow water content, solar radiation, and water loss to the atmosphere.
8. In addition to the above, as per agreement with our NASA monitors, we will prepare Procedural Manuals dealing with the use of remote sensing in the inventory and management of a given area's entire resource complex (i.e., its timber, forage, soils, minerals, fish, wildlife and recreational resources in addition to its water resources). While a great deal of research leading to the preparation of such manuals could be performed to advantage, we believe that we can prepare a useful document by making maximum use of remote sensing-related work that we have done during the past several years for NASA, Department of Interior, and Department of Agriculture dealing with most of the above components of the total resource complex.

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APPENDIX I

Procedural Manual

REMOTE SENSING AS AN AID IN DETERMINING THE AREAL EXTENT OF SNOW

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REMOTE SENSING AS AN AID IN DETERMINING THE AREAL EXTENT OF SNOW

INTRODUCTION

The term "areal extent of snow" pertains to the surface area of the terrain in a specified watershed that is covered with snow at a given time or seasonal state.

For many years the need for an improved method of estimating snow areal extent has been recognized by hydrologists and others concerned with the prediction of water runoff and the estimation of water yield, watershed-by-watershed. Among the methods showing greatest promise is the one dealt with in this Procedural Manual. That method seeks to make maximum use of modern remote sensing techniques, including those which result in the acquisition of aerial and/or space photography of the watershed at suitably frequent intervals. Because of an advantage known as the "synoptic view," it is possible on space photography, and even on high-altitude aerial photography to cover vast watershed areas with only a very few frames of photography. As will presently be seen, this advantage can be of great importance to those wishing to use such photographs as an aid in determining the areal extent of snow.

Of the several remote sensing-based techniques that have been developed for estimating snow areal extent, only two will be mentioned here since they appear to be both representative and highly promising. The first is based merely on the delineation of the apparent snowline on the photographs. The delineated portions of the photographs are then measured in such a way as to provide an estimate of the areal extent of the snow-covered area. This technique is described fully by Barnes and Bowley (1974).

A second technique has been developed which utilizes a two-stage sampling scheme to arrive at an estimate of the snow-covered area. The procedure for employing this technique is described herein. As will presently be seen, the technique employs as much ancillary (i.e., non-remote sensing-derived) information as possible to aid in the accuracy of the final estimate. Furthermore, the design of the model that is employed when this technique is used is such as to largely eliminate final estimate discrepancies, even when two or more photo interpreters are used as a team, since a statistical evaluation of each photo interpreter's results is made. The method, overall, is sufficiently simple and inexpensive to permit it to be used in addition to, rather than instead of, more conventional methods, thereby providing additional confidence in the final estimate of snow areal extent on which operational decisions must be made, in any given instance, by the hydrologist or other resource manager.

When this second method is used by a competent image analyst, in addition to his determining the total area that is covered with snow, he also derives detailed locational information of great value, i.e., he determines the exact portions of the watershed that are snow-covered and differentiates them from the snow-free areas. This can be of great advantage in relation to his desire to make accurate estimations of water yield and water runoff rates because the rate of snow depletion for a given portion of the watershed obviously is a function of its slope, aspect, vegetative cover, and other locally-variable factors.

PROCEDURE

The procedure described here for estimating areal extent of snow is based upon a two-stage analysis of remote sensing imagery. The first stage entails the use of Landsat* color composite imagery, while the second stage employs low-altitude, large-scale aerial photography. The following description provides a step-by-step guide to the use of this method in estimating the areal extent of snow:

Step 1. Prior to the start of the winter season (i.e., the season when the snowpack is to be measured) all of the projected dates when Landsat will be overflying the area of interest during the snow survey period should be systematically listed. In compiling this list one should keep in mind that there is sidelap of about 20 to 30 percent (depending upon the latitude of the area) between the 115-mile swath that is covered by Landsat on one day and that which the same vehicle covers on the following day. Therefore, this factor needs to be considered as the list is being made of all possible dates for the acquisition of Landsat imagery of the area of interest.

Step 2. During the snow-survey period, on each date when a Landsat overflight of the area of interest is about to be made under what is predicted to be suitably cloud-free conditions, by prior arrangement steps should be taken to procure nearly simultaneous low-altitude aerial color photography of preselected flight lines, thereby acquiring the previously mentioned "second stage sample." An optimum scale for such photography is approximately 1/30,000, and 35mm negative color film is preferred.

Step 3. The second stage photography procured in Step 2, above, should be promptly processed and from it standard "3R" prints (i.e., size 3-1/2" x 5") should be made.

* The term "Landsat" applies to various unmanned earth resources technology satellites (formerly called "ERTS"), each of which provides images of the surface of the Earth on an 18-day sun-synchronous cycle (0930 local sun time, approximately) from an altitude of approximately 570 miles and covering a swath width of approximately 115 miles.

Step 4. As promptly as possible after the corresponding Landsat overflight has been made, and again by prior arrangement (in this case normally with the EROS Data Center at Sioux Falls, South Dakota) black-and-white MSS (multispectral scanner) transparencies should be obtained from bands 4, 5 and 7 covering the entire watershed area of interest. The standard 9"x9" transparencies produced by the EROS Data Center are preferred. In addition, either at the time when the first of this snow-season Landsat photography is being acquired, or at some earlier date, an additional summertime (snow-free) set of Landsat imagery also should be acquired for comparative analysis, as indicated below (see Step 15).

Step 5. In each instance, on the Landsat imagery that has been acquired the boundary of the watershed or other area of interest should be delineated.

Step 6. For each of the frames of Landsat imagery required in making the delineation of Step 5, a simulated color infrared color composite should be made, using the three bands (4, 5 and 7) to make a "triple exposure" on negative color film in the manner described in Appendix I-B of this Procedural Manual.

Step 7. From the resulting negative color composites, reflection prints (rather than transparencies) should be made to a size of approximately 8"x10". In those instances where more than one Landsat frame is required to cover the area of interest, the Landsat frames originally selected (and the corresponding areas copied and printed from them) should overlap each other sufficiently to provide complete coverage of the entire watershed or other area of interest.

Step 8. Either at the time when the first of the wintertime Landsat sets of imagery is obtained, or prior thereto, a set of acetate overlays each about 9"x9" in size and gridded at various intervals into squares, should be prepared. In any given instance the size of the grid should be governed by time, accuracy, and cost constraints. Obviously, in most instances as grid size decreases, the accuracy, cost and time factors all increase.

Step 9. Through the use of geographic features that are readily located on Landsat imagery, each successive frame of such imagery should be indexed so that the gridded acetate overlay can be registered in exactly the same way with respect to each of the frames that cover a given area.

Step 10. Similarly, the grids, as they appear on the Landsat frames of imagery, should be transferred to the low-altitude photos (i.e., the stage two photos taken at large scale with 35mm color film) and then labelled in such a manner that any grid unit (i.e., any image sample unit) can be easily located there and readily cross-referenced to the corresponding Landsat imagery.

Step 11. The indexed grids as they now appear on the low-altitude photography should be interpreted for areal extent of snow. Generally four to six snowcover classes should be used, based on the proportion of the grid that appears to be snow-covered. An example using six classes could be: Class 1, 0-9 percent; Class 2, 10-25 percent; Class 3, 25-50 percent; Class 4, 50-75 percent; Class 5, 75-90 percent; Class 6, 90-100 percent. (It has been found that, due to the large amount of detail visible on the large scale prints, it is a fairly easy task for each grid unit to be placed in a specific class with a high degree of certainty.)

Step 12. This set of classified grid units should now be divided into a training and a testing set. The training set should be located on the gridded acetate overlays to the Landsat imagery and should include a wide range of snow appearance types covering the range of snowcover classes.

Step 13. The interpretation set-up should now be constructed. It should consist of a coincident image viewing device, such as a mirror-stereoscope or a transfer scope, the set of 8"x10" Landsat summer color composite prints, for which the determination of snow areal extent is to be made, and the set of classified grid units, as seen on the low-altitude aerial photography, corresponding to the gridded winter color composite prints.

Step 14. As the detailed interpretation of the Landsat winter photos begins, one 8"x10" summer Landsat print should be placed under the stereoscope (or transfer scope) along with the corresponding scene on the gridded winter Landsat print set. The prints should be adjusted so that conjugate images can be fused by the photo interpreter (i.e., so that all common features can be made to coincide with each other, one image viewed with each eye), thus allowing the interpreter to assess both the snow areal extent and the vegetation/terrain conditions in each grid unit.

Step 15. The interpreter should next engage in the task of training himself to recognize different snowcover condition classes within grid units based on: (a) underlying vegetation/terrain features (as seen on the summer Landsat print), (b) the snowcover visible on the gridded winter Landsat print, and (c) the appearance and subsequent classification of the grid units as seen on the low-altitude aerial photography. By viewing through the coincident image device and observing how each grid unit in the training set appears during the winter and summer, and by then referring to the training set grid units on the low-altitude aerial photography, the interpreter can effectively complete this training task in very short order.

Step 16. Once trained, the interpreter should then proceed to classify each grid square (image sample unit) on the winter Landsat print

(in terms of the snow areal extent class to which it belongs) according to his synthesis of the information available as he perceives it on the summer and winter Landsat prints.

Step 17. After all of the winter dates of imagery have been classified, the interpreter's initial interpretation results are ready for the testing phase. Therefore, at this point the results of the grid classification (as made on the low-altitude aerial photography testing set) should be compared to the results obtained by the interpreter in all applicable grid units. A ratio estimator statistic, as described in detail in Appendix I-A of this Procedural Manual should then be applied. This statistic will provide the adjustment calibration necessary to correct the interpreter's initial interpretation results.

Step 18. Once the true value for the snow areal extent has been estimated using the population ratio estimator, two other statistical tests can be applied to clarify the final result. The confidence interval concept can be used to give an idea of the range of the final snow areal extent value. A Chi-square test can be applied to test the snowcover class width selection. Both of these tests are discussed in detail in Appendix I-A.

Note: It is apparent from the foregoing that, even if this procedure is highly successful, its end product is merely an accurate determination of the areal extent of snow, together with an accurate delineation of each portion of the watershed area according to the snowcover class to which it belongs. This is an essential step leading to a prediction of water runoff and the estimation of water yield. The remaining steps are discussed in other procedural manuals.

APPENDIX I-A
A SPECIFIC CASE STUDY

The following case study describes uses that our RSRP personnel have made of the foregoing procedure for the Feather River Watershed, California.

On April 4, 1973 the majority of the Feather River Watershed (located in the central Sierra Nevada Mountains, California) was imaged in a virtually cloud-free condition by the Landsat satellite. In order to document the existing ground conditions in greater detail than that provided by the satellite imagery, a photographic mission was flown over the watershed on April 6, 1973. Four transects were flown using a motorized 35mm camera to acquire photography at a scale of approximately 1:30,000 on the negative (Figures I-3 and I-4).

Landsat imagery from August 13, 1972 was chosen for use as the vegetation/terrain base for the snowpack analysis procedures. The August 13 and the April 4 Landsat images of MSS bands 4, 5, and 7 were photographically combined to produce simulated color infrared enhancements (Figures I-3 and I-4) on color negative film using the previously mentioned technique (Appendix I-B).

The simulated color infrared enhancement of the August 13, 1972 Landsat scene was photographically reproduced to give a 16" x 20" color print of approximately 1:250,000 scale. The April 4, 1973 Landsat color infrared enhancements were enlarged to precisely the same scale as the August 13, 1972 imagery and printed to give overlapping 8" x 10" prints.

An acetate grid (each grid block equalling approximately 2,000 meters on a side at a scale of approximately 1:250,000) was attached to the vegetation/terrain Landsat image. The grid blocks, termed image sample units (ISU), were transferred to the large scale photography where applicable. The image sample units on the large scale aerial photography were coded as shown in Table I-1.

Table I-1

Snowcover Condition Classes Used for Areal Extent of Snow Estimation

<u>Code</u>	<u>Snowcover Class</u>	<u>Midpoints</u>
1	No snow present within ISU	0
2	0-20% of ISU covered by snow	.10
3	20-50% of ISU covered by snow	.35
4	50-98% of ISU covered by snow	.74
5	98-100% of ISU covered by snow	.99

The interpreter then engaged in the training phase to familiarize himself with the imagery and image classification technique. Once trained, the interpreter proceeded to classify all the image sample units on the 8" x 10" Landsat color print for the winter dates. A more detailed description of this process will be found in the Procedural Manual.

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FIGURE I-1

Low altitude aerial photographs of the snowpack taken from a light aircraft using a 35 mm camera. The scale of the negative is approximately 1:30,000. The grid shown on the photograph represents an image sample unit, (ISU), also located on the Landsat color composite imagery (see Figure I-4). The image sample unit shown represents a snowcover class of 3 (See Table I-1).

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FIGURE I-2

altitude aerial photograph of the snowpack similar to Figure I-1 however
representing a snowcover class of 4 (See Table I-1).

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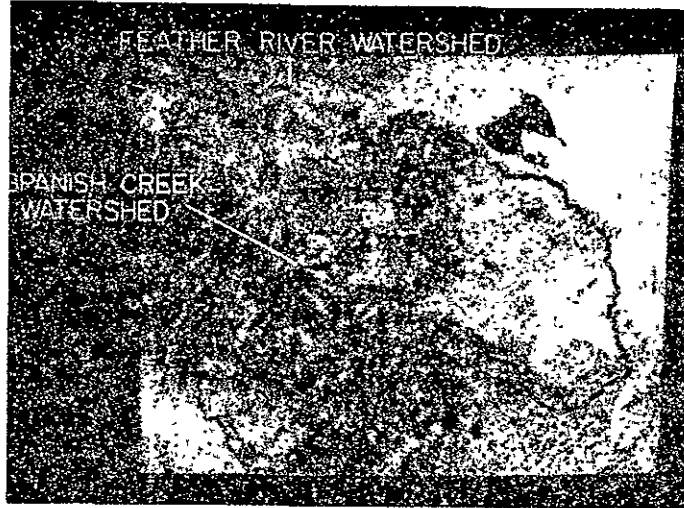


FIGURE I-3

August 13, 1972 Landsat color composite image showing the Feather River and the Spanish Creek Watersheds.

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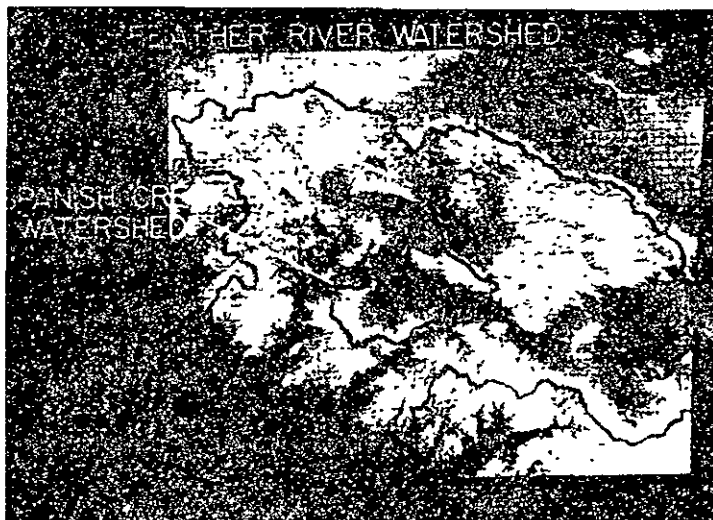


FIGURE I-4

April 4, 1973 gridded Landsat color composite image showing the Feather River and Spanish Creek Watersheds. The grids define the image sample units, each being approximately 400 hectares in size.

FIGURE I-5

A portion of the April 4, 1973 Landsat color composite image showing the snowcover class interpretations on an image sample unit basis.

The classified imagery was then subjected to statistical analysis. The following are the results from the April 4 Landsat areal extent of snow analysis.

	Snowcover (Condition) Class				
	1	2	3	4	5
Total number of ISU's classified per class	403	289	214	453	859

To derive the approximate number of hectares in each class, the image sample unit totals per class were multiplied by the number of hectares per image sample unit (400) with the results indicated below:

	Snowcover (Condition) Class				
	1	2	3	4	5
Hectares	1.612 $\times 10^5$	1.156 $\times 10^5$.856 $\times 10^5$	1.812 $\times 10^5$	3.436 $\times 10^5$

Then to establish the approximate amount of actual snow-covered area per class, the number of hectares/class were multiplied by the snowcover class midpoints (from Table 1) for each class, as indicated below in the following tabular summary:

	Snowcover (Condition) Class				
	1	2	3	4	5
Snowcover condition class midpoint	0	.10	.35	.74	.99
Hectares of snow per class	0	1.156×10^4	2.996×10^4	1.341×10^5	3.402×10^5

By adding the "hectares of snow per class" values, the "total surface area of snow" in hectares was established. Thus for the April 4, 1973 Landsat date the estimate of snow areal extent was found to be 5.1582×10^5 hectares. This value, however, may be biased by any errors which occurred during the classification of the Landsat image sample units for snow areal extent. The uncorrected areal extent of snow estimate can be "corrected" by comparing the interpreter classification results with a series of preselected, preclassified image sample units, chosen for testing purposes from the large scale aerial photographs.

Interpretation results not falling in a given snowcover condition class for both the large scale aerial photographic and Landsat image data represent a misclassification of image sample units by the interpreter (Table I-2). Thus it can be seen that 13 out of a possible 80 image sample units were misclassified. This misclassification error can then be represented by a statistic, the population ratio estimator (Cochran, 1959), which will be used to correct the initial areal extent of snow estimate of 5.1582×10^5 hectares derived from the Landsat image classification.

The statistical approach is defined as follows:

(Equation 1.0) $\hat{Y}_r = X\hat{R}$ = the final, corrected areal extent of snow estimate

(Equation 1.1) where: $X = \sum_{j=1}^N X_j$ = the uncorrected Landsat areal extent of snow estimate

given that: X_j = the Landsat interpretation estimate of snow areal extent, per image sample unit, by snowcover class

j = the index for all Landsat image sample units

N = the total number of Landsat image sample units classified for snow areal extent

(Equation 1.2) where: $\hat{R} = \bar{Y} \div \bar{X}$ = the population ratio estimator

(Equation 1.3) given that: $\bar{Y} = \left(\sum_{i=1}^n y_i \right) \div n$ = the average snow areal extent value for the large scale photographic image sample unit estimates

(Equation 1.4) $\bar{X} = \left(\sum_{i=1}^n x_i \right) \div n$ = average snow areal extent value for the Landsat image sample unit estimates

and that: n = the total number of image sample units used in the testing phase

i = sampling index

y_i = large scale photography snow areal extent estimate for image sample unit i

x_i = Landsat snow areal extent estimate for image sample unit i

Since the uncorrected Landsat areal extent of snow estimate (X) has been calculated to be 5.158×10^5 hectares, the value for the population ratio estimator, R, must be determined to solve for the final, corrected Landsat areal extent of snow estimate, \hat{Y}_R , (from the equation $\hat{Y}_R = X\hat{R}$). Table I-3 represents an expanded version of Table 2 designed to facilitate the calculation of the population ratio estimator, \hat{R} . The table has been enlarged to include listings of snowcover condition class/image sample unit, specific large scale photography estimates of snow areal extent, and Landsat areal extent of snow estimates.

y_u = large scale aerial photography estimate of snow areal extent per image sample unit by snowcover condition class (in hectares)

$$= \begin{bmatrix} \text{snowcover condition class} \\ \text{midpoint} \end{bmatrix} \begin{bmatrix} \text{number of hectares} \\ \text{per image sample unit} \end{bmatrix}$$

and; x_u = Landsat snow areal extent estimate per image sample unit by snowcover condition class (in hectares)

$$= \begin{bmatrix} \text{snowcover condition class} \\ \text{midpoint} \end{bmatrix} \begin{bmatrix} \text{number of hectares} \\ \text{per image sample unit} \end{bmatrix}$$

f_u = image sample unit interpretation frequencies

u = index for table containing the results of the testing phase

Additionally,

n = the number of image sample units used in the testing phase, i.e.,

(Equation 1.5)
$$n = \sum_{u=1}^1 f_u = 80$$

where: u = index for Tables I-2 and I-3

and k = the number of interpretation result blocks in Tables I-2 and I-3 = 11.

\hat{R} , the population ratio estimator, can now be calculated by solving for \bar{Y} and \bar{X} from the data presented in Table I-3. Thus, if

(Equation 1.6)
$$\sum_{i=1}^n y_i = \sum_{u=1}^k f_u y_u$$

(Equation 1.7) and
$$\sum_{i=1}^n x_i = \sum_{u=1}^k f_u y_u$$

then
$$\bar{Y} = \frac{\sum_{i=1}^n y_i}{n} \quad \text{(Equation 1.3)}$$

(Equation 1.8)
$$= \sum_{u=1}^k f_u y_u + n \quad \text{(from Equation 1.6)}$$

(Equation 1.9)
$$= \sum_{u=1}^k f_u y_u + \sum_{u=1}^k f_u \quad \text{(from Equation 1.5)}$$

and
$$\bar{X} = \frac{\sum_{i=1}^n x_i}{n} \quad \text{(Equation 1.4)}$$

(Equation 2.0)
$$= \sum_{u=1}^k f_u + n \quad \text{(from Equation 1.7)}$$

(Equation 2.1)
$$= \sum_{u=1}^k f_u x_u + \sum_{u=1}^k f_u \quad \text{(from Equation 1.5)}$$

Therefore (from Table I-3 and Equations 1.9 and 2.1):

$$\bar{Y} = \frac{(0)(6)+(40)(1)+(40)(10)+(296)(1)+(40)(2)+(140)(6)+(296)(2)+(140)(1)+(296)(12) + (296)(6)+(396)(33)}{6+1+10+1+2+6+2+1+12+6+33}$$

$$= \frac{20784}{80}$$

$$= 259.80$$

and

$$\bar{X} = \frac{(0)(6)+(0)(1)+(40)(10)+(40)(1)+(140)(2)+(140)(6)+(140)(2)+(296)(1)+(296)(12) + 396(6)+396(33)}{6+1+10+1+2+6+2+1+12+6+33}$$

$$= \frac{21132}{80}$$

$$= 264.15$$

Consequently, the population ratio estimator (Equation 1.2) is calculated to be:

$$\begin{aligned}\hat{R} &= \bar{Y} \div \bar{X} && \text{(Equation 1.2)} \\ &= 259.80 \div 264.15 \\ &= .9835\end{aligned}$$

Finally, to solve for \hat{Y}_R (the final, corrected areal extent of snow estimate), the population ratio estimate, \hat{R} , is multiplied by the uncorrected Landsat areal extent of snow estimate, X (Equation 1.0). Thus,

$$\begin{aligned}\hat{Y}_R &= X\hat{R} && \text{(Equation 1.2)} \\ &= (5.1582 \times 10^5) (.9835) \text{ hectares} \\ &= (5.07309 \times 10^5) \text{ hectares} \\ &= 507,309 \text{ hectares}\end{aligned}$$

Once the actual areal extent of snow has been estimated, \hat{Y}_R , it may be useful to know where the true value for the areal extent of snow lies. The confidence interval is useful for this purpose. The statistical approach is as follows, using the 95% level of confidence as an example:

Y_R = the true value for the areal extent of snow

The confidence interval around Y_R can be expressed as:

the probability that

$$\text{(Equation 2.2)} \quad \left[\hat{Y}_R - t_{n-1, .025} \sqrt{V(\hat{Y}_R)} \leq Y_R \leq \hat{Y}_R + t_{n-1, .025} \sqrt{V(\hat{Y}_R)} \right] = .95$$

$$\text{(Equation 2.3)} \quad \text{where } V(\hat{Y}_R) = \frac{N(N-n)}{n(n-1)} \left[\sum_{i=1}^n y_i^2 + \hat{R}^2 \sum_{i=1}^n x_i^2 - 2\hat{R} \sum_{i=1}^n x_i y_i \right]$$

= sample variance

A summary of all the major results from the statistical analysis described previously for the April 4, 1973 snow analysis date is contained in Table I-4.

The final statistical test that was employed in this analysis was used to determine the suitability of the snowcover condition class widths as selected from step 11 in the procedure and Table 1. This test was to determine if the values in the snowcover classes from the Landsat image data came from the same statistical probability distribution as the values in the snowcover classes from the large scale aerial photographic data. If they came from the same distribution it could be expected that the areal extent of snow estimation procedure would provide good results. If these indicated that the two data sets came from different distributions, then new class widths should be selected and the areal extent of snow estimation procedure should be rerun. To perform such probability distribution "likeness tests," a Chi-square statistic was used:

(Equation 2.4)
$$\chi^2 \sim \sum_{i=1}^k \frac{(O_i - E_i)^2}{E_i}$$

where O_i = the observed values

E_i = the expected values

k = the number of snowcover condition classes

i = index.

The values in the snowcover classes from the large scale photo data were designated as the expected values (E_i), since they were assumed to be "ground truth." The values in the snow cover classes from the Landsat image data were designated as the observed values (O_i).

The results of the Chi-square test for the April, 1973 statistical testing data (Table I-2) are shown in Table I-5. The results indicate that the two data sets do come from the same statistical probability distributions; thus it can be assumed that the snowcover class widths used for the areal extent of snow analysis are adequate.

Table I-2

Interpretation results of the testing phase; areal extent of snow estimation for the April 4, 1973 Landsat and April 6, 1973 large scale aerial photographic data.

		Large Scale Aerial Photographic Data					
		Snowcover Condition Class					
		1	2	3	4	5	
Landsat Image Data	Snowcover Condition Class	1	6	.1			
	2		10		1		
	3		2	6	2		
	4			1	12		
	5				6	33	

Key to Table I-2:

$$f_u$$

where: f_u = Image sample unit interpretation frequencies

u = Index for the table.

Table I-3

Interpretation results of the testing phase, areal extent of snow estimation for April 4, 1973 Landsat and April 6, 1973 large scale aerial photographic data. Also included is a listing of uncorrected large scale aerial photographic and Landsat image estimates of snow areal extent per image sample unit by snowcover class.

		Large Scale Aerial Photographic Data					
		Snowcover Condition Class					
		1	2	3	4	5	
Landsat Image Data	Snowcover Condition Class	1	0	0	0	0	0
		2	6	10	1	1	1
		3	6	2	6	2	2
		4	12	1	12	1	1
		5	33	3	33	3	3

Key to Table I-3:

y_u
x_u f_u

- where: x_u = Landsat snow areal extent estimate per image sample unit by snowcover condition class (in hectares)
- y_u = Large scale photography snow areal extent estimate per image sample unit by snowcover condition class (in hectares)
- f_u = Image sample unit interpretation frequency
- u = Index for the table.

Table I-4

Summary of Statistical Results
 Areal Extent of Snow Estimation
 April 4, 1973

Landsat estimate of the areal extent of snow (in hectares)	X	515,820
Population ratio estimator	\hat{R}	.9835
Estimate of the true areal extent of snow (in hectares)	\hat{Y}_r	507,309
Standard deviation of the areal extent of snow estimate (in hectares)	$\sqrt{V(\hat{Y}_r)}$	21,100.6
Confidence interval (95%) around the true value for the areal extent of snow (in hectares)		$465,234 < \underline{Y}_r < 549,384$
Total number of image sample units inventoried on the Landsat imagery	N	2,218
Average surface area of an image sample unit (in hectares)		400
Total number of hectares inventoried		869,456
Total number of image sample units sampled for the statistical testing procedure	n	80

Table I-5

Chi-square Test for April 4, 1973 Data

Null Hypothesis: Ho: The observed values (O_i) come from the same distribution as the expected values (E_i)

Alternative Hypothesis: Hi: The observed values do not come from the same distribution as the expected values

Significance Level: 5%

Test Statistic under the Null Hypothesis: $\sum_{i=1}^k \frac{(O_i - E_i)^2}{E_i} \sim \chi^2_{k-1}$;

where $k-1$ = the degrees of freedom

Full Class Data Summary

Class	O_i	E_i	$\frac{(O_i - E_i)^2}{E_i}$
1	7	6	.1667
2	11	13	.3077
3	10	7	1.2857
4	13	21	3.0476
5	39	33	1.0909

$$\sum_{i=1}^k = 5.8992$$

Conclusion: The null hypothesis is accepted since the calculated value of 5.8992 is less than the table value of 9.49.

APPENDIX I-B

THE PHOTOGRAPHIC CONSTRUCTION OF LANDSAT COLOR COMPOSITE IMAGERY

INTRODUCTION

The value of color composites has long been recognized as an aid to the interpretation of Landsat imagery. The technique described in this technical brief demonstrates how Landsat color composite imagery can be constructed from Landsat positive black-and-white transparencies conveniently and inexpensively.

COLOR COMPOSITE THEORY

Typical color reversal and color negative films consist basically of three light sensitive layers. These layers react individually to blue, green, and red light, each layer corresponding to a particular dye, dependent upon film type, as indicated below:

Light Sensitivity	Color reversal film Dye layers activated	Color negative film Dye layer activated
Red	Yellow and Magenta	Cyan
Green	Yellow and Cyan	Magenta
Blue	Magenta and Cyan	Yellow

If, for instance, color negative film is exposed to blue light, the blue sensitive layer of the film is activated while the other layers remain unaffected. This blue-sensitive layer corresponds to a final yellow dye image and hence the results will appear yellow on the negative.

When color reversal film is exposed to blue light, the blue sensitive layer of the film is activated; however, during processing the two remaining sensitivity layers corresponding to the magenta dye (green sensitive) and the cyan dye (red sensitive) are either chemically or mechanically exposed. The originally exposed blue sensitive layer becomes non-functional and the resulting image appears blue due to the combination of magenta and cyan dyes. The reactions of color reversal and negative film to red and green light can be explained similarly since red is produced by a combination of yellow and magenta dyes and green is produced by a combination of cyan and yellow dyes.

The photographic construction of Landsat color composites relies on the three-layer sensitivity of color film and on the different densities of any given feature as it appears on the various Landsat black-and-white bands. Each of the different Landsat black-and-white bands chosen to make the color composite is photographically copied onto the same sheet (or frame) of color film, each band through a different colored filter (in essence a multiple exposure). Figure I-6 illustrates the set-up used to produce Landsat color composites. Depending on which filter is used with each band of imagery different color renditions may be produced, hopefully enhancing different features.

MATERIALS AND EQUIPMENT

LANDSAT BLACK-AND-WHITE IMAGERY

The construction of Landsat color composites commonly uses Multispectral Scanner (MSS) imagery of bands 4, 5, and 7, usually in the 9½ inch positive transparency form (although the 70 millimeter positive transparencies may also be used). MSS Band 6 is also used for some composites as well as available Return Beam Videcon (RBV) positive imagery. Furthermore, just as a color composite can be formed by combining bands of imagery acquired on a single date, so it also can be formed by combining several dates of imagery acquired in a single band, or any combination of multiband/multidate images.

FILTERS

Eastmak Kodak Wratten filters are suggested for use in the construction of color composites due to their optical quality and the large variety of colors and sizes available. To produce a simulated false-color infrared color composite image (Figures I-3 & I-4), Wratten filter number 25 (tricolor red), 47B (tricolor blue), and 58 (tricolor green) can be used.

FILTER RELATED ACCESSORIES

Eastmak Kodak filter frames provide a convenient way to mount the Wratten filters. The filters so mounted can be easily inserted into a commercially available filter holder which mounts, via adapters, to the filter-threaded receptacle in the front of most enlarging lenses.

PHOTOGRAPHIC LIGHT SOURCE

The light source is used to provide the light which will be transmitted through the Landsat bands during the exposure process. Basically, the light source may be of two common types; incandescent or fluorescent and electronic strobe. Incandescent or fluorescent illumination in the form of a "light table" may be the most convenient form to use initially. One of the problems encountered with using a light table is its relatively low light output, necessitating long exposures times. One way of countering this is by using an electronic strobe light box which could give decidedly greater light output and thus shorter exposures.

REGISTRATION SHEET

The registration sheet is used to register the individual Landsat bands with respect to one another. It also serves as a convenient base for introducing grids, watershed boundaries or other data directly on the color composite. The material used for the registration base should be translucent (frosted preferably), dimensionally stable and have a surface amenable to scribing.

SCRIBING TOOLS

The scribing tools consist of a scriber and a metal straight edge. The scriber can be constructed by inserting a drafting compass needle in an engineering drafting pencil while the metal straight edge may simply be a metal engineering scale. The scribing tools are used to transfer the Landsat registration marks onto the registration sheet.

CAMERA SYSTEM

A large variety of cameras and related accessories ranging in format from 35 millimeter to much larger image sizes can be used to construct Landsat color composites. The only requirement is that the camera be capable of making accurate multiple exposures on a single sheet or frame of film. The most convenient camera used to develop this system was found to be a type of copy camera which utilizes a leaf shutter system allowing as many exposures as desired on a single sheet or frame of film. A camera system of this type is desirable due to its ability to accept film formats from 35 millimeters to 4 x 5 inches.

The camera lens used for making color composites should be of very high quality. Since the construction of color composites utilizes most of the light-sensitive spectral range of conventional color film, the lenses used should be color corrected. The lenses should be of very high uniform edge-to-edge resolution and contrast to assure that no information is lost throughout the image area.

EXPOSURE METER

An exposure meter should be used to determine how much exposure should be given to each of the Landsat black-and-white images in making the color composite. The meter used should have a locking needle, a wide sensitivity range and a narrow acceptance angle so that selective area measurements can be made.

FILM TYPES

If reflection prints are to be made of the color composite, it is most convenient to use a fine grain negative color film such as Kodak Vericolor II Type S. If positive color transparencies are desired (e.g. for projection purposes) the use of either Kodachrome or Ektachrome film is appropriate, depending on the film format used.

PROCEDURE

The following step-by-step description will detail the procedure used to construct a Landsat color composite.

- Step 1. Tape one band of a Landsat black-and-white set of imagery for a specific date to a light table in proper viewing position.
- Step 2. Tape a sheet of the registration base material over the Landsat image so that the four registration marks (+) in the corners of the Landsat image are completely covered by the overlying sheet.
- Step 3. Transfer the registration marks to the registration base material using the scribe and the metal straight edge. The scribed line should be narrow in width and extend beyond the actual Landsat registration marks to facilitate the actual registration process.
- Step 4. The registration sheet should be labeled with the latitude/longitude and date of the Landsat imagery from which it was made. This information is placed on the same edge as observed on the Landsat image below so that the Landsat black-and-white bands may be oriented correctly during the registration process.
- Step 5. The completed registration sheet is removed and placed in proper position on the light table or flash box and taped down.
- Step 6. One of the Landsat bands to be used for making the composite is taped down in register over the registration sheet. The registration marks and the information line are used to register and orient the two, relative to one another.
- Step 7. The camera system is focused upon this registered image and locked into position.
- Step 8. An exposure measurement of the Landsat band is then made on the ground glass focusing screen of the camera with the lens set at a fixed aperture, usually maximum. This reading is recorded. The other Landsat bands to be used are then placed one at a time on the registration sheet with the image projected onto the focusing screen and the exposure measurement for each is recorded again at the same fixed aperture.
- Step 9. The exposure measurements for the Landsat bands are averaged and referred to exposure graphs (which are explained in the next section).
- Step 10. The camera/lens exposure controls are then set according to the exposure graphs.
- Step 11. The film on which the composite is to be made is then loaded in the camera.

Step 12. One at a time, the Landsat bands are placed on the registration sheet and exposed through the appropriate filter. The film is not advanced or removed until all exposures have been made.

Step 13. The film is then processed normally yielding the final color composite.

EXPOSURE DETERMINATION

In determining the proper exposure to give each of the Landsat black-and-white images the separate bands are assumed to be matched separation positives. The actual deviation from this assumption is generally so slight that it may be ignored in most if not all cases.

Since no two light source systems developed to construct Landsat color composite imagery will have equal light outputs, the graph used to determine proper exposure must be empirically established. The following describes the determination of the exposure graph necessary for proper exposure calculation. Since each exposure graph can be calculated for one particular color composite type (i.e., band/filter combination) only, the following description will deal with the construction of a simulated false color infrared composite. To make this particular rendition Landsat band 7 is exposed through a Wratten 25 (Red) filter, band 5 through a Wratten 58 (Green) filter and band 4 through a Wratten 47B (Blue) filter.

To empirically determine the exposure graphs for the various band/filter combinations, a series of color composites are constructed at different overall exposures. Each series of color composites has exposure values measured for each band as per step 8 under "procedures". The values measured are averaged for each set and then plotted versus the actual overall exposure found to give an acceptable color composite. All light measurement values are taken with the lens set at a fixed aperture. This aperture will always be used for the through-the-lens exposure measurements of each band. This is necessary to provide a consistent index system for reference to the exposure graphs.

The averaged exposure measurements taken from the individual Landsat bands are plotted on the x-axis versus Exposure Values (EV) on the y-axis. EV refers to equal light intensities; hence equal combinations of shutter speed and aperture which yield the same exposure to the film. For example, EV 13 equals 1/30 second at f/15, 1/60 second at f/11, 1/125 second at f/8, 1/250 second at f/5.6, etc. Figure I-7 illustrates the appearance of such an exposure graph.

Due to the different optical densities of the filters used to construct a color composite, different exposures are needed for each band/filter combination. These different densities can be referred to as filter factors. The filter factor for a given filter changes with the film type as well as the light source; consequently filter factors must be calculated for each film type/light source combination. One practical way of calculating specific filter factors is to photograph a transparent gray scale through each of the filters for which the filter factor is to be determined. These will produce individual exposures through the filters onto color film, either positive or negative. Several exposures are taken through each filter, advancing or changing the film after each exposure. All exposures must be recorded for the final determination of the filter factors. For each filter an exposure is found which best reproduces the gray scale (i.e. all gray levels are

clearly distinguishable from each other) by examining the color film. In all cases each individual gray level should have the same optical density for all of the filter types used. This is best done through the use of a densitometer but can be done visually if necessary. A comparison of the exposures used for the various filters to obtain equal densities gray level-by-gray level, will give the filter factors for each filter. These filter factors may then be translated into EV's to give the relative exposure differences for the filters used.

To establish the exposure graphs for the various band/filter combinations, a series of color composites are constructed, all at different overall exposures. Each composite so constructed must have the filter factors (in terms of individual exposure differences) included. If, for example, for a specific film/light source combination, it is determined that a Wratten 47B filter requires 1 EV more exposure than a Wratten 58 filter, (which requires itself $\frac{1}{2}$ EV more exposure than a Wratten 25 filter to obtain equal density levels) then a series of exposures can be made using these differences. For the first composite the overall exposure might be EV13 through the Wratten 47B filter, EV 14 through the Wratten 58 filter, and EV 14.5 through the Wratten 25 filter. For the second composite overall exposure might be EV14 through the Wratten 47B filter, EV 15 through the Wratten 58 filter, and EV 15.5 through the Wratten 25 filter and so on. Since the individual filters require different but equal relative exposure differences maintained during the construction of the composites, color balance is kept stable, but overall composite density is not. Thus the best composite density from this series of different overall exposures can be determined. By plotting the exposures used for each filter in the best composite constructed, one group of points may be plotted on the exposure graph for this particular band/filter combination. Once two groups of points, each representing a good color composite overall exposure for a specific band/filter combination have been plotted, the graph can be completed.

CONCLUSIONS

Several critical points are worth mentioning again to assure that the color composites are correctly constructed:

1. During the actual photographic construction, several exposures are made on the same sheet or frame of film; the film is not removed or advanced during these exposures.
2. All exposure measurement values of the various bands are made through the camera/lens assembly on the ground glass using a fixed aperture. This aperture may change depending upon the actual responses of the various bands during the copying process.
3. The individual exposure measurements of the bands to be used are mathematically averaged and then referred to the exposure graph for the exposure setting of each band/filter combination.

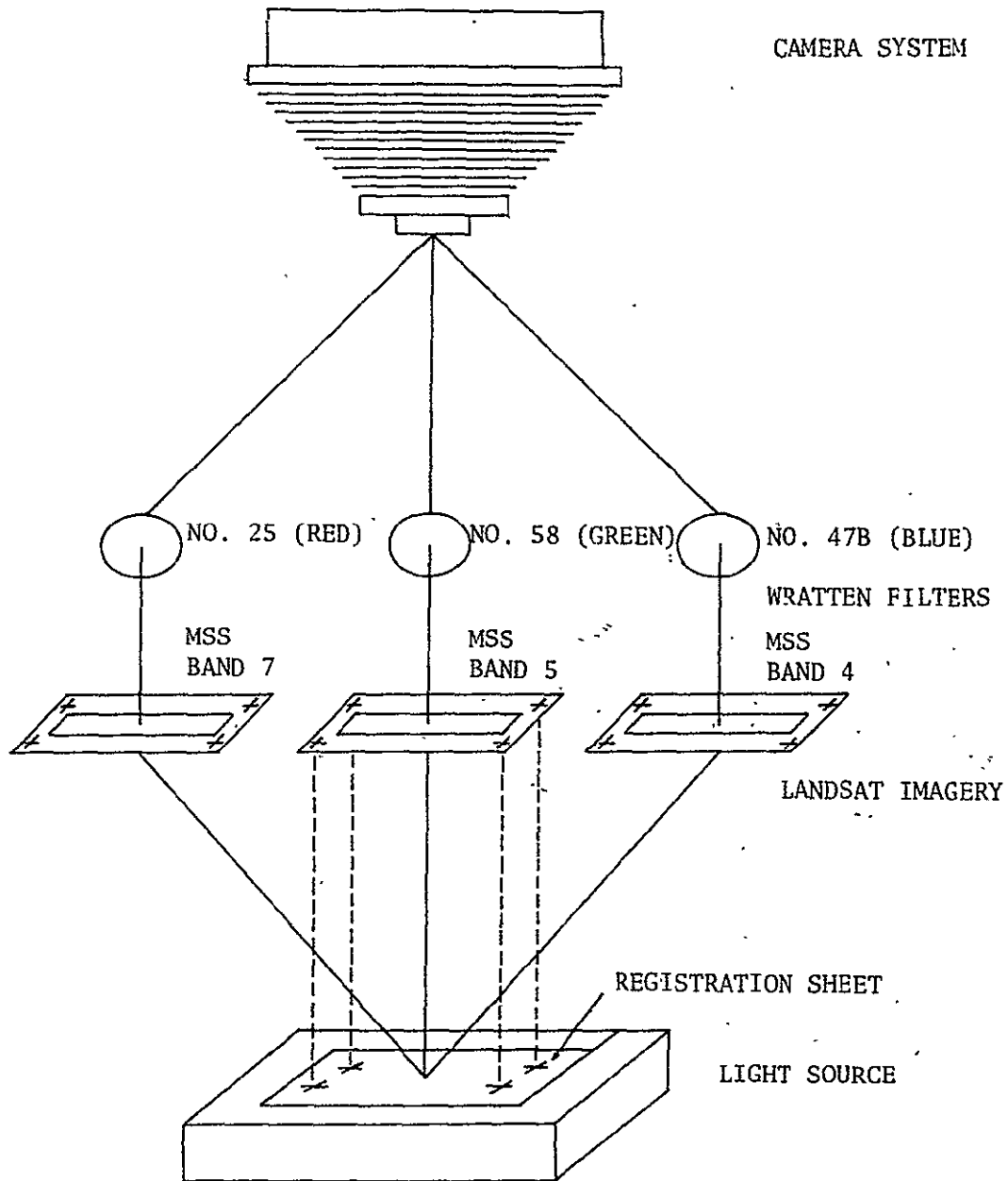


Figure I-6. This schematic diagram illustrates the photographic technique for constructing color composite images. A camera, color film, colored filters, LANDSAT imagery, a registration sheet and a light source are employed. Note that all three bands are placed separately on the registration sheet for copying. The band/filter combinations shown in the diagram above are used to produce simulated false color infrared composites. Different band/filter combinations will produce differently colored composites.

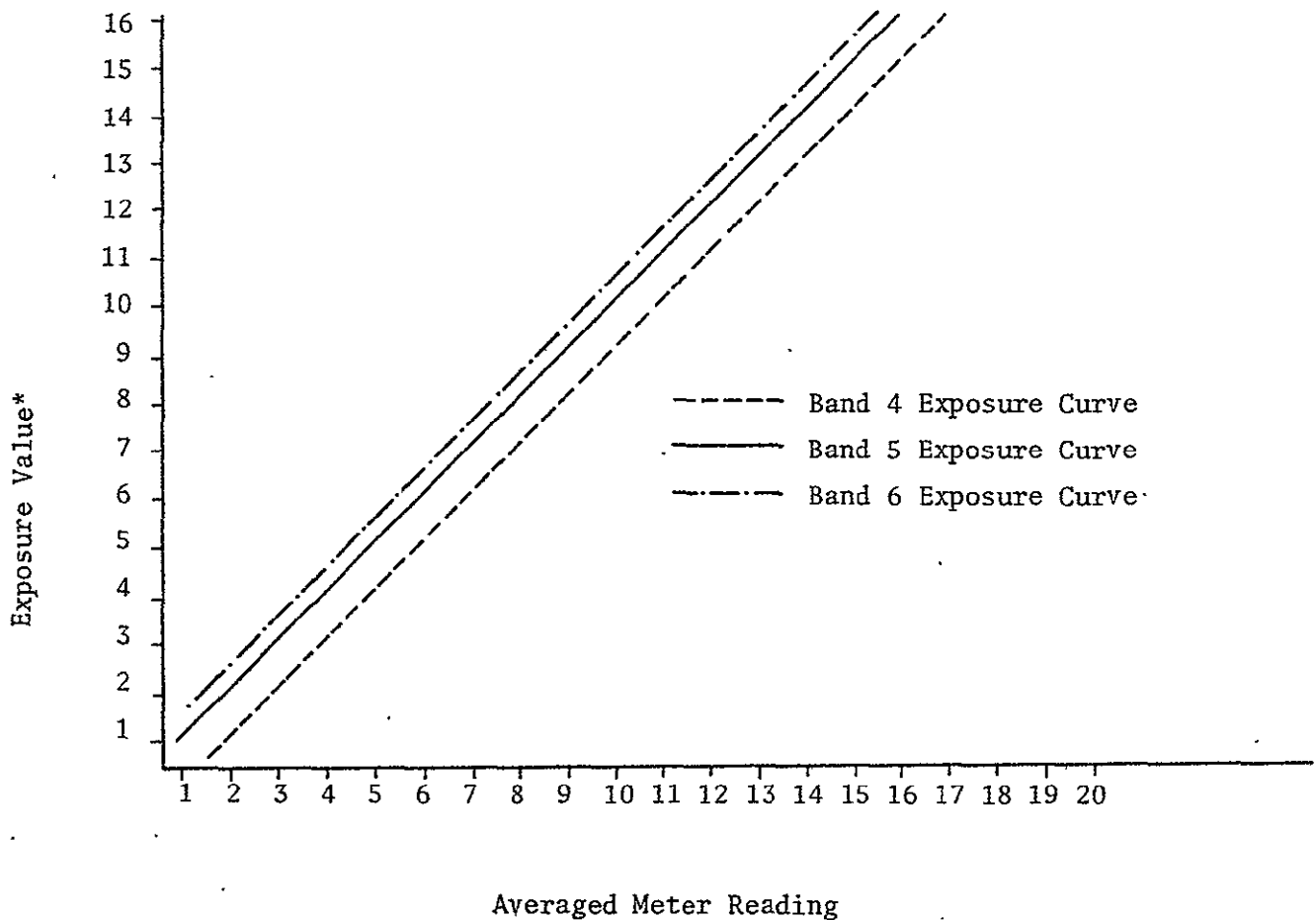


Figure I-7. Example exposure data for the construction of a simulated false-color infrared three band color composite using a conventional light table or a flashbox. LANDSAT MSS Band 4 is combined with a Wratten 47B filter, Band 5 with a Wratten 58 filter, and Band 7 with a Wratten 25 filter. Different exposure curves must be derived for different film speeds and/or different band/filter combinations, as explained in the text.

*Exposure values (EV) are those unique combinations of shutter speed and aperture which yield the same exposure. For instance EV 13 represents the combinations 1/125 second at f/8, 1/60 second at f/11, 1/30 second at f/16, etc.

REFERENCES

Barnes, J. C. and C. J. Bowley, 1974, "Handbook of Techniques for Satellite Snow Mapping", Environmental Research & Technology, Inc., Concord, Massachusetts, 95 pgs.

APPENDIX II

PROCEDURAL MANUAL

REMOTE SENSING AS AN AID IN DETERMINING THE WATER CONTENT OF SNOW

1.0 Introduction

This procedural manual describes the use of Landsat data in combination with conventional ground snow course data to provide an estimate of watershed or subbasin snow water content. The technique is designed to be readily implementable in current operational water runoff forecasting models. Only a small initial capital investment is required and man-time requirements need not be substantial. The technique is designed to complement current snow measurement methods by providing spatial information on snow water content. Consequently it permits more accurate estimates to be made on a basin or subbasin basis. Normally, snow water content estimates are obtained directly from ground-based snow course or snow sensor measurements. The procedure described herein introduces a stratified double sampling approach that relates the ground-based estimates to snow areal extent data gathered from Landsat imagery. The resulting relationships enable low-cost remotely sensed data to statistically characterize the spatial and temporal variability of specific snow depletion environments sampled with ground snow course data. In this manner, satellite data can be used to determine the weight assigned to a particular snow course measurement and also to provide more frequent assessment of snow water content.

For determining snow areal extent, itself, this technique utilizes the Landsat-based procedure described in our Snow Areal Extent Procedural Manual as the remote sensing input. However, non-Landsat remotely sensed data types could potentially provide useful information to characterize the spatial variability, watershed-wide with respect to snow water content. For example, meteorological satellite data could be used with the Snow Areal Extent Procedure to provide more frequent (daily) information, although of lower spatial resolution, basin-wide. The technique can also be refined by the user, if desired, to include machine processing of the satellite data.

2.0 General Approach

The following provides an overview of the remote sensing-aided snow water content estimation procedure.

Sample Design and Measurement

A stratified double sample method is used to develop a basin-wide estimate of snow water content. Under this approach, snow water content information for the whole watershed, as obtained inexpensively on a sample unit basis from Landsat data is combined with that gained from a much smaller and more expensive sample of ground-based measurements at snow courses (see Figure 13). The result is a basin-wide estimate of snow water content based on Landsat data calibrated by regression on snow course data. Since much of the watershed snow water content variation is accounted for by information gained from the Landsat sample stage, an overall estimate of basin snow water content is possible at more precise levels than available for the same cost from conventional snow course data alone.

The sequential sampling/measurement process proceeds by first locating a sample grid over the watershed. Snow areal extent estimates are quickly made for each sample unit by manual techniques (See Snow Areal Extent Procedural Manual) for the previous snowpack build-up dates and then for the specific forecast date. The snow areal extent data is then combined by a linear equation to generate an index parameter that is correlated with snow water content information that is specific to the forecast date for each sample unit. This linear model is designed to reflect the relationship between snow areal extent and snow depletion behavior, and is specific to the watershed being studied. Some users may choose to develop more complex, physically realistic areal extent-to-water content transformations.

By specifying the precision and level of confidence desired in the basin-wide snow water content estimate and by considering measurement costs in relation to the available budget, one is able to calculate the necessary ground subsample size. Ground snow water content measurements are then allocated to Landsat-based snow water content-index classes (strata) according to weighted random stratified sampling procedures.

Regression relationships are developed between the Landsat snow water content index data and the ground snow water content measurements. These equations are then used to correct all Landsat-based data by ground values of snow water content. The ground corrected values of Landsat-based snow water content information in each stratum or class are added to give a total basin-wide estimate of snow water content, together with an associated precision statement.

STRATIFIED MULTIDATE LANDSAT DATA PLANE
CALIBRATED BY SNOW COURSE MEASUREMENTS
FOR WATERSHED SNOW WATER CONTENT ESTIMATION

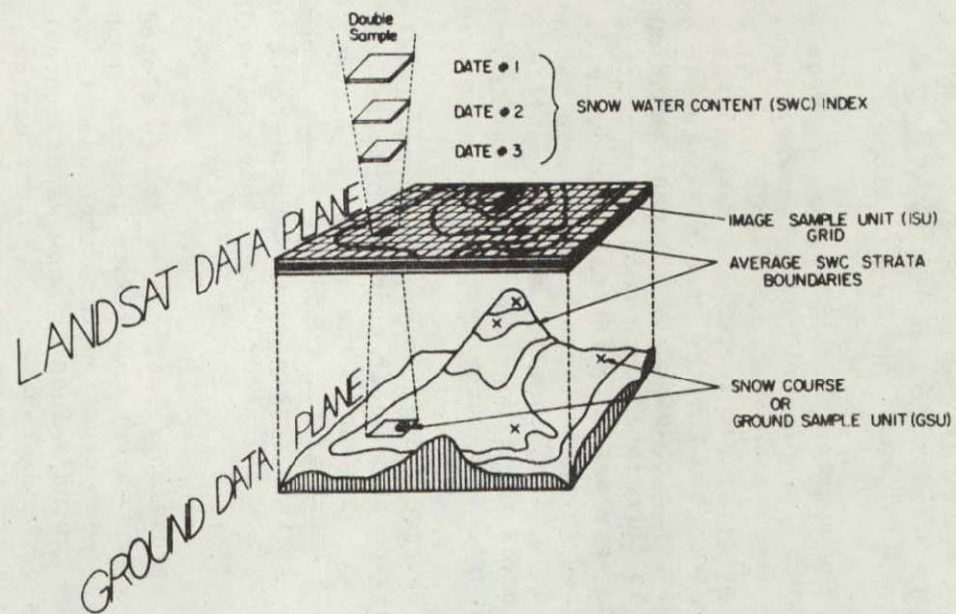


Figure 13. Stratified Multidate Landsat data plane calibrated by snow course measurements for watershed snow water content estimation.

Results and Their Applications

The Landsat-aided snow water content estimation procedure is designed to generate an estimate of total watershed snow water content and an associated statement of precision for a given forecast period. The estimate may then be related by regression equations directly to basin water yield for a given period. Or the statement may be used as another predictor variable in current snow survey or river forecast equations. Grid overlays, when placed either on watershed maps or directly on Landsat imagery, give a location-specific estimated snow water content index for each sample unit. Such information can be used to produce improved hydrologic modelling procedures incorporating this spatial data.

Performance Criteria

Performance criteria for this procedure consist of 1) the precision and accuracy of the estimate of snow water content over the watershed versus the cost of making the estimate, 2) the timeliness of the estimate; and (3) the value of any in-place map products of improved quality that can be produced through use of the procedure.

3.0 MATERIALS AND METHODS

The stepwise procedure for estimating snow water content with the aid of remote sensing is described below:

Step 1: An overall plan should first be developed which will facilitate adoption of the remote sensing-aided snow water content estimation procedure by the user organization. This implementation plan should consider (1) available budget, (2) requirements for either training or obtaining image interpreter(s), (3) type of products desired, e.g. watershed and/or sub-watershed estimates or in-place snow water content maps (4) performance requirements in terms of estimate precision and satellite image acquisition to forecast turnaround time requirements (5) interface of the snow water content procedure with current operational forecasting operations, and (6) startup equipment (stereoscope, photographic laboratory facility) and labor requirements.

Step 2: Color composites should be prepared from Landsat imagery and/or from other satellite imagery types, (e.g. weather service) and the appropriate image sample unit (ISU) grid should be placed over each watershed of interest. In the performance of this step, black-and-white Landsat transparencies should be obtained (e.g. from the EROS Data Center) and transformed into a simulated infrared color composite by a sample photographic procedure described in our "Snow Areal Extent Procedural Manual". In the color-combining process, an ISU grid is

randomly placed over each image so as to cover the watershed of interest. Watershed boundaries should be located on the satellite imagery from 1:250,000 scale U.S. Geological Survey topographic data via use of optical rectification devices (if available) or by manual transfer from map to image. A complete description of the boundary and sample grid overlay is given in the Snow Areal Extent Procedural Manual. Grids on all dates must be in common register. Square image sample units each 400 hectares in size, are recommended. This size is large enough to stabilize variance and small enough to give location-specific snow water content-related information at reasonable cost. The user may choose to modify these image sample unit dimensions as experience is gained with the estimation procedure.

Step 3: The snow areal extent should then be estimated for each Landsat ISU for previous season(s) or current season snow build-up dates. Each ISU should be interpreted, manually, as to its average snow areal extent cover class according to a snow environment-specific technique described in the Snow Areal Extent Procedural Manual. Previous dates of imagery used should include: 1) one of the images covering the average date of maximum snow accumulation in an average snow year; 2) at least one image from an early season snow date in the current snow season; and 3) if possible, another image from a date well into the snow season representing average snow distribution for that date. As will later be discussed in Step 5, these previous snow season images are used to maximize the correlation between the satellite-derived snow water content indices and ground measurements of snow water content for any given sample unit on the forecast date in question.

Step 4. Snow areal extent should be estimated by ISU for Landsat snow season forecasting date of interest, again using the procedure described in the Snow Areal Extent Procedural Manual. Length of the delay that can be tolerated between image acquisition by the satellite and imagery receipt by the user will depend on the use of the snow water content estimate. A very short turn-around times (hours) will be required for weekly or sub-weekly water yield forecasts, but longer times usually will be satisfactory for monthly or seasonal forecasts.

Step 5: Snow areal extent data should next be transformed to snow water content data by Landsat ISU. Snow water content is estimated from the following first order, time-specific model, designed to reflect physical snow depletion behavior in a given melting environment:

$$X_i = \sum_{j=1}^J (M_{ij}) (G_j) K_i$$

where X_i = estimated snow water content index for image sample unit i , correlated to corresponding actual ground snow water content data,

- M_{ij} = snow cover midclass point based on photo interpretation; expressed on a scale of 0.00 to 1.00 for image sample unit i on the j th Landsat snow season date,
- G_i = weight (related to snow depletion zone behavior characteristics) assigned (0.00-1.00) to a past M_{ij} according to the date of the current estimate,
- K_i = the number of times out of j that sample unit i has greater than zero percent snow cover, and
- J = total number of snow season dates considered.

The basic assumption of this simple model is that the greater the sum of areal snow extent over all dates used and the more often snow is present, the higher will be the expected snow water content. This model is most appropriate in mountainous environments. Each user may want to specify a more sophisticated, and more physically realistic model for his own watershed(s).

Definition of the weighting factor, G_j , will be watershed specific. Generally, weights should approach 1.00 as the dates of imagery approach the date of forecast. The justification of the weighting relationship is that successively more recent climatic events have progressively more importance in determining the actual snow water content on the forecast date in question. To insure reasonably high correlation between X_i and corresponding snow water content values, there usually should be at least three snow season dates considered ($j \geq 3$). Normally, one or two dates of Landsat imagery would be required during the early snow accumulation season. Occasionally, j may be only two, such as when the first date consists of an April 1st snow water map, based on the past year's Landsat data, and the second is the current early snow season date in question. In all cases the sample unit grids on all dates must be in common register with respect to a base date grid location. Starting initial weight suggestions are : 0.25 for the previous year image that is representative of an average maximum snow accumulation date; 0.50 for the early snow season date; 0.75 for dates occurring a month or two before the forecast date; and 1.00 for the forecast date and for all dates occurring within one or two months prior to the forecast date.

Step 6: The ISU's should next be classified and summarized into snow water content strata. Stratification is used to minimize the variance of the final snow water content estimate. Without prior experience on a given watershed, it is best to define two or three strata for first implementation. These strata can be defined by dividing the range of ISU snow water content index values over the watershed into two or three natural groupings (seen by plotting snow

water content index versus number of ISU's). If no natural groupings are present, then the range of ISU snow water content index values should be divided into two or three ranges having approximately equal numbers of ISU's in each stratum.

After each ISU has been coded as to its stratum, the number of ground sample units (GSU's) consisting of snow courses required to satisfy the precision user criterion (allowable error), as established by the user for the snow water content estimate, should be calculated by stratum. (The procedure which our group would consider most suitable for sample size determination on the ground is in the process of development).

Initial implementation of this procedure requires previous information regarding the variability, in each stratum, of the snow water content index, and also a determination of the correlation between ISU and GSU data, the total number of ISU's needed per stratum, and average ISU and GSU costs. This data is most efficiently gained by obtaining Landsat data for a previous snow season that was as similar to average as possible. Steps 1 through 5 should be followed for a mid-season snow date. The stratification portion of Step 6 should then be performed to classify ISU's into strata from which the total number of ISU's per stratum is immediately gained. The variance in Landsat snow water content index by stratum can then be calculated by the standard statistical formula for variance. Next, current ground snow courses and snow sensor locations should be determined relative to the given ISU in which they fall. The overall correlation coefficient between ground snow water content measurements and Landsat-based snow water content index values should then be calculated for the matched ISU's and GSU's. Additional correlation coefficients also should be determined for each stratum if a sufficient number (e.g. ≥ 10) of snow courses exist for each stratum.

Image preparation and interpretation costs should also be documented during this initial exercise. Labor, materials, and overhead costs should be documented on an ISU basis as in the example given in Table . Cost per GSU (snow course) measurement can be developed from the individual user organization's pre-existing data. All cost data for sample allocation should represent operational costs.

Step 7: For the first year of actual implementation, the calculated number of GSU's per snow water content index stratum should be allocated for given ISU's in those strata. This allocation should be based on equal probability selection from the tabular summaries of ISU's generated in Step 6. Consequently, ISU's should be numbered from 1 to N_h in a given stratum and a random number table (or calculator/computer analogue) used to select the calculated number of ISU's to which GSU's will be matched.

TABLE 1. EXAMPLE CALCULATION OF IMAGE SAMPLE UNIT COSTS FOR A LANDSAT-AIDED MANUAL SNOW WATER CONTENT INVENTORY¹

	<u>Total Cost</u>	<u>Cost per ISU²</u>
I. Pre-Inventory		
A. Image Acquisition		
3 LANDSAT dates with 3 bands per date @ \$3 per band; the costs of 2 of these dates amortized over 5 dates	\$12.60	\$.006
Resource Photography (Medium Scale Aerial Photography for Image Analyst Environmental Type Training)	\$14.29	\$.006 ³
B. Image Sample Unit		
Grided LANDSAT Color Composite Print Generation		
Film, Processing, and Printing		
3 dates @ \$11 per date		
The costs of 2 of these dates amortized over 5 dates	\$15.40	\$.007
Labor 0.5 hours per date @\$13.50/hr including overhead, 3 dates, the costs of 2 of which are amortized over 5 dates	\$ 9.45	\$.004

-
1. Cost data based on 1975 University of California figures.
 2. Cost per image sample unit assuming 2218 (780,000^{ha} test watershed) image sample units in the watershed(s) of interest.
 3. Two \$500 flights amortized over 5 years, 7 dates per year, and two watersheds.

TABLE 1 (continued)

	<u>Total Cost</u>	<u>Cost per ISU</u>
II. Inventory		
A. Interpreter Training		
1 hr per date, @ \$13.50/hr 3 dates, the costs of 2 of which are amortized over 5 dates	\$18.90	\$.009
B. Image Interpretation		
Ave. 6 hrs per date @ \$13.50/hr (2218 Image Sample Units)		
3 dates, the costs of 2 of which are amortized over 5 dates	\$113.40	\$.051
C. Data Key punching		
6 hrs per date @ \$13.50/hr; 3 dates, the costs of 2 of which are amortized over 5 dates	\$113.40	\$.051
D. Computer Analysis of Image Analyst Results		
0.075/hr @ \$40/hr	\$ 3.00	\$.001
E. Selection of Random Numbers to Define Ground Sample Units		
0.5/hr @ \$13,50/hr amortized over 5 dates @ \$13.50/hr	<u>\$ 1.35</u>	<u>\$.001</u>
TOTAL	\$301.79	\$.136

The snow course or sensor should be located in a snow accumulation and depletion environment representative of the average of such environments covered by the given ISU. If it is not efficient to reallocate an already established network of snow courses and sensors, then the snow water content stratum should be identified for each such ground unit by determining the stratum associated with the ISU covering that ground location. After several years of using this remote sensing-aided technique for snow water content estimation, the user may find it desirable from a precision (i.e. variance control) standpoint to reallocate some ground courses to achieve the optimum stratum-by-stratum GSU sample sizes calculated previously. However, before this is done, updated GSU sample sizes should be calculated using stratum-specific ground or image snow water content variance data averaged over successive seasons.

Step 8: Estimates of watershed or sub-watershed snow water content should be calculated, using the equation described in step 5. The values thus obtained should be entered into statistical or physical models to predict water yield. For example, the user could employ the remote sensing-aided snow water content estimate as an input variable in a regression equation for predicting water runoff.

Step 9: Finally, the utility of the above-described procedure for using remote sensing as an aid to estimating snow water content should be evaluated in meeting the water yield forecasting organization's legal or contractual requirements. Utility can be judged by new information gained (e.g. watershed physical relationships), forecasting accuracy or precision improvement, cost savings, or forecast timeliness. Information gained on the precision/cost effectiveness of the procedure and the sensitivity of the water yield forecast models to the resulting snow water content estimates can be used to:

- 1) refine the model (Step 5) used to calculate the snow water content index,
- 2) better define snow water content index strata,
- 3) generate better GSU sample sizes and allocation strategies, and
- 4) refine the actual snow areal extent interpretation and imagery enhancement and analysis procedures used in Steps 2, 3 and 4.

APPENDIX III

Procedural Manual Outline

REMOTE SENSING AS AN AID IN WATERSHED-WIDE ESTIMATION OF WATER LOSS TO THE ATMOSPHERE

I. INTRODUCTION

- A. Need for the data on evapotranspiration (Et) for water yield forecast models.
- B. Importance of evapotranspiration in agriculture, silriculture, reservoir operation, etc.
- C. Impact of remote sensing techniques in aquisition of required data for evapotranspiration estimation

II. OBJECTIVE

- A. Objective of this procedural manual
- B. Definition of terminologies used for maximum potential, potential, and actual evapotranspiration

III. MATERIALS AND METHODS

- A. General approach
- B. Multistage statistical sampling design
- C. Three information levels
- D. Required input data and data source
- E. Physical modeling of evapotranspiration

IV. EXPECTED RESULTS

- A. Areal distribution of input parameters to ET models
- B. Watershed-wide distribution of evapotranspiration based on level I models

V. IMPLICATION OF RESULTS

- A. Application of ET results in RFC hydrologic model
- B. Evaluation of RFC model output after using ET models results as a direct input
- C. Direct comparison of the ET models results with available conventional data on evapotranspiration

VI. CONCLUSIONS

- A. General conclusions
- B. Importance of remote sensing

VII. CASE STUDY

- A. Application of the methodology developed in this investigation to the Middle Fork of Feather River Watershed, Northern California

APPENDIX IV

Procedural Manual Outline

REMOTE SENSING AS AN AID IN WATERSHED -WIDE ESTIMATION OF SOLAR RADIATION

- I. INTRODUCTION
 - A. Need for the data on solar radiation components for evapotranspiration and hydrologic models
 - B. Impact of remote sensing in acquiring solar radiation data
- II. OBJECTIVE
 - A. Objective of this procedural manual
 - B. Definitions of terminologies used for several solar radiation components
- III. MATERIALS AND METHODS
 - A. Statistical approach
 - B. Required input data and data source
 - C. Physical modeling of shortwave and longwave radiation
- IV. EXPECTED RESULTS
 - A. Areal distribution of watershed parameters, i.e., boundary, elevation, slope, aspect, etc.
 - B. Watershed-wide distribution of net shortwave, net longwave, and net solar radiation
 - C. Implementation of net solar radiation data in hydrologic models
- V. CONCLUSIONS
 - A. General conclusions
 - B. Importance of remote sensing
- VI. CASE STUDY
 - A. Application of the procedure developed in this investigation to the Middle Fork of Feather River Watershed, Northern California

CHAPTER 4

REMOTE SENSING OF AGRICULTURAL WATER DEMAND INFORMATION

Co-Investigator: John E. Estes, U.C. Santa Barbara

Contributors: John Jensen, Larry Tinney,
Sue Atwater, Tara Hardoin

Chapter 4

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CHAPTER 4

REMOTE SENSING OF AGRICULTURAL WATER DEMAND INFORMATION

Co-Investigator: John E. Estes, U.C. Santa Barbara

Contributors: John Jensen, Larry Tinney,
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4.0 ABSTRACT

Agricultural water demand information for arid or semi-arid climates is important for effective water resource management. Remote sensing methodologies utilizing high altitude photography or LANDSAT imagery provide accurate, economic alternatives to conventional survey techniques. Manual and digital remote sensing techniques described herein are capable of producing information for semi-operational water demand predictions by California state and county agencies who must maximize the use of the finite amount of local, state, and federal water.

A Procedural Manual for using remote sensing to derive cropland information for water demand predictions is included in this chapter, beginning on page 4-14.

4.1 INTRODUCTION

Food and energy production are primary research frontiers for the future. A recent study by a major research organization predicts the following effects of world exponential population growth to impact mankind during the 1980 to 2000 period:¹

- * intensified landuse pressures and a growing list of critically short mineral resources will come into being
- * international trade of all types will reach a new high with particular increases in foodstuffs, minerals, and energy;
- * international cooperation in agricultural research and production will increase as the world seeks to maximize its ability to feed itself;

¹ The TERSSE study (Total Earth Resources Systems for the Shuttle Era); was conducted by General Electric for the National Aeronautics and Space Administration to identify high priority areas for the 1980-2000 time frame. Many of the findings in this study are based on an assumed population growth from 3.2 billion in 1973 to around 7 billion in the year 2000. General Electric Space Division: Definition of the Total Earth Resources System for the Shuttle Era (General Electric, Philadelphia, 1974) Vol. 3, p. 4.

government funded research and development coupled with the use of large scale modeling data banks will increase in societies such as the United States where government is expected to act as the catalyst to conduct resource ecological surveys.

In the United States, there is enough water to meet projected agricultural demands to the year 2000 given the amount of countrywide precipitation and groundwater supplies. A major problem, however, is that often this water is not where the demand exists² (see Figure 4-1). One response has been the development of large scale water transport projects. The State Water Project and All-America Canal in California, and the Welton-Mohawk Project in Arizona are recent prime examples of our technological response to such conditions.³ Another response is to drill more and deeper wells, essentially mining groundwater supplies.⁴ One has only to examine temporal LANDSAT images of the Colorado High Plains, Texas, Kansas, Nebraska, and the Dakotas to see the proliferation of center pivot irrigation systems mining groundwater in these areas.⁵

The effective management of inter-regional water transport and increased groundwater extraction is dependent upon accurate water supply and demand statistics at the regional, state, national, and even international level. The basic need for such information caused investigators conducting the TERRSE⁶ study for the National Aeronautics and Space Administration (NASA)

² U.S. Department of Agriculture: Recommendations on Prime Lands. (U.S. Government Printing Office, Washington, D.C. 1976), pp. 22-23.

³ Estes, John E. and Leslie W. Senger: Remote Sensing for Monitoring a Water Transportation Project - The California Aqueduct. Paper presented at the XII Congress of the International Association of Aeronautics and Astronautics (Baku Azerdaydzhai, USSR, 1973).

⁴ Falkenmark, M. and G. Lindh: "How Can We Cope with the Water Resources Situation by the Year 2015?" Ambio Vol. 3, pp. 114-122.

⁵ Bowden, L. W. (ed.), 1975. Manual of Remote Sensing, Vol. II, Falls Church, Va. American Society of Photogrammetry, pp. 1973-1978. Also see Poracsky, J., 1976, "Distribution of Center Pivot Irrigation Systems in Southwest Kansas," University of Kansas Center for Research, Inc., Tech. Rept. SAL-7606.

⁶ The basic criterion for the inclusion of a mission was that there be a reasonable change of the mission being performed during the 1980's time frame under consideration. Definition of the 30 missions were based on the following inputs to the study: 1) mandated tasks of Major Federal Organizations; 2) information requirements of the Other Dominant Organizations; and 3) assessment of the relative amenability of the information classes to remote sensing. On the basis of a review and evaluation of these inputs a list of 40 basic TERRSE missions was synthesized. General Electric Space Division, op. cit. (see Footnote 1 above), pp. 3-11.

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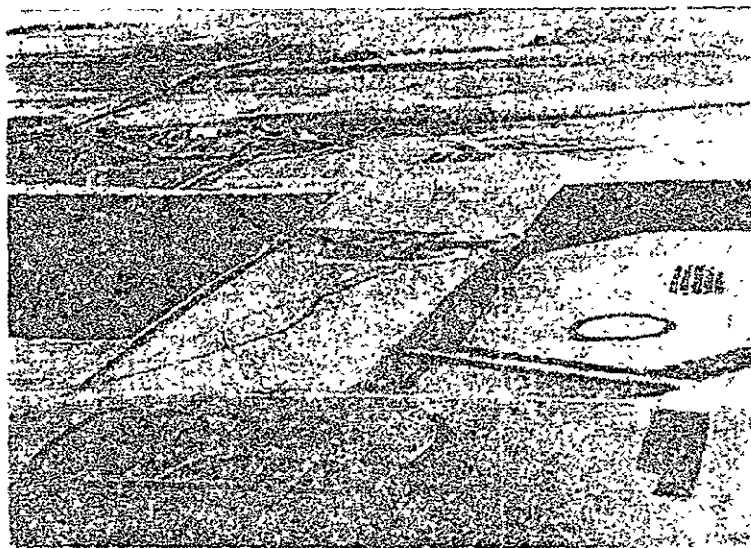


FIGURE 4-1. While the Pacific Northwest received its usual abundant rainfall in 1976, the midwest United States suffered a severe water shortage. South Dakota farmer Don Clelland, suffering through the long drought, took his case to a higher court. He plowed a plea for rain into a stubble field. (Associated Press Wirephoto in the Los Angeles Times, November 29, 1976, p. 1).

to identify two priority missions as:

- * Survey and inventory the volume and distribution of surface and groundwater to assess available supplies for urban and agricultural consumption.
- * Survey and monitor U.S. cropland to calculate long- and short-term demand for irrigation water.

Such information is incorporated into water supply and demand models which rely heavily on historical data and past trends in water supply and use.

The basic premise for utilizing remote sensing in acquisition of water demand information stems from the fact that several of the key parameters cannot be economically monitored on a seasonal or long-term basis without such technology. For example, water resource managers responsible for areas which are solely dependent on exotic water transported from other regions can easily predict next year's agricultural water demand by examining the present year's canal records. However, for areas dependent on both imported water and groundwater, managers have a difficult time assessing water demand because there is usually no way to accurately measure the amount of groundwater pumped. Consequently, canal records alone produce a serious underestimate of local water demand. If the aquifers being mined are continually lowering the water table, as is common in many western states, a serious overdraft situation may develop. Continuation of such practices could eventually lead to the regional depletion of an aquifer and subsequent loss of valuable agricultural production. Planned recharge of the aquifer through accurate long-term water demand predictions could rectify this situation. Remote sensing techniques can be used to inventory agricultural acreage. These data in conjunction with average irrigation rates can provide accurate multiple-year water demand predictions.

In the short-term, agricultural water demand information could be applied to seasonal intra-regional transport of water if a serious imbalance is identified in a geographic area. For example, a near real-time water demand estimate in May could alert water resource managers that new water demanding acreage has come into production in a region where previous groundwater mining had already lowered the water table. An administrative decision to acquire additional water from alternative sources could be made in order to maintain the groundwater level. An appropriate taxation schedule could also be applied to those users who continually mine groundwater and escape payment for transported water necessary to recharge the aquifer.

For several years prior to the TERRSE evaluation, NASA funded the University of California to develop remote sensing procedures to be used in

predicting water demand.⁷ University researchers interfaced with California's local, regional and state agencies to document the accuracy and cost-effectiveness of remote sensing aided agricultural water demand predictions. These studies have focused on the identification of critical water demand parameters which can be inventoried by high altitude and LANDSAT analysis techniques. A study area in Kern County, California will be used to demonstrate, in a step-by-step manner, the application of remote sensing techniques to water demand prediction.

4.12 Kern County, California Water Demand Study Area

California contains approximately one quarter of all the irrigated land in the United States and the irrigation of these 8 million acres accounts for more than 85% of the water used in California.⁸ The state leads the nation in agricultural production with a gross crop value over \$4 billion annually, with another \$2 billion in value-added by processing. These statistics provide ample testimony to the wealth producing ability of irrigated land in California.

As population figures continue to mount in this most populous of the 50 states, the water supply problem will be the same as it has been in the past; not of insufficiency, but maldistribution. About 75% of the state's precipitation and runoff occurs north of San Francisco, while about 75% of the need for and use of water occurs south of this point. The problem of maldistribution will continue to be solved by water transportation... and eventually coordination with large scale desalinization projects when this technique becomes economically viable with the costs associated with future import developments.

Kern County, California (Figure 4-2) is the second most productive agricultural county in the United States with an estimated value of direct farm marketing in 1975 of over \$744,000,000. Production is primarily dependent on the irrigation of about 926,000 harvested acres (374,000 hectares). Kern County consumed approximately 800,000 acre-feet of California Aqueduct water in 1975 at a mean cost of \$20 per acre-foot for the 16 county water districts (Figure 4-2B). Groundwater in excess of two million acre-feet,

⁷ Estes, John E., et al., "Water Demand Studies in Central California" in An Integrated Study of Earth Resources in the State of California Using Remote Sensing Techniques, Berkeley; University of California, Annual Progress Report, May 1976, pp. 3-10 to 3-23.

⁸ Irrigation Districts Association of California. California Water Resources Development (Irrigation Districts Association of California; Scaramento, 1975).

⁹ Ibid.

¹⁰ Stockton, James W., 1975 Annual Crop Report for the County of Kern. (U.S. Department of Agriculture, Bakersfield, 1976). pp. 1-8.

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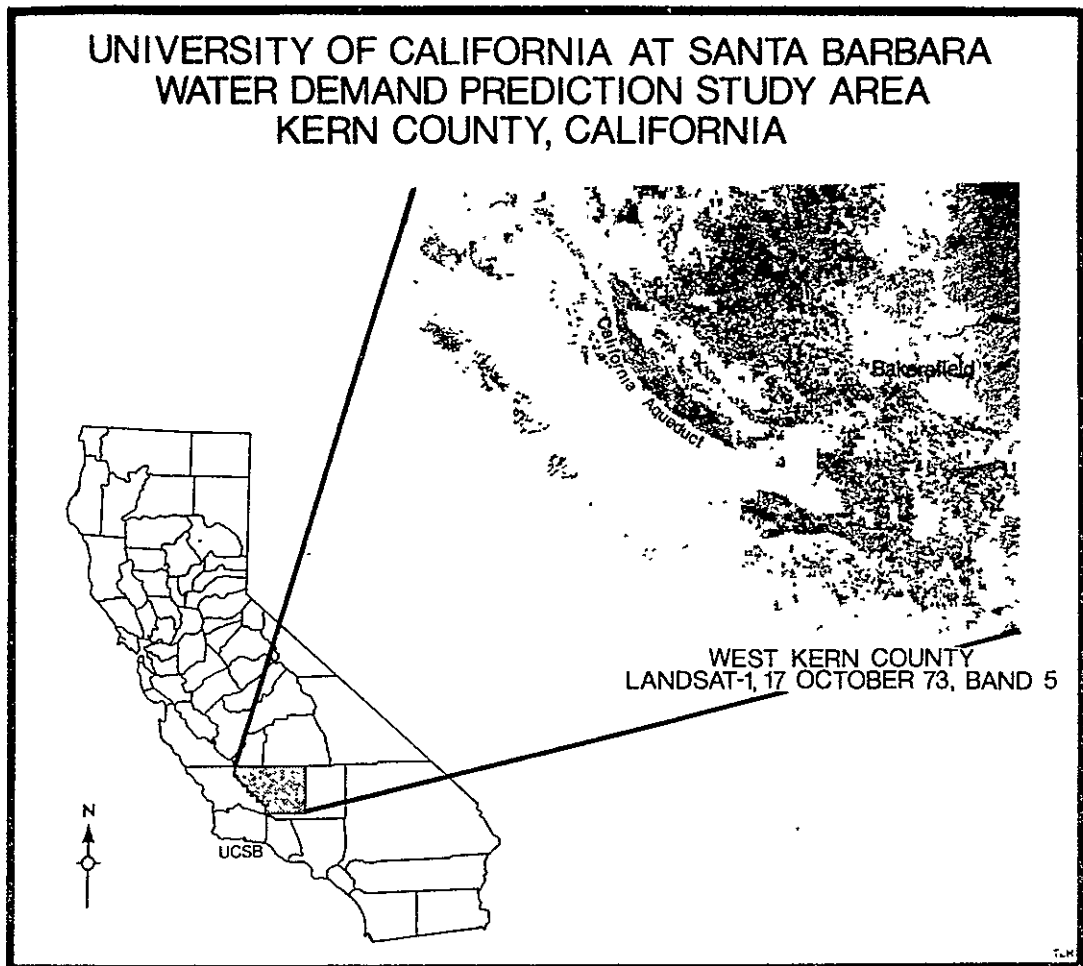
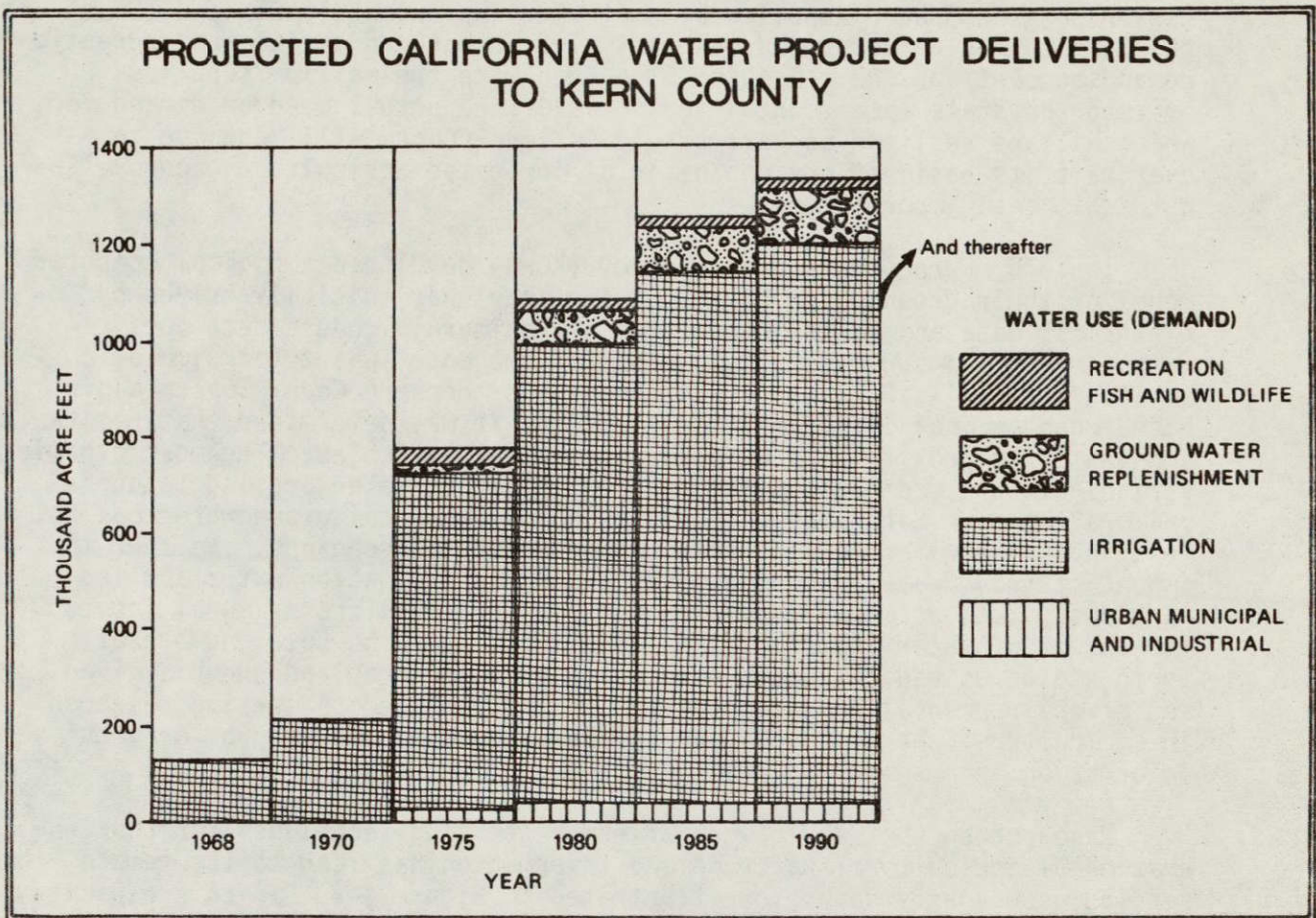


FIGURE 4-2A. The agricultural water demand prediction study area in Kern County, California. Situated in the semi-arid southern part of the San Joaquin Valley, it is the second most productive agricultural county in the United States.



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Figure 4-2B. Kern County consumed approximately 800,000 acre-feet of California Acqueduct water in 1975. 1990 projections indicate that irrigation water and groundwater replenishment will account for approximately 85 and 10% of the Kern County water demand, respectively. Urban-industrial and recreation account for the remaining 5 percent.

or four times that amount being imported by the state project, is extracted annually. Kern County's dependence on groundwater at rates exceeding a safe yield has resulted in a continuous decline of water table levels throughout most of the county.¹¹

Analysis of projected California Water Project deliveries through 1990 indicate that irrigation water applied to crops and water used to replenish groundwater supplies account for approximately 85% and 10% of the Kern County water demand respectively. Urban-industrial and recreation demands account for the remaining 5%. Even with the maximum supplies of imported state water contracted in 1990 (the actual need or demand for which will be realized as early as 1980) Kern County will continue to overdraft its basin if any expansion of irrigated agriculture occurs without additional importations.

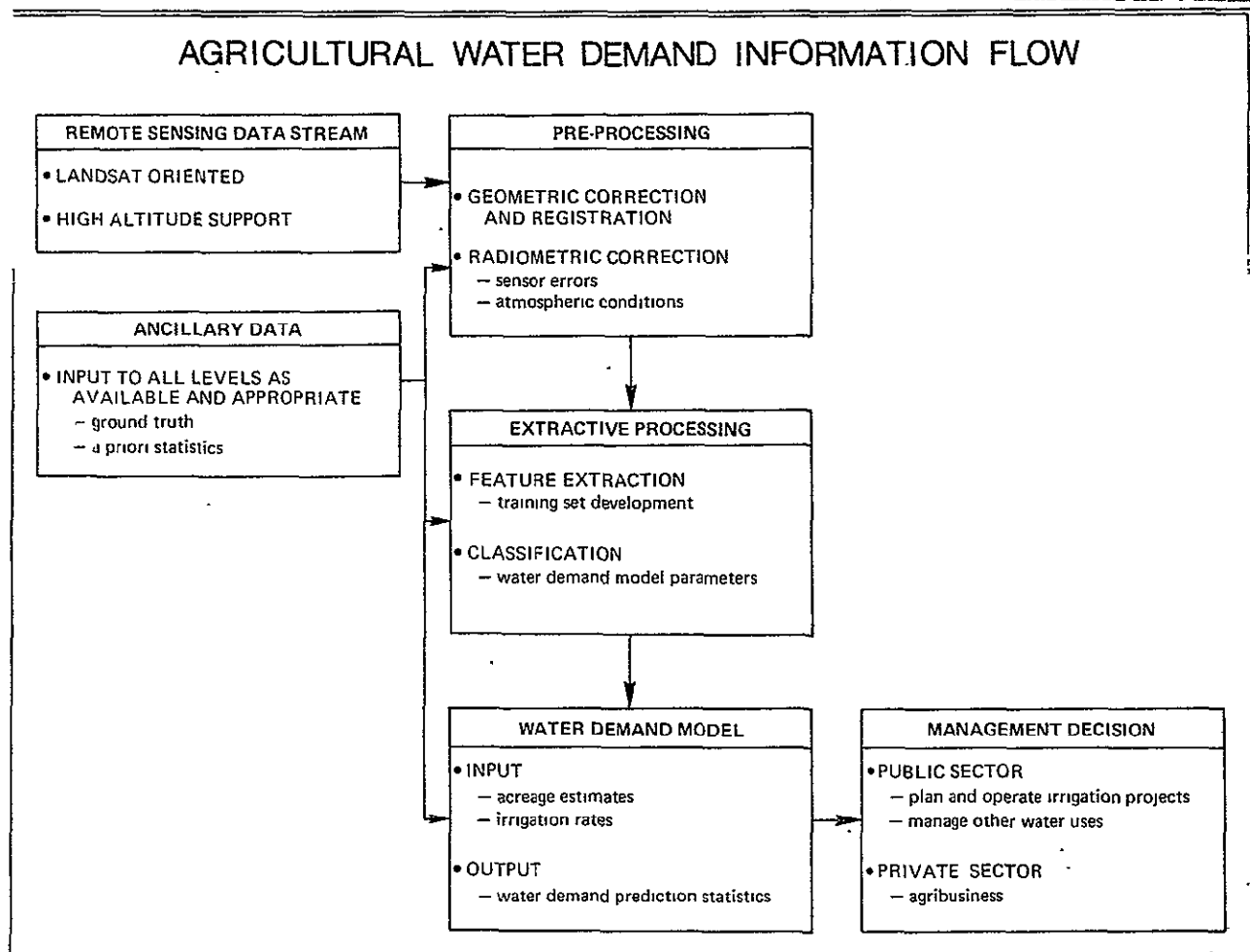
In 1970, Kern County Water Agency (KCWA) developed a digital computer model of their groundwater basin.¹² The model was initially driven by historical data and relied heavily on agricultural land use data derived from terrestrial surveys. The purpose of the model was total simulation of water transmission and storage throughout the Kern County water basin. Based upon an analysis of all model inputs, it was determined that remote sensing could provide data on several critical variables. The most dynamic variable in the model is the amount of irrigation water applied to agricultural lands. Water may either be pumped from local groundwater basins, lowering groundwater levels, or imported from other regions. Neither the amount of groundwater pumped nor the amount of irrigation water applied is known. Yet, accurate estimates for both are required as model inputs. The amount of water applied is best estimated from the total number of irrigated acres and the water requirements of the cropland under a given set of environmental conditions. The majority of remote sensing research in agricultural water demand modeling has been directed at providing this information.

Research on the development of remote sensing techniques for the generation of agricultural water demand information has led to the remote sensing-user agency data flow illustrated in Figure 4-3. In this capacity, remotely sensed agricultural acreage data (i.e. croptype, fallow, double cropping, etc.) are extracted primarily from LANDSAT and high altitude imagery. The irrigation rates from ancillary sources may be refined through remote sensing (i.e. croptype, pre-irrigation, salinity leaching requirements, etc.). These two data sets are then interrogated to yield the output irrigation water demand prediction statistics. These statistics are

¹¹ Kern County Water Agency, Annual Report - 1972 and 1973, KCWA, Bakersfield, 1974, p. 8.

¹² The Kern County Water Agency's groundwater model was developed by TEMPO, Center for Advanced Studies, Santa Barbara, California, a subsidiary of General Electric.

used by the user agencies to optimize water management decisions. The following section discusses how one should proceed to empirically identify the major components of agricultural water demand for a given environment. Subsequent sections describe in a procedural manner, the specific aspects of remote sensing-aided cropland and croptype inventories and the generation of water demand estimates. Cost estimates and equipment requirements are provided in Appendix I.



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Figure 4-3. A diagrammatic representation of data flow through a remote sensing water demand prediction system. Once user information requirements are defined, the remote sensing data stream is processed (pre-processing and extractive processing) in conjunction with ancillary data to provide acreage and irrigation rate estimates. These basic inputs into the water demand prediction essentially drive the model. Water demand predictions are then used in both the public and private management decision sectors.

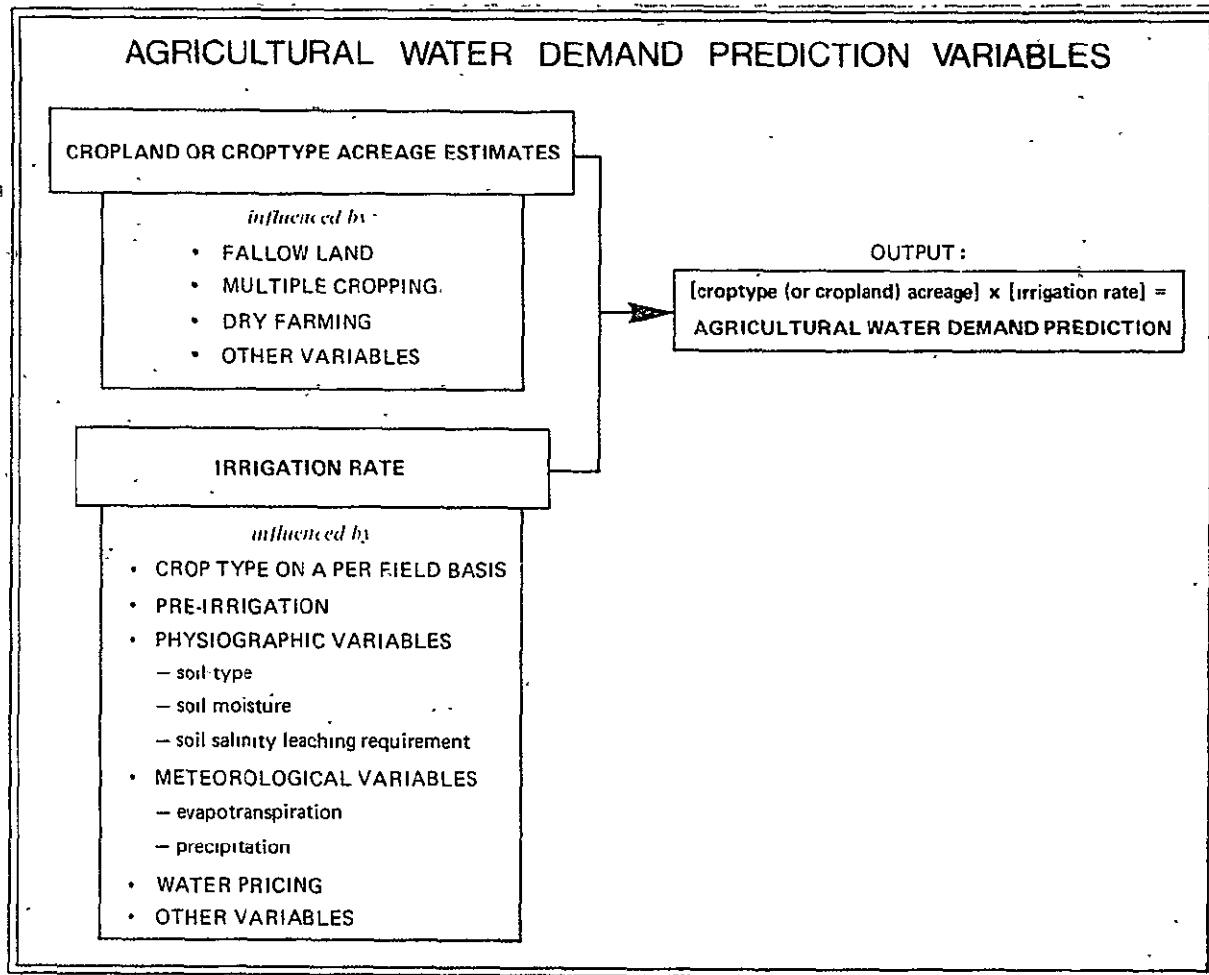
4.2 WATER DEMAND PREDICTION VARIABLES

4.21 Resolution of Prediction

Water demand predictions have both "spatial" and "temporal" resolutions, which means they pertain to a given area (a square mile, state, etc.) over specific time periods (monthly, yearly, etc.). In addition to spatial and temporal resolution, we may also consider a "categoric" resolution which specifies the level of information detail used in the classification scheme from which water demand predictions are derived, (e.g. irrigated vs. non-irrigated being general data, croptype data being more specific). The level of detail or specificity of a water demand prediction in each of these three dimensions will affect its utility as well as cost. In general, more specific data is both more useful and more costly. Planned and anticipated needs for water demand data should therefore be carefully examined on a case-by-case basis to match the resolution requirements of a specific application with appropriate procedures to acquire data at that detail. Spatial and temporal resolutions are usually well defined by the type of application. For example, water demand on a regional ten year basis may be adequate for general planning purposes while water demand on a yearly field-by-field basis may be required for specific canal routing or taxation purposes. Categoric resolution is usually governed by the need to achieve given accuracy levels. Even before specifying categoric resolution, however, it is necessary to select the appropriate categories or variables to be used in the water demand prediction. Figure 4-4 graphically illustrates those variables considered to be of importance to agricultural water demand prediction in the Southern San Joaquin Valley of California. It should be noted that there are two primary components of a water demand prediction, viz. acreage and irrigation rates. Each environment should be individually assessed in a similar manner when attempting a water demand prediction. Furthermore, it is necessary to perform this assessment in a quantitative manner, as will be discussed later using the Kern County example.

4.22 Kern County Example

In Kern County, California a need exists for yearly water demand data spatially aggregated to nodal polygons approximately three miles square. These data are used as input to a groundbasin hydrologic model. The total Kern County hydrologic system is both complex and dynamic. The KCWA groundbasin model must therefore incorporate detailed, yet relatively stable geologic information, in conjunction with constantly changing agricultural land use information. The most dynamic element of this system is the amount of irrigation water applied to agricultural lands. This water may either be pumped from local groundwater basins, with a negative impact on groundwater levels, or imported from other regions, thus potentially having a positive impact on local groundwater levels. At present, approximately 1,150,000 acre-feet of water is imported yearly through state and federal projects. However, since the exact amount of groundwater pumpage and irrigation water applied



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Figure 4-4. The range of variables considered to be of importance in determining agricultural water demand in the Southern San Joaquin Valley of California.

to the land is not known, accurate estimates for both of these quantities are required as model inputs. In areas where complete metering of groundwater pumpage is not available, as is common in Kern County, the total amount of applied water (i.e. demanded water) must be estimated by knowledge of irrigated acreages and water application rates. Even for this specific application there exists a wide spectrum of techniques which can be utilized to generate water demand predictions, as illustrated in Figure 4-5. These vary primarily according to the generality of the two primary inputs, i.e. acreage and application rate estimates. For the specific variables discussed in this report the two most extreme levels of input generality have been used. These levels entail irrigated cropland acreages and countywide average application rates for the most general approach, and croptype acreage and application rates as the most specific approach. It should be pointed out that the optimization of operational procedures may result in some intermediate approach.

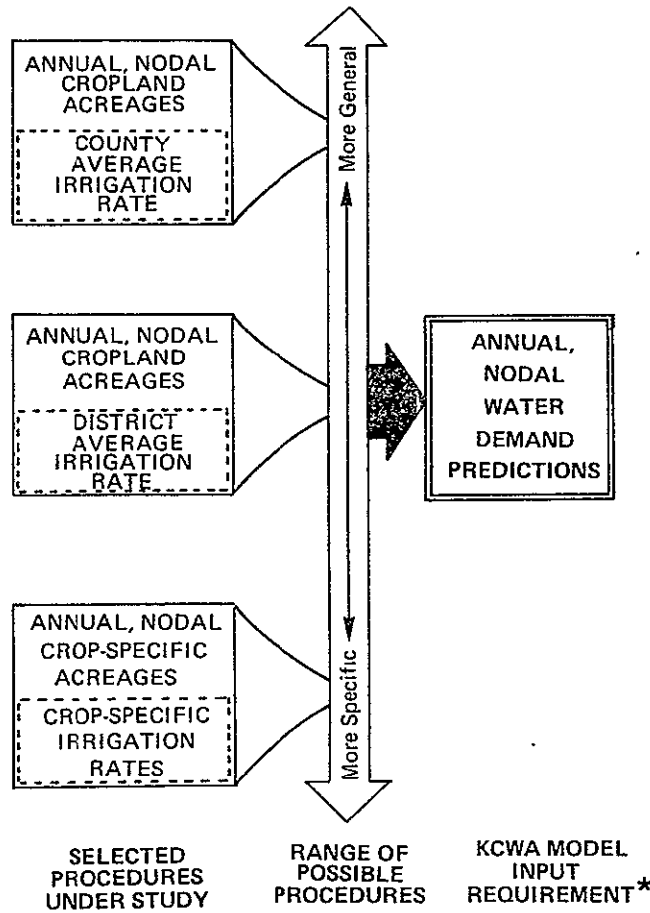
Given that the spatial and temporal resolutions have been defined (nodal, yearly) it is possible to proceed to quantitative assessments of the impact of each major variable (refer back to Figure 4.4 for listing). Four major variables have been investigated to determine their impact in a large water district (Wheeler Ridge-Maricopa Water District) of Kern County. These variables have been selected for study because of their anticipated importance and/or their amenability to study using remote sensing techniques.

Each variable, i.e. croptype, fallow land, pre-irrigation, and double cropping, has been individually investigated, to quantify the particular effect on the accuracy, of its inclusion or exclusion in a water demand prediction procedure. For most variables, the effect on accuracy has been quantified for both of the two basic prediction methods, one using cropland data and the other utilizing croptype data.

The variation in accuracy due to the inclusion or exclusion of a variable in a specific water demand prediction using *croptype* data is quantified by comparing nodal croptype water demand predictions to the same predictions which have been improved through the consideration of the particular variable. For the purposes of comparison, the improved croptype prediction is assumed to be 100% correct. The difference in accuracy is calculated as the percent error of the prediction which did not consider the variable being investigated.

The difference in accuracy due to the inclusion or exclusion of a variable in a water demand prediction using *cropland* data is quantified in the following process: 1) The unimproved cropland prediction is compared to the improved croptype prediction. The latter prediction, as before, is assumed to be 100% correct. If the two predictions are compared the resulting improvement in accuracy is due not only to the inclusion of the variable in question, but also to the inclusion of croptype data. In order to separate the improvement due to croptype data, it is necessary to make an additional comparison.

RANGE AND SPECIFICITY OF AGRICULTURAL WATER DEMAND PREDICTION PROCEDURES FOR THE KCWA GROUNDBASIN MODEL



*The Kern County Water Agency hydrologic model requires that the water demand prediction data be spatially accurate to at least the nodal (9 x 9 sq. mile) level.

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Figure 4-5. The range of procedures from general to specific which may be employed to estimate nodal agricultural water demand in Kern County.

2) If an improved cropland prediction is compared to an improved croptype prediction, the resulting difference in accuracy is due to the inclusion of croptype data only. If this percent accuracy value is subtracted from the percent accuracy value resulting from the first comparison (unimproved cropland versus improved croptype prediction) the resulting difference is the change in accuracy caused by the inclusion of the variable in a cropland water demand prediction. Results are presented in Table 4-1.

TABLE 4-1

Summary Ranking of Water Demand Prediction Variables Investigated to Date and Their Influence on Nodal Water Demand Predictions in the Wheeler Ridge-Maricopa Water Storage District

Rank	Variable	Prediction Procedure	District-Wide Mean Nodal Increase in Water Demand Prediction Accuracy Due to Inclusion of the Variable (%)	Range of Nodal Errors (%)
1	Fallow Land	Cropland	7.9	0-75
		Croptype	8.0	0-98
2	Croptype	Cropland vs. Croptype	6.3	0-90
3	Multiple-Cropping	Cropland	2.8	0-19
		Croptype	3.6	0-16
4	Pre-Irrigation	Cropland	2.8	0-20
		Croptype	3.3	0-29

One of the most interesting effects noted in Table 4-1 is that produced by fallowing practices (8.0%), which exhibits a somewhat larger impact on water demand prediction accuracies than croptype data (6.3%). Since fallow land usually receives no irrigation, the rationale for its large impact is simple; its inclusion from models will result in over-estimations equal to the irrigation rate otherwise assumed. Also of major importance are the errors attributable to the lack of croptype data, which will be equal to the difference between the assumed irrigation rate and the true crop specific irrigation rate. Both fallow and croptype data were found to have two to three times the impact on water demand prediction accuracies when compared to multiple-cropping and pre-irrigation data. Of even greater importance is the larger range of potential nodal errors (nearly 5 times that of multiple-cropping and pre-irrigation) which are possible when crop-

type and fallow land data are not included in a prediction procedure.

This research was conducted to identify, in a quantitative manner, the individual effects of several variables on water demand predictions. Analyses were completed on a nodal basis using both of the major data gathering techniques, i.e. cropland and croptype inventories. This research is proving useful for determining the specific types of information necessary for accurate water demand predictions. From similar ranked variable lists, water resource managers may be able to design an optimum data collection system for their respective regions by selecting those components most responsible for maximizing accuracy levels.

It is important to remember that these variables are not necessarily independent, and any prediction procedure may incorporate one as a subset of another. For example, a thorough croptype inventory would be expected to include all four components, i.e. croptype, multiple-cropping, fallow and pre-irrigation data. The summary Table 4-1 thus documents only the individual impacts associated with each data component and suggests what types of data should be obtained.

4.3 PROCEDURAL MANUAL FOR USE IN REMOTE SENSING CROPLAND INFORMATION FOR WATER DEMAND PREDICTIONS

4.31 Introduction

The purpose of the procedures discussed in the previous section was to identify those specific types of information that should be incorporated into a water demand prediction procedure to achieve a desired accuracy level. When studied in conjunction with the feasibility and costs associated with their acquisition it should be possible to develop cost-effective procedures that meet specific applications requirements. An analysis of major water demand variables and acquisition costs may indicate that an adequate prediction can be generated from cropland data alone or cropland data at some basic level of refinement, e.g. by identification and subsequent subtraction of fallow acreage or addition of multiple-cropped acreage. This section will detail those procedural steps necessary to accomplish a cropland inventory, using as an example a region located in Kern County. As one might suspect, practical means for economically predicting water demand cannot be developed in isolation from the environmental characteristics of the region to which they are to be applied. Each location will possess some unique characteristics that might significantly affect the acquisition costs for each specific type of water demand information. Some examples of these characteristics include: cloud cover conditions (both daily and seasonally); field shapes and sizes, crop assemblage and relative proportions of each type, phenologies for each crop, local cultural practices (e.g. harvesting techniques, etc.), possible stratifications of the region into more homogeneous sub-regions or "strata," and confusing "other" classes such as natural vegetation. Similarly, one cannot ignore the availability of various sources of remote sensing imagery, nor the suitability of each available type of

imagery for specific purposes. It is strongly recommended that a feasibility study or at least "trial run" of each procedure be accomplished before undertaking any single procedure on a large-scale basis. The following steps are therefore not offered in a rigid procedural format but rather act as a conceptual ordering of stages that should be undertaken only after all the interrelated aspects are properly understood.

4.32 Procedure

Step 1. Acquisition of Suitable Imagery: Acquiring suitable imagery is perhaps the most critical aspect of remotely mapping cropland acreage. Flying and developing costs associated with single purpose aircraft missions for croplands mapping often are prohibitively high. In addition to satellite imagery, several alternatives exist, including the acquisition of multi-purpose photography on a cost-sharing basis with those who might find such photography useful for other purposes. Care should be exercised, however, to ensure that such photography would adequately meet the requirements for cropland mapping. Some sources of multi-purpose photography are:

- * Commercial firms that photograph large regions on a routine basis (e.g. yearly)
- * NASA high altitude photography flown for various research institutions
- * Various other service agencies (e.g. in the United States these include USDA-SCS and -SRS) that systematically inventory crop, soil, or water resources.

In assessing the value of these sources one should examine and weigh their relative merits on each of several grounds including:

1. The time frame for availability of the imagery (e.g. is it available monthly, annually, or only every five to ten years?). A crop calendar is helpful in matching availability to temporal requirements on a monthly or seasonal basis (crop calendar development is deferred here until the following section dealing with crop-type identifications).
2. The suitability of the scale and spatial resolution characteristics of the imagery for extracting needed cropland information.
3. The spectral characteristics of the imagery.
4. The costs associated with acquisition of the imagery.
5. The probability that continued acquisition of suitable imagery will be possible in the future, if needed.

Regardless of the source of the imagery, photographic transparencies are preferable to prints for the techniques discussed herein because of their high resolution characteristics. Figure 4.6 shows an example of multi-date LANDSAT multispectral imagery.

- Step 2. Acquisition of a Suitable Base Map: A photogrammetrically controlled (i.e., spatially accurate) base map is required to ensure that reliable croplands acreage statistics can be obtained from the mapped data. An accurate base map also ensures that information gathered in one year can be directly compared to that of other years. This map should include any features that will aid in the visual transfer of information from the imagery to a map, such as rivers, aqueducts, roads, and survey networks.

There are usually several sources of suitable base maps, most of which are governmental. Within the United States, examples include statewide planning agencies and various county departments such as assessor offices, water agencies, transportation departments, etc. The United States Geological Survey (USGS) topographic maps or their equivalent, especially those of scales smaller than 1:24,000, provide a nearly ubiquitous nationwide base map source. Figure 4-7 is an example of a base map for Kern County.

- Step 3. Production of a Work Copy: A work copy of the base map should be drafted or photographically created on frosted acetate or similar translucent material. This copy of pertinent base map features must be capable of accepting pencil annotations because croplands data to be acquired by image analysis will need to be annotated directly onto this copy. The purpose of the base map features (such as roads, etc.) is to allow simple orientation between the imagery and this work copy.

It is very useful to match the scale of the photography to that of the work copy. This allows the visual transfer of cropland detail to be accomplished with relative ease by direct overlay of the translucent map onto the photography. Standard tracing or lighted drafting tables provide the necessary illumination for examining the photography through the translucent base map.

If photographic prints must be used, either the work map needs to be nearly transparent, in which case pencil or even ink annotation is difficult, or other means must be used for simultaneously examining the work map and the photography. Various devices are available for this task, ranging from simple mirror stereoscopes to sophisticated optical transfer scopes.

- Step 4. Selection of a Suitable Classification Scheme and Subsequent Image Interpretation: In developing such a scheme, the photo interpreter usually will need to work out with the potential user of the croplands map a compromise between (1) that which the user considers ideal for his purposes, and (2) that which the photo interpreter finds is consistently identifiable on the imagery which he must interpret. In some instances the development of a

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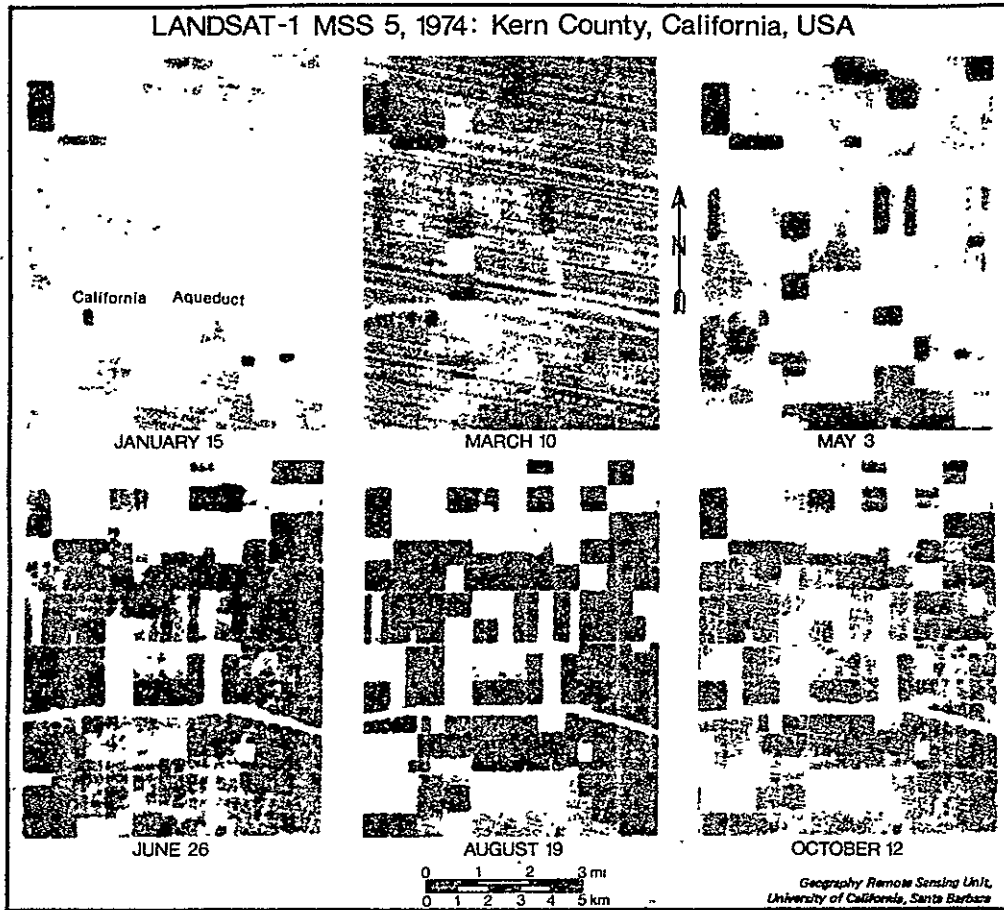


Figure 4-6. Six date sequence of LANDSAT-1 MSS band 5 imagery for a test site in Kern County, California. In this imagery healthy vegetation appears dark.

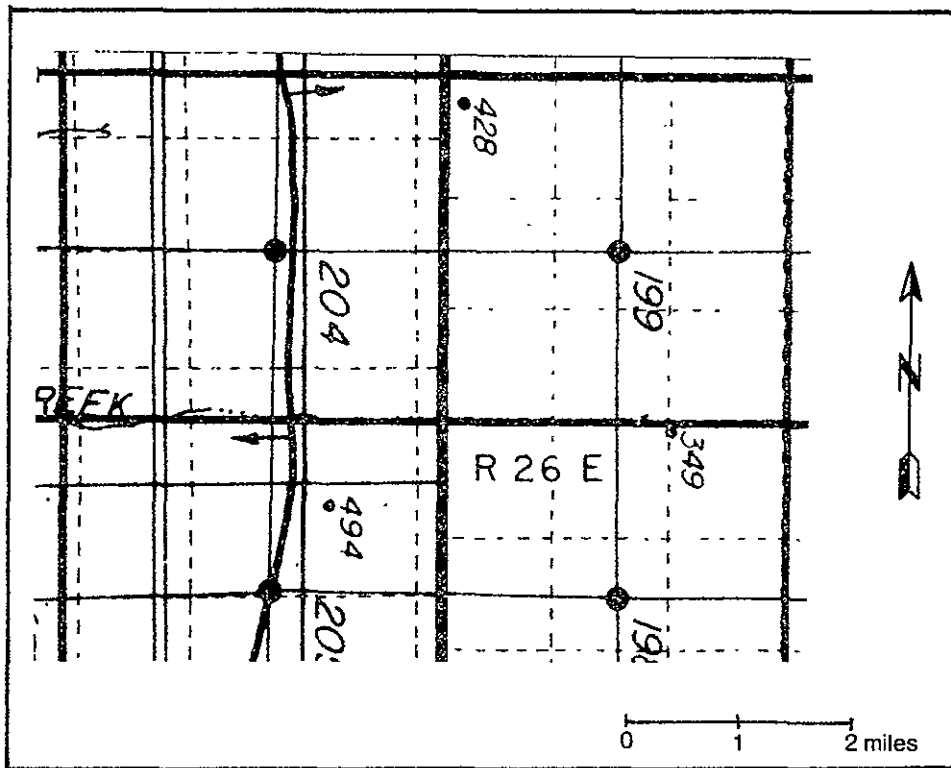


Figure 4-7. Pertinent detail in basemap, such as survey network, roads, canals, etc., allows rapid correlation of image information to a planimetric base. (Source: Kern County Water Agency — Polygonal Zones and Node Points.)

photo interpretation key to the classes that are to be identified should be undertaken at this point.

In those instances in which preliminary tests show that the necessary crop classification can be done from (multidate) LANDSAT imagery, great cost savings usually can be effected by the use of such imagery. Several approaches are available for the interpretation of croplands data from LANDSAT imagery. The approach followed will govern the amount and type of imagery acquired, type of work copy used, and image interpretation procedure. It has been found in numerous tests that mapping accuracies usually can be maximized by taking full advantage of sequential LANDSAT overpasses. When an adequate number of images are involved (such as monthly throughout the growing season), highest accuracies seem possible using a simple dichotomous decision rule: i.e., on any given date of imagery, an actively growing crop is or is not visible. A significant advantage of this binary decision rule is that fallow or abandoned land can be removed from active cropland status. Fallow land, especially, is nearly impossible to identify on single date inventories. This simple dichotomous procedure requires only one LANDSAT MSS band, i.e., band 5, taken in the red spectral region (.6 to .7 μm). The combined orbits of LANDSAT's 1 and 2 presently offer the potential of 9-day coverage cycles, or approximately 40 imaging dates per year. The availability of such a large amount of coverage requires that a catalog be maintained of all available imagery. Microfilm browse files and a computerized geographic search service are available from the USGS Earth Resources Observation System (EROS) Data Center, Sioux Falls, South Dakota, and elsewhere. NASA publications are also available that specify geographic coordinates and image characteristics for each LANDSAT image created. These sources should be examined to determine frame number, cloud cover, and overall quality of each potential image. As with photography, LANDSAT image transparencies are generally preferable to prints for the techniques described herein because of their higher resolution.

When LANDSAT imagery is to be used, the scale and material used for the work copy will be dependent upon the technique used to transfer information (from image to map) and the interpretation scheme. Standard 1:1,000,000 scale LANDSAT imagery will, of course, require an 8X enlargement if 1:125,000 scale work maps are used. If the imagery is enlarged to 1:125,000 a frosted acetate work map is suitable since, as previously discussed, it is translucent and will accept penciled annotations. This work map can be placed upon the imagery and interpretations directly annotated upon the acetate. Alternatively, opaque material can be used for the map if other means are involved in correlating the image to map, such as a mirror stereoscope or optical transfer device.

When croplands information is being interpreted from LANDSAT imagery, the primary interpretive cues are grey level (or color if color composites are used) and field shape. In many regions, including the western two-thirds of the United States, for example, the interpretation and transfer tasks

are facilitated because field shapes are usually rectangular and in alignment with a systematically surveyed grid network. If the multidate MSS band 5 dichotomous procedure is used on any given date a field is classified as being "cropland" if it appears dark on MSS band 5 imagery on that date, indicating healthy vegetation. With some training the interpreter should be able to accurately distinguish between vegetated fields and natural vegetation, the former usually appearing more uniform and darker in tone than the latter. Since several images may be involved in each inventory it is necessary to verify and annotate each field as to its cropland status. It is sometimes best to begin a new work copy for each inventory. If possible, this work copy should indicate the previous status of all fields to assist the interpretation of questionable fields. Interpreters making use of color composite imagery should become familiar with all distinguishing stages of agricultural fields. These stages include freshly plowed, young crop, mature crop, dry crop (e.g., barley near harvest), defoliated crop (e.g., cotton), and stubble or burned-over conditions. Irrigation activities may also be noticeable on LANDSAT imagery during young crop stages.

Step 5. Interpretation of the Photos and Annotation of the Base Map: These two tasks usually are accomplished in concert. Since the tasks need to result in the production of accurate croplands information, they should be accomplished by someone familiar with both the agricultural region and type of photography being used. While the work performed in this step typically is the most time-consuming, it merely employs the classification schemes and implements the procedures that have been described in the previous step. When several inventories are to be performed over a period of years different colors can be used to distinguish one inventory from another. In this manner it is not necessary to completely redo each successive inventory. The work copy of the croplands map can be placed upon new photography, in which case only changes need to be annotated. This procedure allows for the simple production of change maps which depict only the changes in cropland acreage between any two inventory periods. Five or six inventories can be easily distinguished by proper color choice.

Step 6. Production of the Final Copy of the Cropland Map: Usually this copy should be made on drafting paper. It should have inked features and be suitable for blue-line reproductions. An adhesive tone/pattern in the form of "press transfer" material can be used to delineate all cropland acreages. This material can simply be removed if the land should revert to non-cropland status. Updates of this map require only the addition or removal of pattern to those regions where the photo interpreter detects change. The legend of the final copy should clearly indicate all photography and/or imagery used in the composite cropland. Figure 4-8 is a final copy croplands map made from the six dates of LANDSAT imagery shown in Figure 4-6. Figure 4-9 is a final copy croplands map for the entire San Joaquin Valley portion of Kern County.

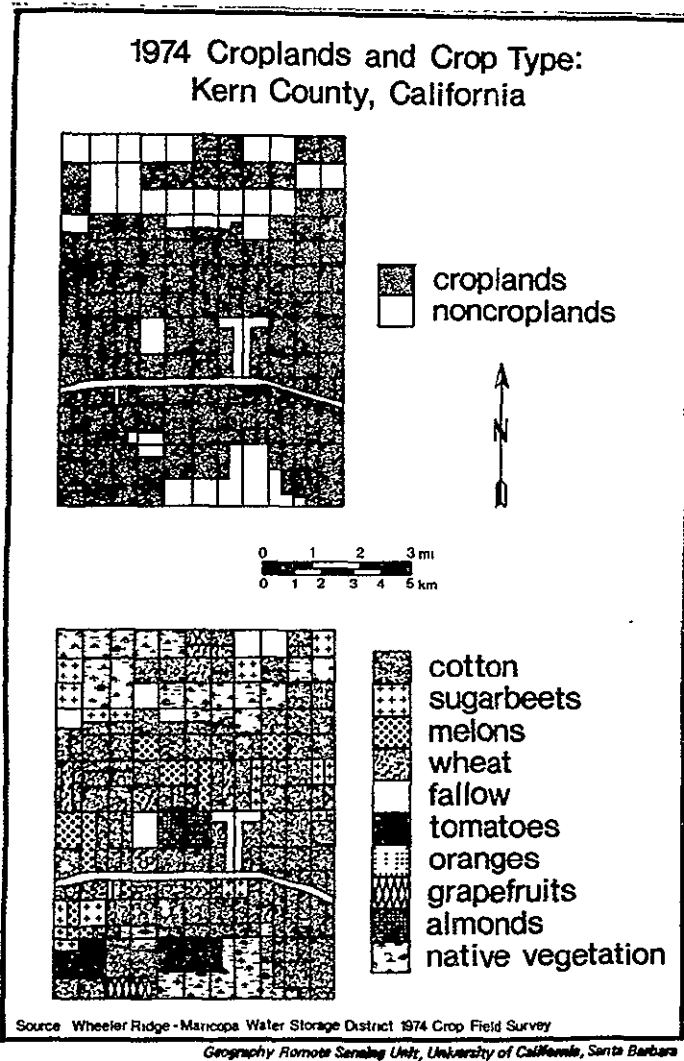
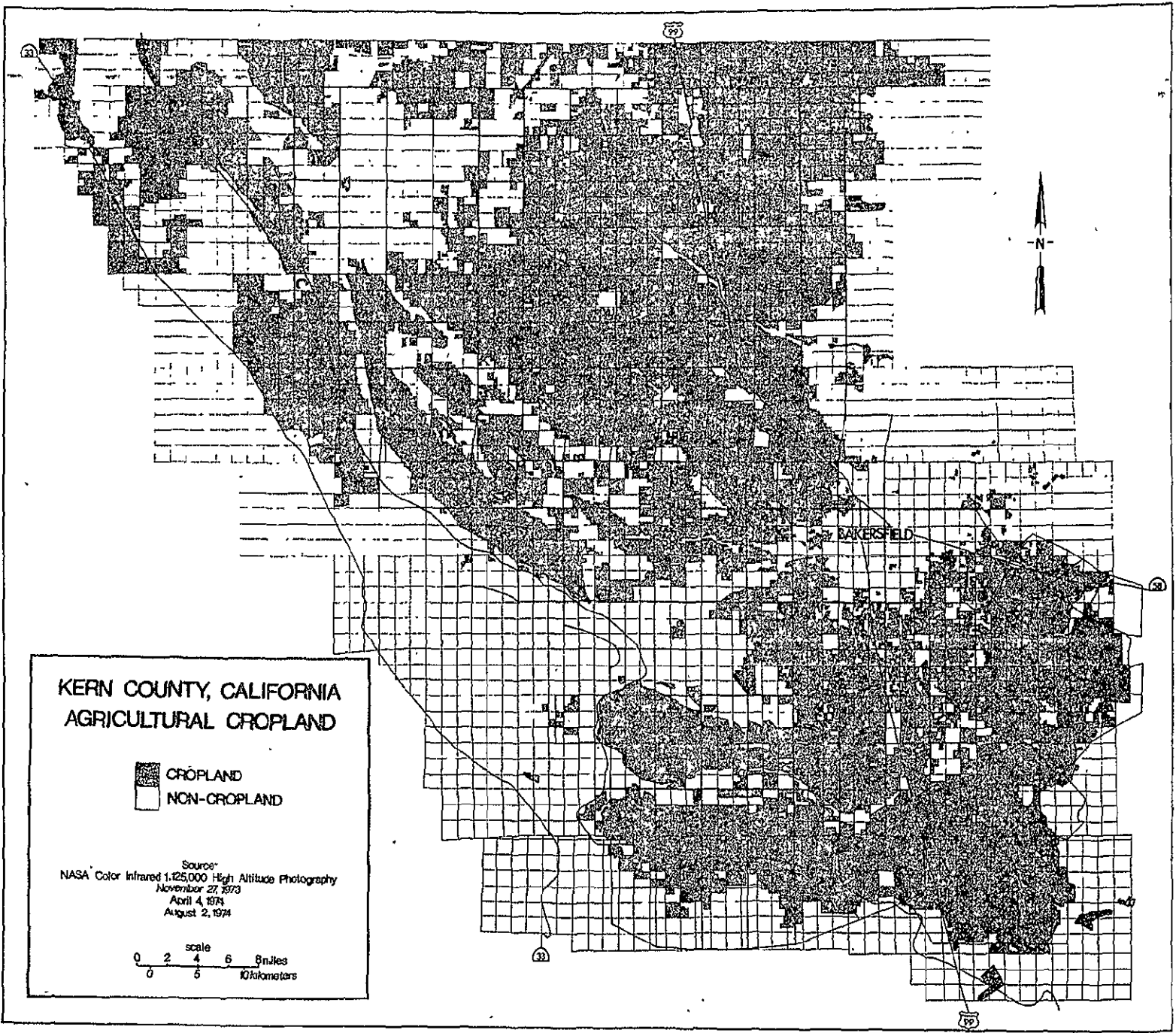


Figure 4-8. Upper portion is croplands data as interpreted from LANDSAT imagery in Figure 4-6. Lower portion shows same area as inventoried by field procedures, i.e. "wind-shield" survey.



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Figure 4-9. San Joaquin portion of Kern County as interpreted from multirate NASA high altitude photography. Original scale is 1:125,000.

- Step 7. Production of Various Reproduction Copies, as Required: It is usually desirable to produce several blue-line copies of each inventory. One should always be designated as the archive copy, since the final copy is continually updated. If it is necessary to produce a large number of copies, it is preferable to create a photographic transparency of each update; this transparency can serve both as an archive copy for future reference and as a master from which all blue-line copies can be made, thereby saving the original. Photographic reproduction can always be used when it is necessary to enlarge or reduce the scale of the inventory map.
- Step 8. Proceed to the Making of Subsequent Analyses, as Appropriate: Obviously a cropland map should rarely, if ever, be regarded as an end in itself. The ultimate usefulness of the procedure that has just been described normally will be found in the extent to which it facilitates, among other things: (A) the estimation of water demand, month-by-month and year-by-year, as imposed by those agricultural crops within the project area that are in need of irrigation; (B) a general approximation of agricultural yield in each portion of the area; and (C) the development of intelligent plans for future land use.

4.4 REMOTE SENSING CROP SPECIFIC INFORMATION FOR WATER DEMAND PREDICTIONS

4.41 Introduction

For many purposes it is not sufficient merely to determine, field-by field, whether crops are being grown. Instead, there is a need to know the specific type of crop. In contrast to the relatively simple croplands mapping procedure just discussed, crop identification requires a great deal of training and optimizing to maximize accuracies. On the plus side, crop-specific information allows more accurate water demand predictions and can be used in a greater variety of applications (such as agricultural reports, etc.). Axiomatically, the potentially wider audience increases the possibility of cooperative ventures to obtain such data.

The procedural manual will describe the following remote sensing approaches to obtaining crop specific information:

- (A) Manual interpretation of multidate High Altitude color infrared photography (1:125,000) and enlarged LANDSAT (1:125,000) color composites.
- (B) Digital classification of multidate LANDSAT computer compatible tapes (CCTs) using LARSYS¹ image processing software.
- (C) Digital classification of multidate LANDSAT transparencies using a point densitometer and standard statistical analysis software.

These techniques represent a continuum from manual interpretation (A) requiring very modest resources, to the digital CCT method (B) which requires substantial hardware and programming expertise. The digital crop identification procedure based on manual point densitometer readings (C) is an intermediate alternative available to those with access to modest densitometric equipment and standard statistical software packages. An agency should select that procedure which is most compatible with existing data requirements and agency resources. For the purposes of this procedural document, both the manual (A) and digital CCT method (B) are applied to a common 54 square mile study area in the Wheeler Ridge-Maricopa Water Storage District of Kern County, California. For comparative purposes the techniques are applied to similar temporal data sets.

¹ LARSYS is an acronym for a pattern recognition program developed by the Laboratory for Applications of Remote Sensing, Purdue University, Indiana.

Since these techniques require several of the same procedural steps it is instructive to analyze the procedures in unison. The last technique (C) based on point densitometry will be discussed separately.

4.42 Manual (A) and Digital CCT (B) Crop Identification Techniques: Image Inventory, Assessment, Acquisition and Formatting

Image Inventory: The cataloging of available imagery takes on added importance when specific crop identifications are undertaken. Final classification accuracies are very dependent upon the dates of imagery used since interpretations usually rely both upon the timing and sequence of stages that a field undergoes. In some instances imagery must be acquired during a limited time period when two otherwise indistinguishable crops may be correctly discriminated. The acquisition of both high altitude photography and LANDSAT imagery should first begin with a geographic search of EROS Data Center's image files. For example, for the 1974 growing season a search would provide most of the information shown in Table for the Wheeler Ridge-Maricopa study area.

Suitability and Acquisition: The suitability and subsequent purchase of imagery should be evaluated in terms of percent cloud cover, spectral and spatial resolution, and particularly the phenological make-up of the crop assemblage. If possible, a "browse" file should be consulted to view tentatively selected LANDSAT imagery. If this is not possible, a single LANDSAT channel from each date in transparency format aids in the selection of CCT's. For the high altitude photography, there is practically no way to detect cloud cover, color balance, or vignetting problems prior to the actual purchase.

Examination of Table 4-2 reveals that, for the Wheeler Ridge study, the LANDSAT digital CCT's were selected so as to be comparable with the high altitude data set. As these dates are spaced at approximately four-month intervals throughout the 1974 growing season they represent a reasonable first-cut at multidate crop identification for the crop assemblage in the Southern San Joaquin Valley. A more rigorous method of selecting optimum LANDSAT channels for crop identification is introduced in the section on manual densitometry/digital classification.

Format: The high altitude color infrared photography and LANDSAT color composites (bands 4, 5, and 7) are purchased in positive, hard copy format for the manual crop identification procedures. An alternative approach for the creation of the LANDSAT color composites is to color combine the three channels either optically or photographically.

For the LANDSAT digital analysis the multidate CCTs must be geometrically rectified so that each date is mutually congruent with other (see Figure 4-10). This processing requires substantial image processing software. In this instance the Jet Propulsion Laboratory's VICARS software

Table 4-2. 1973 AND 1974 HIGH ALTITUDE AND LANDSAT IMAGERY

Available for the Wheeler Ridge-Maricopa Test Site

<u>LANDSAT</u>				
	<u>Date</u>	<u>Band Quality</u> **	<u>Cloud Cover</u>	<u>Suitability</u> ***
1.	11/04/73*	P P P P	10%	good
2.	11/22/73	G G G G	70%	unusable
3.	12/10/73	G G G G	10%	unusable
4.	12/28/73	G G G G	50%	unusable
5.	1/15/74	P P P P	0%	good
6.	2/02/74	P P - P	10%	good
7.	2/20/74	P P P P	0%	good
8.	3/10/74	P P P P	40%	good
9.	3/28/74*	P P P P	60%	unusable
10.	4/15/74*	P P P P	10%	good
11.	5/03/74	G G G G	70%	good
12.	5/21/74	P G P P	0%	good
13.	6/08/74	P G G G	30%	good
14.	6/26/74	G G G P	0%	good
15.	7/14/74	P G G G	40%	not advisable
16.	8/01/74*	G G P G	40%	good
17.	8/19/74*	P P P P	10%	good
18.	9/06/74	P P P G	40%	good
19.	9/24/74	G G G G	50%	good
20.	10/12/74	G G P P	30%	good
21.	10/30/74	- - - -	n.a.	no listing
22.	11/17/74*	G G G -	40%	unusable
23.	12/05/74*	P P P G	10%	good
24.	12/23/74	F F F F	10%	good

HIGH ALTITUDE

	<u>Date</u>	<u>Photographic Quality</u>	<u>Cloud Cover</u>	<u>Suitability</u>
1.	11/27/73*	G	0%	good
2.	4/04/74*	G	0%	good
3.	8/15/74*	G	0%	good
4.	12/06/74	F	0%	good

* Indicates CCTs or high altitude photography purchased.

** MSS bands 4, 5, 6, and 7 respectively. Quality codes are

*** Suitability in terms of cloud-free test site coverage.

G = good

F = fair

P = poor

- = not available

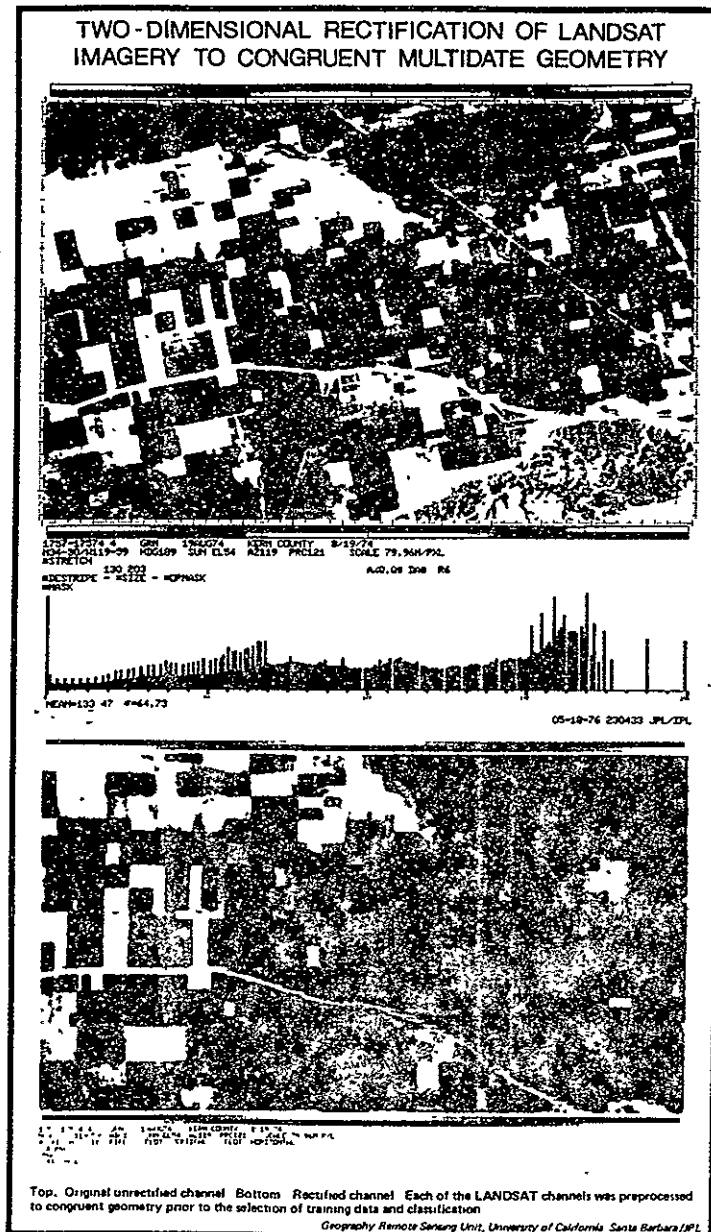


Figure 4-10. A comparison of unrectified (top) and rectified (bottom) Landsat images of the same area. For further explanation, see text.

was used to contrast stretch,¹ rectify, and in some cases spatially filter (fourier) the image (Figure 4-11). If image rectification is not possible, single date classifications might be attempted. However, satisfactory single date results are possible only if great care is taken in the evaluation of crop cycles.

4.43 Manual (A) and Digital CCT (B) Crop Identification Techniques: Ground Truth, Field Boundary Overlay and Crop Phenology Information

Ground Truth: A limited amount of field verified crop information is required for remote sensing crop identification procedures. This information is used to "train" the manual interpreter or digital classifier concerning the crop signatures in a specific region. It may also be used to assess "test" field classification accuracies.

When available, one should try to obtain the field verified data from existing sources. For our example, the Wheeler Ridge-Maricopa Water District provided 1974 spring and fall crop maps compiled for district planning purposes. These inventories were conducted by district personnel using standard terrestrial survey techniques. Based upon an analysis of this data in conjunction with the high altitude photography the study area was subdivided into three parts: a training area, an adjacent primary test area, and a more distant secondary test area for signature extension tests. The primary and secondary test area boundaries coincide with the 9 square mile "nodal" units of the KCWA hydrologic model. Specifically, the primary test area encompasses model nodes 197, 205, and 206 and the secondary test site encompasses nodes 198, 199, and 204 (see Figure 4-12).

When conducting ground truth surveys, limiting factors such as time and money usually preclude a complete inventory. Obviously, if it were economically possible to make a complete check there would be no need to use remote sensing to collect data. Sampling eliminates the necessity of doing a complete field check. It reduces costs, increases speed, and improves the accuracy of the limited amount of training and test data required. Obviously, such estimates are subject to error. Representative sampling errors must be small and the sample unbiased to achieve accurate results. When sampling a new environment of unknown characteristics the most reliable procedure is one which relies on a stratified systematic unaligned sample. An example is shown in Figure 4-13. The resulting sample combines the advantages of randomization and stratification with the useful aspects of systematic samples, while avoiding possibilities of bias because of possible periodicities.

¹ GEOMA is the VICARS program used to rectify the LANDSAT channels to congruent geometry. VICARS is an acronym for Video Image Communication and Retrieval System.

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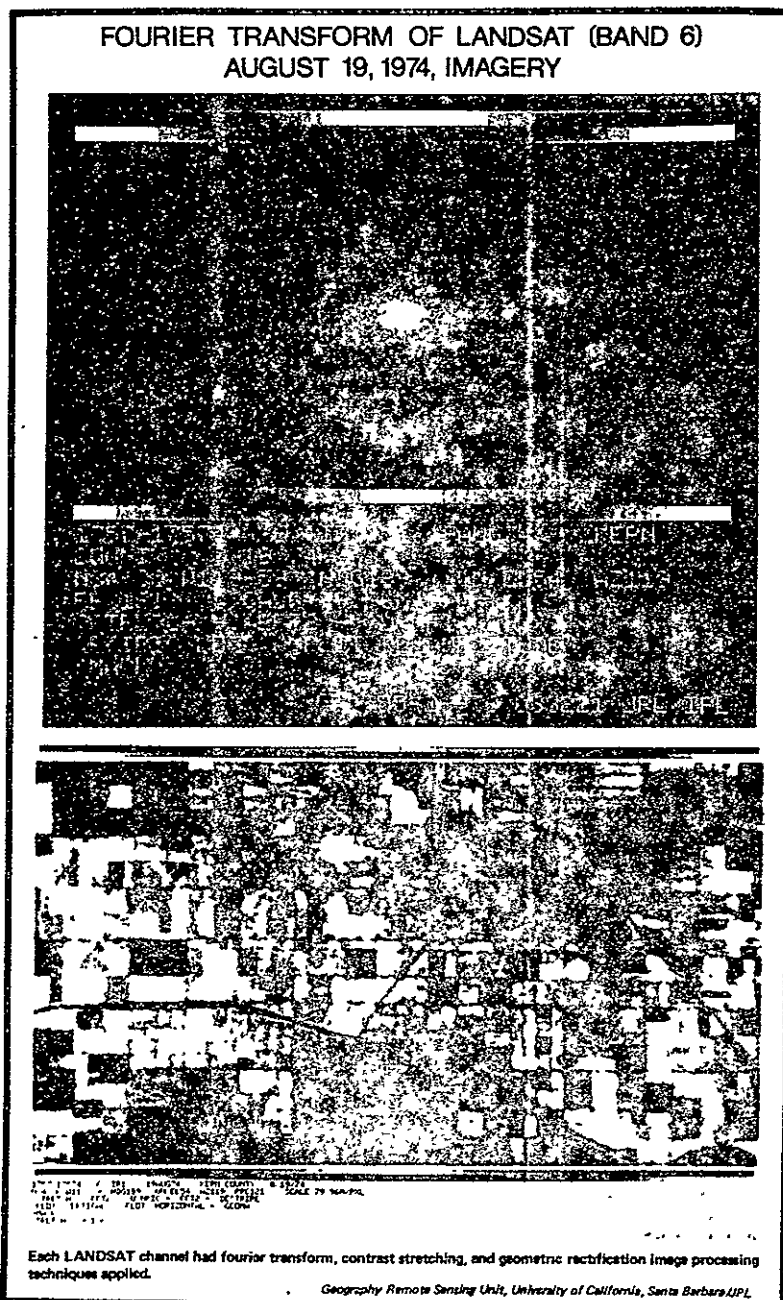


Figure 4-11. Illustrated here is the result obtained when the VICARS software is used to rectify Landsat imagery.

AGRICULTURAL GROUND TRUTH:
 NODES 197, 198, 199, 204, 205, 206 OF THE
 WHEELER RIDGE - MARICOPA WATER STORAGE DISTRICT*

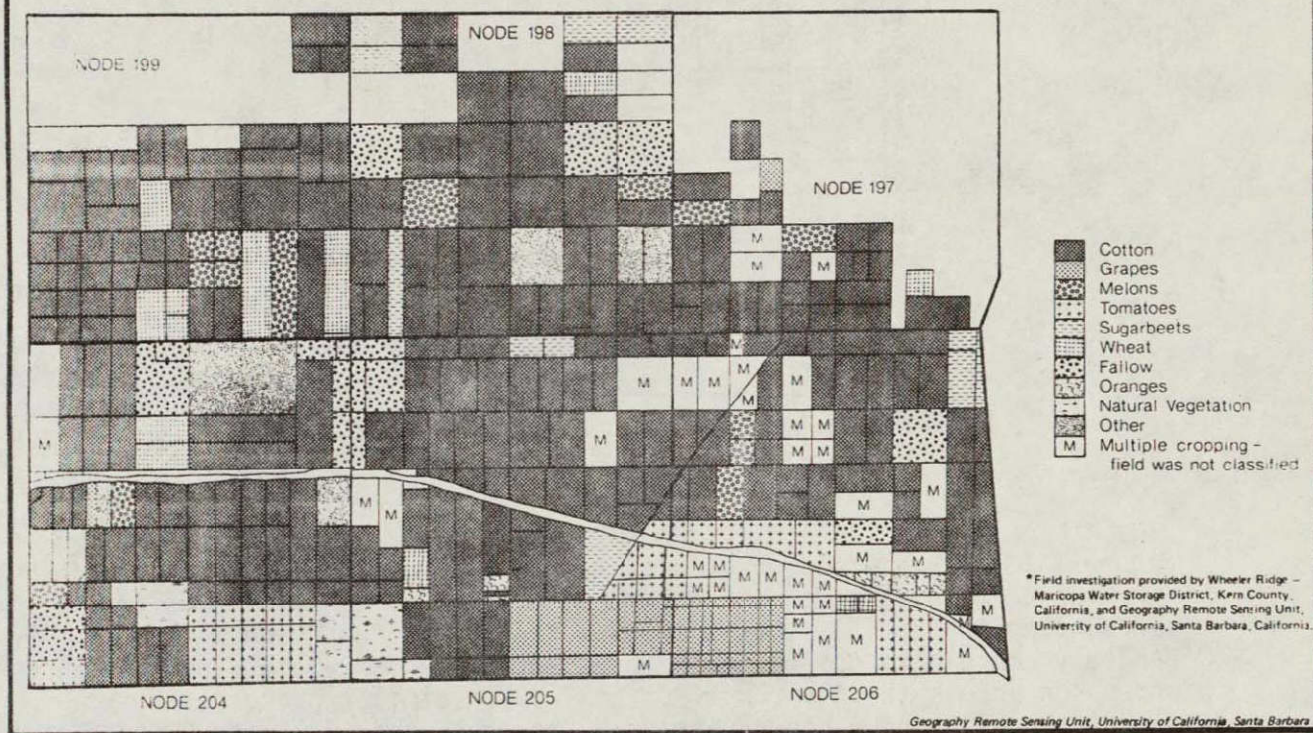


Figure 4-12. Agricultural Ground Truth provided by the Wheeler Ridge-Maricopa Water Storage District. This data was primarily used to assess classification accuracies. Additional similar information was used to select training fields.

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A STRATIFIED SYSTEMATIC UNALIGNED SAMPLE

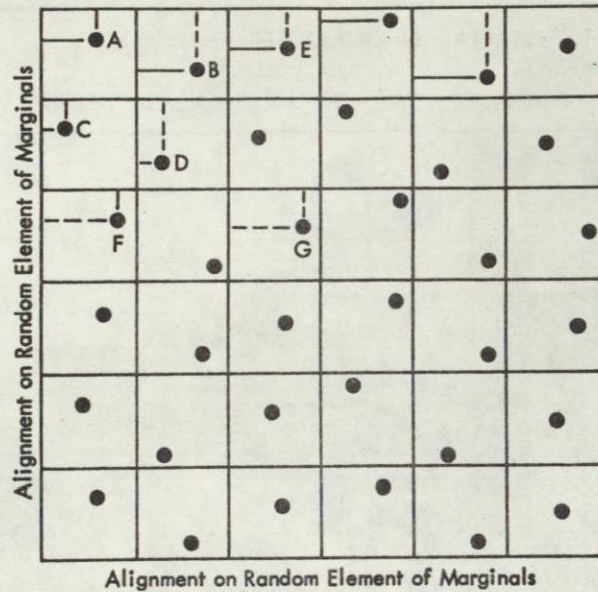


Figure 4-13. Example of a stratified systematic unaligned sample grid. First point A is selected at random and a given number of fields inventoried surrounding that point. The x coordinate of A is then used with a new random y coordinate to locate B, and a second random y coordinate to E, and so on across the top row of strata. By a similar process, the y coordinate of C and y coordinate of B are then used to locate D, of E and F to locate G, and so on until all crop classes have sufficient training elements. The number of sample elements should vary depending on the complexity of the original crop assemblage. The greater the number of different crop types, the larger the sample needs to be. Further information regarding this sample technique or others may be obtained from Sampling, Coding and Storing, Flood Plain Data by Brian J. L. Berry, Agricultural Handbook No. 237, Economic Research Service, United States Department of Agriculture.

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Field Boundary Overlay: For the manual interpretation of both high altitude and LANDSAT false color imagery it is helpful to create a field boundary overlay of the training and test area (Figure 4-14). In this manner it is possible to keep an accurate account of individual field identifications and croptype for the selection of training fields and for the assessment of classification accuracies. These overlays are simple field boundary outlines extracted at contact scale (1:125,000) from the high altitude photography. Since it is recommended that LANDSAT color combined images be optically enlarged to this same scale the overlay may be used for both manual procedures.

Crop Phenology Information: As previously mentioned, the regional "crop calendar" is of primary importance when selecting dates of imagery to be used in a crop classification. This data is often available from existing sources. For example, the University of California Agricultural Extension Office in Bakersfield provided most of the crop calendar information in Table 4-3. A monthly description identifies the phenological stages through which individual crops progress. Comments at the right of the table provide additional descriptive information on the appearance of each crop. *A priori* probabilities seen at the far left of the table are derived from 1973 crop acreage statistics for this region. The crop calendar and associated *a priori* probabilities represent the most important collateral information used by interpreters in the manual crop identification procedures.

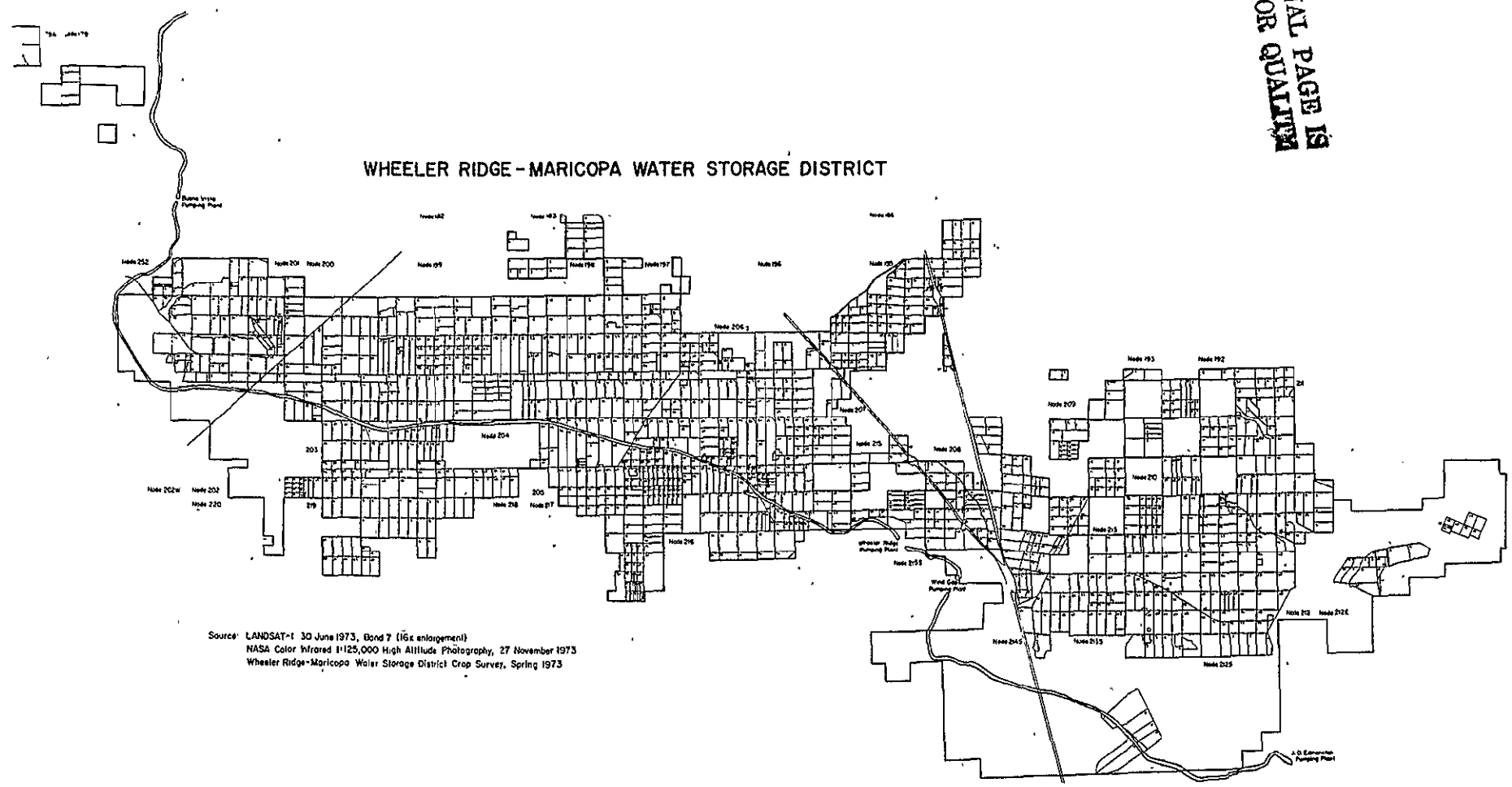
4.44 Manual Crop Identification (A): Training Field Selection, Key Creation, Classification and Water Demand Prediction Results

Training Field Selection and Key Creation: Once the ground truth data, field boundary overlays, and multirate high altitude or LANDSAT imagery are available the training fields may be selected. During the selection procedure one should evaluate the ground truth and collateral information (e.g. crop specie, soils, etc.) to be certain that training data is selected from homogeneous "strata" representative of the test region. Ordinarily the training data is selected from areas which surround the test region. For both the LANDSAT and high altitude manual approach each training field is individually located, cut out, and placed into a key format as shown in Figure 4-15. Note that the training field number is found on the left with the four multirate images of each field appearing from left to right as they progress through the growing season.

Ideally, the crop key should be developed from the same imagery as that used by the interpreter in the test region classification. For example, the individual training fields in Figure 4-15 were extracted from the same high altitude photography used to produce the test region in Figure 4-16. This eliminates potential variations caused by atmospheric conditions or photographic processing that could create differences between the keys and imagery to be classified.

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WHEELER RIDGE - MARICOPA WATER STORAGE DISTRICT



Source: LANDSAT-1 30 June 1973, Band 7 (15x enlargement)
NASA Color Infrared 1:125,000 High Altitude Photography, 27 November 1973
Wheeler Ridge-Maricopa Water Storage District Crop Survey, Spring 1973

4-33

Figure 4-14. Field Boundary overlay of the Wheeler Ridge-Maricopa Water Storage District.

TABLE 4-3 .
PHENOLOGICAL CYCLE OF SELECTED CROPS IN THE SOUTHERN SAN JOAQUIN VALLEY PORTION OF KERN COUNTY, CALIFORNIA

Probability of Occurrence ^o	Crop Type	CROP CALENDAR														REMARKS	
		1973						1974									
		N	D	J	F	M	A	M	J	J	A	S	O	N	D		
52%	Cotton ⁺	D/H	D/H/-	-	-	-	-/Y	Y/M	M	M	M	M/D	D/H	D/H	D/H/-	Cotton as bare soil in Mar & Apr; young in May & June; mature in July, Aug, Sept; defoliated in Sept & Oct; plowed under by Dec. 15.	
9%	Grapes	M	-	-	-	-	-	Y	Y/M	M	M	M	M	M	M	-	Grapes depending on age will appear as bare soil in Apr; mature in Aug when field may have broad stripped look & still shows some degree of red to red black thru Nov & Dec
5%	Melons ⁺	-	-	-	-	Y	Y/M	M	M	M/H	M/H/-	-	-	-	-	Apr image should appear as bare soil of young crop. Aug image will show a mature crop or bare soil signature. Nov & Dec signatures may be other crops; previously melons.	
4.5%	Tomatoes ⁺ (spring)	-	-	-	Y	M	M	M	H	H	-	-	-	-	-	Signatures for spring tomatoes will be bare soil in Nov & Dec. Young crop in lightly rowed crop in Apr & Aug.	
4.5%	Tomatoes ⁺ (fall)	M/H	-	-	-	-	-	-/Y	Y/M	M	M	M/H	M/H	M/H	-	Fall tomatoes will appear mature in Aug and show signs of crop in Nov & Dec & be bare soil in Apr.	
4-3 1/4	3%	Lettuce ⁺	-	-	-	-/Y	Y/M	M	H	H	-	-	-	-	-	Apr is the only date where lettuce fields should appear to be in crop	
	3%	Sugarbeets	-	-	-	-	Y	Y/M	M	M	H	H/-	-	-	-	Apr signature of sugarbeets should range between that of a young & mature crop. Other dates should appear as bare soil.	
	3%	Almonds	M/-	-	-	-	-	-/Y	Y	M	M	M	M	M	M/-	Most almonds here appear to have a bare soil signature for all dates except Nov when fields have reddish tinge.	
	3%	Small Grain ⁺⁺	-	-	Y	Y	Y/M	M	M/H	H	H	S	S	S	-	Small grains will appear as mature crop in Apr; bare soil in other dates.	
	3%	Fallow	BS/S	BS/S	BS/S	BS/S	BS/S	BS/S	BS/S	BS/S	BS/S	BS/S	BS/S	BS/S	BS/S	Will appear as a light bare soil signature on all dates.	
	2%	Natural Vegetation														Depending on area and date this signature may range from that of bare soil to a crop but will usually lack regular shape of a cultivated field.	
	1%	Oranges(young)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Will appear as a rowed field of young crops on all dates.	

TABLE 4-3 (continued)

Probability of Occurrence ^o	Crop Type	CROP CALENDAR														
		1973					1974									
		N	D	J	F	M	A	M	J	J	A	S	O	N	D	
1%	Oranges (mature)	M	M	M	M	M	M	M	M	M	M	M	M	M	M	Signature will appear as a mature field on all dates; rowing may or may not be evident.
1%	Peppers ⁺	-	-	-	-/Y	Y/M	M	H	H	-	-	-	-	-	-	Peppers in image examples from this area appear mature in Nov. & bare soil on other dates.
1%	Onions	-	-	Y	Y/M	Y/M	M	M	H	H	H	-	-	-	-	Image examples of onions in this area appear as bare soil for all dates.
1%	Safflower ⁺	-	-	-	-	-/Y	Y	M	M	H	H	-	-	-	-	Safflower appears as a young to mature crop in Apr and as bare soil on other dates.
1%	Plums	-	-	-	-	-	Y	Y	M	M	M	M	M/-	-	-	In this test area, plums appear dark in Aug and red to black on LANDSAT & a lightly rowed pink on highlight all other dates.
4-5% 1%	Potatoes ⁺	-	-	Y	M	M	M/H	M/H	M/H	M/H	M/H/-	-	-	-	-	Potatoes will appear reddish in Apr; red to pink in Aug; other dates as bare soil.
.75%	Alfalfa(hay)	-	-	-	-	-/Y	M	M/H	M/H	M/H	M/H	M/H	M/H/-	-	-	Alfalfa appears as smooth, reddish tone on all dates of LANDSAT. On highlight, alfalfa appears pink to red with a fine linear texture present.
.25%	Alfalfa(seed)	-	-	-	-	-	Y	M	M	M	H	H/-	-	-	-	

Bare Soil -
 Young Crop Y
 Mature Crop M
 Defoliated D
 Harvesting H
 Stubble S

^o Statistics for probability of occurrence are based on historical data and field verification information supplied by local water districts
 / denotes approximately one half month
^M/_H this type of symbol indicates that although the crop is being harvested it may still appear mature
 * small grain is used here to denote fields identified as wheat or barley
 + denotes crops which are typically double cropped; that is a given field contains tomatoes in the spring and lettuce in the fall

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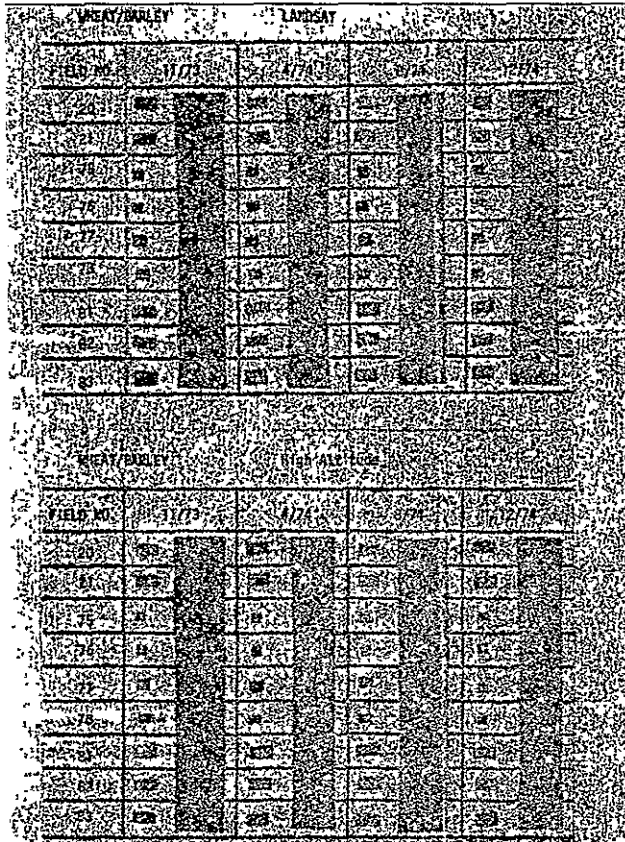


Figure 4-15. Example (reduced) of a wheat/barley image key for both the high altitude and LANDSAT manual crop identification procedures. FIELD NO. refers to the training field number from which each field was extracted. Note the slits which allow analysts to compare training fields with test fields. A key such as this is developed for each croptype in the study area.

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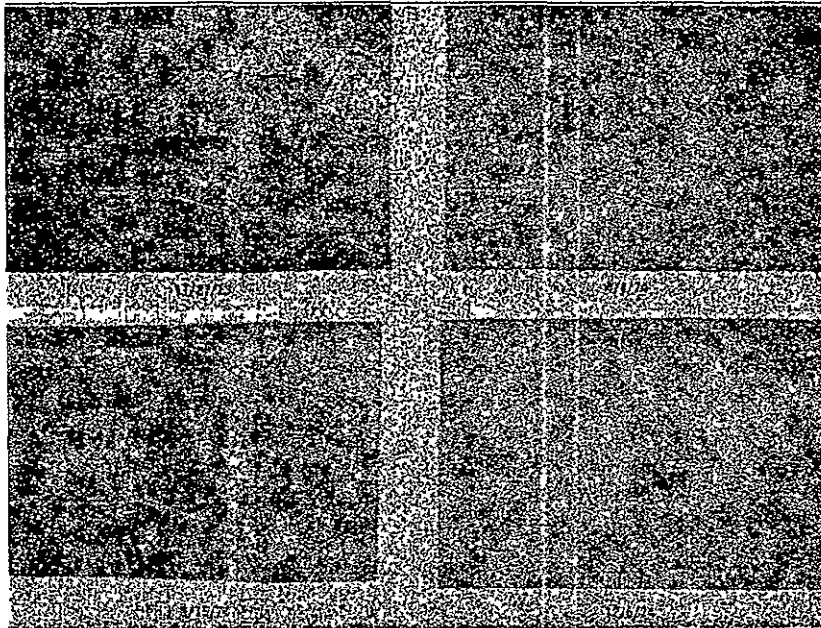


Figure 4-16. Test Region Color Infrared High Altitude Photography
(original 1:125,000; here reduced) Wheeler Ridge-Maricopa Water District.

The key, along with the crop calendar previously discussed (refer to Table 4-3), comprise the training data for the manual interpretation methodology. Interpreters can use the image keys as overlay devices in order to match up a particular test field with what appears to be a similar croptype in the training field keys. Most interpreters work consecutively from node to node and from field to field in order to classify the test fields. Interpreters keep in mind the relative total acreage (frequency of occurrence) normally exhibited by each croptype within the project area when deciding upon the classification of a given field. This information is provided in the crop calendar (Table 4-3). Once the initial interpretation of the entire project area has been completed, a comparison of total assignments versus expected probabilities may lead to a revision of questionable classifications which can increase accuracies significantly.

Interpreted field croptypes may be annotated directly upon a work copy of the field boundary map or listed on answer sheets indexed by field identification codes. Answer sheets with each field's acreage included can be used quickly to transform specific crop application rates and acreages into water demand.

The cues used to manually identify each croptype will depend upon the crop signatures present, their relative proportions, the dates and quality of imagery used. Interpretation schemes can range from simple choices (such as "anything growing in January is a grain crop") to integrative, multirate decisions. Each environment must be individually assessed to optimize the interpretation scheme. The cost of acquiring the imagery, creating the keys, and typical interpretation time are presented in Appendix I.

Manual Crop Identification and Water Demand Prediction Results: Manual crop identification and water demand predictions presented in this manual are based on previous research which compared the effectiveness of LANDSAT versus high altitude techniques.¹ In this previous study eight trained image analysts took part in the manual crop identification, four examining high altitude photography and four the LANDSAT imagery. Results for only one of the four high altitude and LANDSAT interpreters will be discussed because a mean classification accuracy for four interpreters cannot be developed into an agricultural water demand prediction.

High Altitude: One interpreter's per field classification accuracies are reported in Table 4-4. Note that in this primary test region closest

¹ Jensen, John R., Larry R. Tinney, and John E. Estes. "An Analysis of Manual and Digital Crop Identification Procedures Applied to High Altitude Photography and LANDSAT Multispectral Scanner Imagery." Scanner Versus Camera Evaluation. Pasadena: Jet Propulsion Laboratory (January, 1977), (in press).

Table 4-4

MANUAL HIGH ALTITUDE PER FIELD CROP CLASSIFICATION
 NODES 197, 206, 206 OF THE WHEELER RIDGE-MARICOPA WATER STORAGE DISTRICT, 1974

R.S. CLASSIFICATION DISTRICT GROUND TRUTH	% ACCURACY	COTTON	GRAPES	MELONS	TOMATOES	SUGARBEETS	WHEAT	FALLOW	ORANGES	NATURAL VEGETATION	OTHER	TOTAL
COTTON	90	99	2	3			3				3	110
GRAPES	86	8	48								-	56
MELONS	0	4	1									5
TOMATOES	59	4			10						3	17
SUGARBEETS	0	2	1	1	1							5
WHEAT	25	1					1				2	4
FALLOW	0	2		3	1							6
ORANGES	0										9	9
NATURAL VEGETATION	100									2		2
OTHER	33		4	1		1	4				5	15
TOTAL	72	120	56	8	12	1	8	0	0	2	22	165 229

Table 4-5

MANUAL HIGH ALTITUDE ACREAGE WEIGHTED CROP CLASSIFICATION AND WATER DEMAND PREDICTION
 NODES 197, 206, 206 OF THE WHEELER RIDGE-MARICOPA WATER STORAGE DISTRICT, 1974

R.S. CLASSIFICATION DISTRICT GROUND TRUTH (AC.)	% ACCURACY	COTTON	GRAPES	MELONS	TOMATOES	SUGARBEETS	WHEAT	FALLOW	ORANGES	NATURAL VEGETATION	OTHER	TOTAL
COTTON	92	6635	90	100			285				120	7230
GRAPES	59	480	680									1160
MELONS	0	260	80									340
TOMATOES	45	280			314						110	704
SUGARBEETS	0	95	80	30	125							330
WHEAT	32	40					50				65	155
FALLOW	0	200		200	80							500
ORANGES	0										195	195
NATURAL VEGETATION	100									280		280
OTHER	38		200	15		40	330				360	945
TOTAL	71	7990	1130	365	519	40	665	0	0	280	850	8319 11839

R.S. WATER DEMAND PREDICTION (acre feet) ADSL REL		26367	2503	1095	1557	140	731	0	0	0	2873	35266
73	21895	2108	0	942	0	55	0	0	0	1216	26217	
100	23859	3596	1020	2112	1155	171	0	585	0	3194	35692	

Table 4-6

CROP SPECIFIC IRRIGATION RATES	
WHEELER RIDGE -- MARICOPA WATER STORAGE DISTRICT, 1974	
COTTON	3.3 ACRE FEET
GRAPES	3.1
MELONS	3.0
TOMATOES	3.0
SUGARBEETS	3.5
WHEAT	1.1
FALLOW	0
ORANGES	3.0
NATURAL VEGETATION	0
DISTRICT AVERAGE	3.38

to the training data the interpreter correctly identified 90% of the cotton, 80% of the grapes, and 59% of the tomatoes which account for most of the acreage. By acreage weighting each of the classified fields and multiplying by its appropriate crop specific irrigation rate (refer to Table 4-5) a 73% absolute water demand prediction is obtained compared to water district records.

Examination of Table 4-7 reveals that for the secondary test area (nodes 198, 199, 204) located further from the training data, the interpreter achieved a 63% acreage weighted crop identification accuracy, a drop of 9% yielding a 65% accurate water demand prediction (Table 4-8). This drop in classification accuracy going from the primary to the secondary test region is mainly attributed to vignetting in the original high altitude photography. Both the training and primary test regions were located near the border of the 9 x 9" photography on two dates causing these regions to image darker. The secondary area in this photography was located near the principle point resulting in normal color balance and contrast. Consequently, when conducting manual high altitude crop inventories be certain to either process the photography with an anti-vignetting filter or stratify training and test regions with this constraint in mind. Vignetting is a common problem and could significantly lower classification and water demand prediction accuracies as demonstrated.

Table 4-9 is a summary of both the primary and secondary test area acreage weighted crop classification and water demand predictions. Overall, the 66% acreage weighted crop identification yielded a 70% absolute water demand prediction. An important statistic to consider is the 98% relative water demand accuracy. The high accuracy is the result of acres in one crop class being misclassified into another crop class with an approximately equal irrigation rate. For example, Table reveals that melons, tomatoes, and oranges have water application rates of 3 acre-ft./year⁻¹. Any misclassification among the three categories will not affect the relative water demand prediction. This suggests that users should carefully evaluate their individual situations to determine if crop groups might be more easily identifiable than specific crops.

LANDSAT: Manual crop identification and water demand prediction using LANDSAT color composites proved slightly superior yet not significantly different than the high altitude techniques.¹ For example, one interpreter's

¹ To determine if there was a statistically significant difference between the LANDSAT and high altitude techniques, previous research applied a t-test to eight individual analysts' results on a nodal basis. This test is specifically designed for small sample data sets. This analysis concluded that there was no statistically significant difference between the manual high altitude and LANDSAT approaches for crop identification ($t = .505$; 2.07 required for .05 level of significance).

Table 4-7

MANUAL HIGH ALTITUDE PER FIELD CROP CLASSIFICATION
 NODES 198, 199, 204 OF THE WHEELER RIDGE-MARICOPA WATER STORAGE DISTRICT, 1974

R.S. CLASSIFICATION / DISTRICT GROUND TRUTH	% ACCURACY	COTTON	GRAPES	MELONS	TOMATOES	SUGARBEETS	WHEAT	FALLOW	ORANGES	NATURAL VEGETATION	OTHER	TOTAL
COTTON	81	90	5	2	8	1					5	111
GRAPES	0										1	1
MELONS	0	3			2					1	3	9
TOMATOES	0		1	10								11
SUGARBEETS	50	1			3	4						8
WHEAT	78				1		7				1	9
FALLOW	33	1	2	1				2				6
ORANGES	0										1	1
NATURAL VEGETATION	100									5		5
OTHER	5	2	15							1	1	19
TOTAL	60	97	23	13	14	5	7	2	0	7	12	109 179

Table 4-8

MANUAL HIGH ALTITUDE ACREAGE WEIGHTED CROP CLASSIFICATION AND WATER DEMAND PREDICTION
 NODES 198, 199, 204 OF THE WHEELER RIDGE-MARICOPA WATER STORAGE DISTRICT, 1974

R.S. CLASSIFICATION / DISTRICT GROUND TRUTH (AC)	% ACCURACY	COTTON	GRAPES	MELONS	TOMATOES	SUGARBEETS	WHEAT	FALLOW	ORANGES	NATURAL VEGETATION	OTHER	TOTAL
COTTON	80	7035	390	310	640	100					320	8795
GRAPES	0										15	15
MELONS	0	400			80					60	140	680
TOMATOES	0		80	600								680
SUGARBEETS	53	100			180	320						600
WHEAT	70				110		440				80	630
FALLOW	13	160	335	25				80				600
ORANGES	0										45	45
NATURAL VEGETATION	100									320		320
OTHER	22	160	565							60	215	1000
TOTAL	63	7855	1370	935	1010	420	440	80	0	440	815	8410 13365

R.S. WATER DEMAND PREDICTION (ABS & REL)	93	25922	4247	2805	3030	1470	484	0	0	0	2755	40713
65	23215	0	0	0	1120	484	0	0	0	727	25546	
DISTRICT TRUTH	100	29024	47	2040	2040	2100	693	0	135	0	3360	39459

Table 4-9

MANUAL HIGH ALTITUDE ACREAGE WEIGHTED CROP CLASSIFICATION AND WATER DEMAND PREDICTION
 NODES 197, 198, 199, 204 206 206 OF THE WHEELER RIDGE-MARICOPA WATER STORAGE DISTRICT, 1974

R.S. CLASSIFICATION (AC) DISTRICT GROUND TRUTH (AC)	% ACCURACY	COTTON	GRAPES	MELONS	TOMATOES	SUGARBEETS	WHEAT	FALLOW	ORANGES	NATURAL VEGETATION	OTHER	TOTAL
COTTON	85	13670	480	410	640	100	285				440	16025
GRAPES	50	480	680								15	1175
MELONS	0	660	80		80					60	140	1020
TOMATOES	23	280	80	600	314						110	1384
SUGARBEETS	34	195	80	30	305	320						930
WHEAT	62	40			110		490				145	785
FALLOW	7	360	335	245	80			80				1100
ORANGES	0										240	240
NATURAL VEGETATION	100									600		600
OTHER	30	160	765	15		40	330			60	575	1945
TOTAL	66	15845	2500	1300	1529	460	1105	80	0	720	1665	16729
												25204

R.S. WATER DEMAND PREDICTION (acre feet)	96	52289	7750	3900	4587	1610	1216	0	0	0	5628	76980
ABS. REL.	70	45111	2108	0	942	1120	539	0	0	0	1926	51746
DISTRICT TRUTH	100	52883	3643	3060	4152	3255	864	0	720	0	6574	75151

LANDSAT results for the primary test area (Table 4-10) reveal a 4% increase in crop identification and 5% increase in water demand prediction accuracy for the primary test region (Table 4-11). As in the high altitude technique accurate cotton and grape classification were very important.

The manual interpretation of LANDSAT imagery also experienced a drop in classification accuracy as analysts moved from the primary to the secondary test regions. For example, the interpreter under consideration dropped 6% in acreage weighted crop identification accuracy (76% to 70%; Tables 4-11 and 4-13). The decrease in accuracy for both manual techniques suggests that, in addition to the vignetting which is known to be a factor in the high altitude procedure, some inherent difference between the sites may be responsible. For example, soil type variation such as the increasing occurrence of salt-affected soils in the secondary test site is but one environmental parameter that could be contributing to the signature extension problem.

Table 4-14 reports the total primary and secondary LANDSAT acreage weighted crop identification and water demand prediction accuracies. Note that the 73% crop classification accuracy resulted in a 73% accurate absolute and a 94% relative water demand prediction. As discussed in the high altitude procedure, a crop grouping procedure might capitalize on the relative water demand prediction accuracies.

The manual LANDSAT technique described here has been developed for large scale irrigated agriculture in an arid environment, specifically Kern County in California. Other environments may not find the present 80m ground resolution of LANDSAT adequate because of smaller or more irregularly shaped fields. In general, the manual technique as discussed does not appear to be reliable for fields that are less than 20 acres in size.

4.45 Digital LANDSAT Crop Identification: Training and Test Field Selection, Channel Selection, Classification and Water Demand Prediction Results.

Training and Test Field Selection: Manual stratification of training and test field regions should occur in the manner described in the manual high altitude and LANDSAT procedures. In addition to the manual stratification, however, a "clustering"¹ analysis of the digital data will provide optimum discrimination of homogeneous classes

¹ Clustering is a LARSYS subroutine.

Table 4-10

MANUAL LANDSAT COLOR COMPOSITE PER FIELD CROP CLASSIFICATION
 NODES 197, 206 208 OF THE WHEELER RIDGE-MARICOPA WATER STORAGE DISTRICT 1974

R.S. CLASSIFICATION DISTRICT GROUND TRUTH	% ACCURACY	COTTON	GRAPES	MELONS	TOMATOES	SUGARBEETS	WHEAT	FALLOW	ORANGES	NATURAL VEGETATION	OTHER	TOTAL
COTTON	90	99	4	2	1	1	1	2				110
GRAPES	84	7	47					1			1	56
MELONS	0	3	1								1	5
TOMATOES	0	4	8			3		1			1	17
SUGARBEETS	20	2				1		1			1	5
WHEAT	50						2				2	4
FALLOW	67	1						4			1	6
ORANGES	89		1						8			9
NATURAL VEGETATION	100									2		2
OTHER	67	2					1	2			10	15
TOTAL	76	118	61	2	1	5	4	11	8	2	17	173 229

Table 4-11

MANUAL LANDSAT COLOR COMPOSITE ACREAGE WEIGHTED CROP CLASSIFICATION AND WATER DEMAND PREDICTION
 NODES 197 206 208 OF THE WHEELER RIDGE-MARICOPA WATER STORAGE DISTRICT, 1974

R.S. CLASSIFICATION DISTRICT GROUND TRUTH (AC)	% ACCURACY	COTTON	GRAPES	MELONS	TOMATOES	SUGARBEETS	WHEAT	FALLOW	ORANGES	NATURAL VEGETATION	OTHER	TOTAL
COTTON	92	6630	170	100	120	40	125	45				7230
GRAPES	80	140	930					50			40	1160
MELONS	0	180	80								80	340
TOMATOES	0	125	292			185		90			12	704
SUGARBEETS	32	115				105		80			30	330
WHEAT	58						90				65	155
FALLOW	44	120						220			160	500
ORANGES	79		40						155			195
NATURAL VEGETATION	100									280		280
OTHER	65	55					160	120			610	945
TOTAL	76	7365	1512	100	120	330	375	605	155	280	997	9020 11839

R.S. WATER DEMAND PREDICTION (ACR FEET)	ABS \ REL	DISTRICT TRUTH	COTTON	GRAPES	MELONS	TOMATOES	SUGARBEETS	WHEAT	FALLOW	ORANGES	NATURAL VEGETATION	OTHER	TOTAL
58	24305	4687	300	360	1155	412	0	465	0	3370	35054		
78	21879	2883	0	0	315	99	0	465	0	2062	27703		
100	23859	3596	1020	2112	1155	111	0	585	0	3194	35642		

Table 4-12

MANUAL LANDSAT COLOR COMPOSITE PER FIELD CROP CLASSIFICATION
 NODES 198, 199, 204 OF THE WHEELER RIDGE-MARICOPA WATER STORAGE DISTRICT, 1974

R.S. CLASSIFICATION / DISTRICT GROUND TRUTH	% ACCURACY	COTTON	GRAPES	MELONS	TOMATOES	SUGARBEETS	WHEAT	FALLOW	ORANGES	NATURAL VEGETATION	OTHER	TOTAL
COTTON	83	92	1	7	7		1	2			1	111
GRAPES	0							1				1
MELONS	0	1	1					5			2	9
TOMATOES	0							10			1	11
SUGARBEETS	25		1			2					5	8
WHEAT	17		1				1				7	9
FALLOW	100							6				6
ORANGES	0										1	1
NATURAL VEGETATION	100									5		5
OTHER	74	1						3			14	19
TOTAL	67	94	4	7	7	2	2	27	0	5	31	120 179

Table 4-13

MANUAL LANDSAT COLOR COMPOSITE ACREAGE WEIGHTED CROP CLASSIFICATION AND WATER DEMAND PREDICTION
 NODES 189, 190, 204 OF THE WHEELER RIDGE-MARICOPA WATER STORAGE DISTRICT, 1974

R.S. CLASSIFICATION / DISTRICT GROUND TRUTH (AC)	% ACCURACY	COTTON	GRAPES	MELONS	TOMATOES	SUGARBEETS	WHEAT	FALLOW	ORANGES	NATURAL VEGETATION	OTHER	TOTAL
COTTON	85	7450	15	640	480		80	70			80	8795
GRAPES	0							15				15
MELONS	0	160	80					360			80	680
TOMATOES	0							600			80	680
SUGARBEETS	27		80			160					360	600
WHEAT	13		110				80				440	630
FALLOW	100							600				600
ORANGES	0										45	45
NATURAL VEGETATION	100									320		320
OTHER	68	80						240			680	1000
TOTAL	70	7670	285	640	480	160	160	1885	0	320	1765	9270 13365

R.S. WATER DEMAND PREDICTION (acre feet) / ABS. REL.	DISTRICT TRUTH	COTTON	GRAPES	MELONS	TOMATOES	SUGARBEETS	WHEAT	FALLOW	ORANGES	NATURAL VEGETATION	OTHER	TOTAL
92	25311	884	1920	1440	560	176	0	0	0	5665	56257	
70	24519	0	0	0	560	88	0	0	0	2299	27465	
100	29024	47	2040	2040	2100	693	0	135	0	3380	39459	

Table 4-14

MANUAL LANDSAT COLOR COMPOSITE ACREAGE WEIGHTED CROP CLASSIFICATION AND WATER DEMAND PREDICTION, NODES 197, 198, 199, 204, 205, 206 OF THE WHEELER RIDGE-MARICOPA WATER STORAGE DISTRICT 1974

RS CLASSIFICATION (AC.) DISTRICT GROUND TRUTH (AC.)	% ACCURACY	COTTON	GRAPES	MELONS	TOMATOES	SUGARBEETS	WHEAT	FALLOW	ORANGES	NATURAL VEGETATION	OTHER	TOTAL
COTTON	88	14060	185	740	600	40	205	115			80	16025
GRAPES	80	140	930					65			40	1175
MELONS	0	340	160					360			160	1020
TOMATOES	0	125	292			185		690			92	1384
SUGARBEETS	28	115	80			265		80			390	930
WHEAT	22		110				170				505	785
FALLOW	75	120						820			160	1100
ORANGES	65		40						155		45	240
NATURAL VEGETATION	100									600		600
OTHER	66	135					160	360			1290	1945
TOTAL	73	15035	1797	740	600	490	535	2490	155	600	2762	18290 25204

RS WATER DEMAND PREDICTION (acre feet) ABS \ REL	DISTRICT TRUTH	PREDICTION VALUES										
		94	49616	5571	2220	1800	1715	583	0	465	0	9336
73	46398	2883	0	0	928	187	0	465	0	4360	55221	
100	52883	3643	3060	4152	3255	864	0	720	0	6574	75151	

from which training data can be selected. Once selected, the next task is to identify the coordinate location of the fields in order to train the digital classification algorithm. This is accomplished by digitizing the coordinates of rectangular areas within each of the training fields on either an alphanumeric line printer or film-writer output of a single rectified LANDSAT band. In this particular study, a "tickmark" mask superimposed around the border allowed calibration between the digital and photographic coordinates. Once digitization was completed the training field coordinates were graphically scribed onto a channel of the LANDSAT data set to judge the digitization accuracy (see Figure 4-17). Since a per field classifier was implemented using LARSYS software, all 408 test field boundaries in the six node area were also coordinate digitized.

Channel Selection: Conventional digital classification algorithms are usually based upon a maximum likelihood discriminant function. It has been previously discussed and is intuitively obvious that multivariate analyses should allow better crop identification performance than single date analysis. Contrary to intuition, however, continual addition of dates or channels does not always improve crop identification performance. Also, substantial increases in computation costs accrue with each additional channel. It has been observed in many instances that four or five channels of LANDSAT MSS data usually provide maximum classification accuracies, with additional channels sometimes even resulting in degraded performance.¹ The basis for this phenomenon, which has been aptly termed the "curse of dimensions," lies within the assumptions made by most classification algorithms. In addition to normal distributions, each class training set is assumed to be randomly representative of the entire class distribution. Maintaining constant confidence levels in class assignments, as additional channels are added, requires increased sampling. It also follows that increasing the number of dates involved increases the likelihood of training set degradation or capture by non-representative or irrelevant samples. In many regions it is simply not feasible to acquire an adequately representative sample of training data in accordance with the highly dimensional nature of temporal imagery that satellite systems such as LANDSAT can provide. In accordance with this, there usually exists an optimal subset of available channels for which classification performance is maximized.

A statistical measure termed "divergence" is commonly used to select the best subset of channels by which a classification is to be performed. All class pairwise combinations and channel combinations are individually evaluated. As in the maximum likelihood classification

¹ Steiner, Dieter, "Time Dimension for Crop Surveys from Space," Photogrammetric Engineering, February 1970, Vol. 3, pp. 187-194.

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TRAINING FIELDS SCRIBED ONTO LANDSAT BAND 7, DECEMBER 5, 1974



U.S. GEOLOGICAL SURVEY
LANDSAT PROGRAM
DECEMBER 5, 1974
LANDSAT BAND 7
GEOMETRY - HORIZONTAL
PROJECTION - UTM
SCALE - 1:250,000
UNIT - METERS
ORIGIN - 11E, 33N
ZONE - 18N
ELECTRONIC - 11E, 33N
FLIGHT - VERTICAL
SCENE - 11E, 33N

1974 11E 33N 02 1974 11E 33N 02

Geography Remote Sensing Unit, University of California, Santa Barbara/JPL

Figure 4-17. Training fields scribed onto a single band of LANDSAT imagery to assess location accuracy.

algorithm, an assumption is made that all class training data is normally distributed and representative of the test data. Each class pairwise combination in the divergence calculations may be weighted according to class a priori probabilities.

Classification: All test fields of LANDSAT data are classified using the LARSYS per field classification algorithm. This algorithm is based upon an equally weighted maximum likelihood decision rule. A simple maximum likelihood decision rule is one which treats each pixel independently and assign a pixel having pattern measurements or features d to that category e whose samples are most probable to have given rise to pattern or feature vector d , that is, such that the conditional probability of d given e , $P(e/d)$, is highest. Normal or "gaussian" distributions are assumed to exist.

LANDSAT Digital Crop Identification and Water Demand Prediction

Results: With LANDSAT digital data sets preprocessed into geometric congruency, training and test field coordinates identified, and channel selection performed via divergence, a LARSYS per field classifier is applied to the test regions. Figure 4-18 depicts the classifications derived from the LARSYS per field classifier which can be compared with the district ground truth presented in Figure 4-12. A per pixel output of the classified dataset (using channels 11/4/76 MSS 5; 8/19/74 MSS 5,7; 12/5/74 MSS 7) is shown in Figure 4-19. A crop specific pixel histogram for the entire training and test field region is shown in Figure 4-19B. Note the predominance of cotton in the study area.

The primary test area was classified 78% correctly resulting in an 80% accurate water demand prediction (Table 4-15). The digital classification of the primary test site would have achieved significantly higher accuracies if the grape fields were excluded from the analyses. Of the 56 grape fields in the primary test region, 46 were less than 40 acres in size. Consequently, LANDSAT's 80m resolution was hard pressed to accurately classify these fields since the original CCT data was sampled at every fourth pixel. This accounts for the large misclassification of grape acreage as fallow (455) natural vegetation (470), and melons (190) in nodes 205 and 206 (compare Table 4-15 with Figures 4-12 and 4-18).

The LANDSAT CCT analysis of the secondary test area resulted in an 86% accurate acreage weighted crop identification and an 85% absolute water demand prediction. This represents an increase in absolute water demand prediction accuracy of 20% and 15% over the manual high altitude (Table 4-8) and manual LANDSAT (Table 4-13) techniques respectively.

Table 4-17 summarizes the total primary and secondary LANDSAT

¹ Haralick, Robert M., "Glossary and Index to Remotely Sensed Image Pattern Recognition Concepts," Pattern Recognition, 1973, Vol.5, pp. 391-403.

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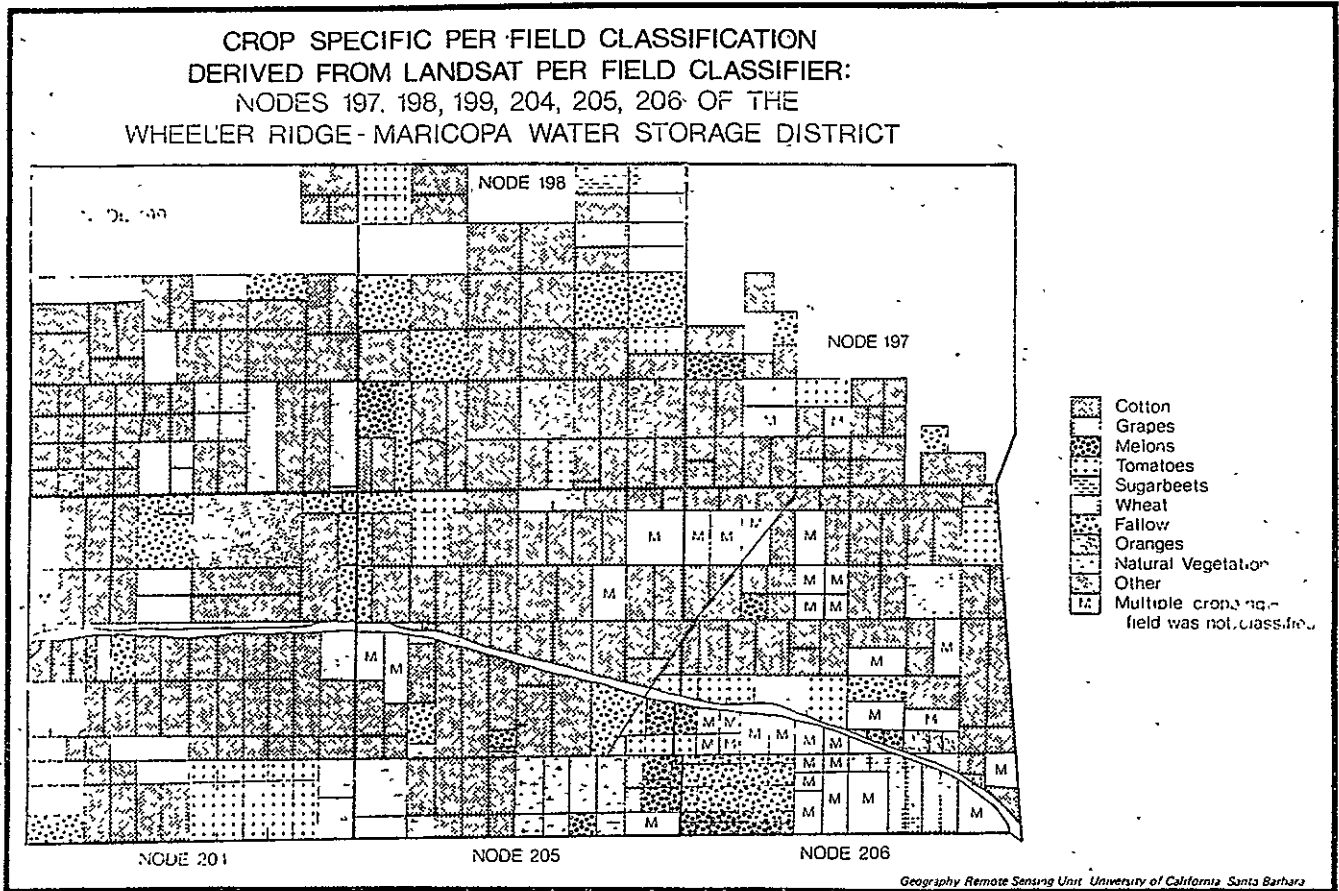


Figure 4-18. LANDSAT digital crop classification of the 1974 growing season in the Wheeler Ridge-Maricopa Water Storage District, Kern County, California.

MULTIDATE - MULTIBAND LANDSAT 1974 PER PIXEL CLASSIFICATION
 OF TEST AND TRAINING AREAS
 WHEELER RIDGE - MARICOPA WATER STORAGE DISTRICT

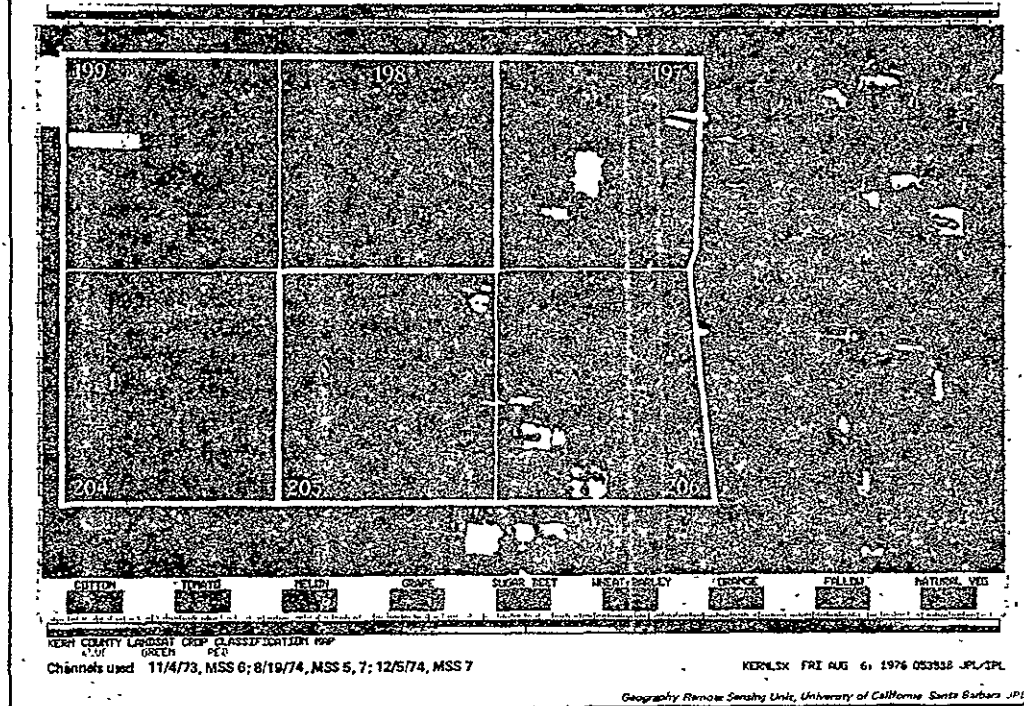
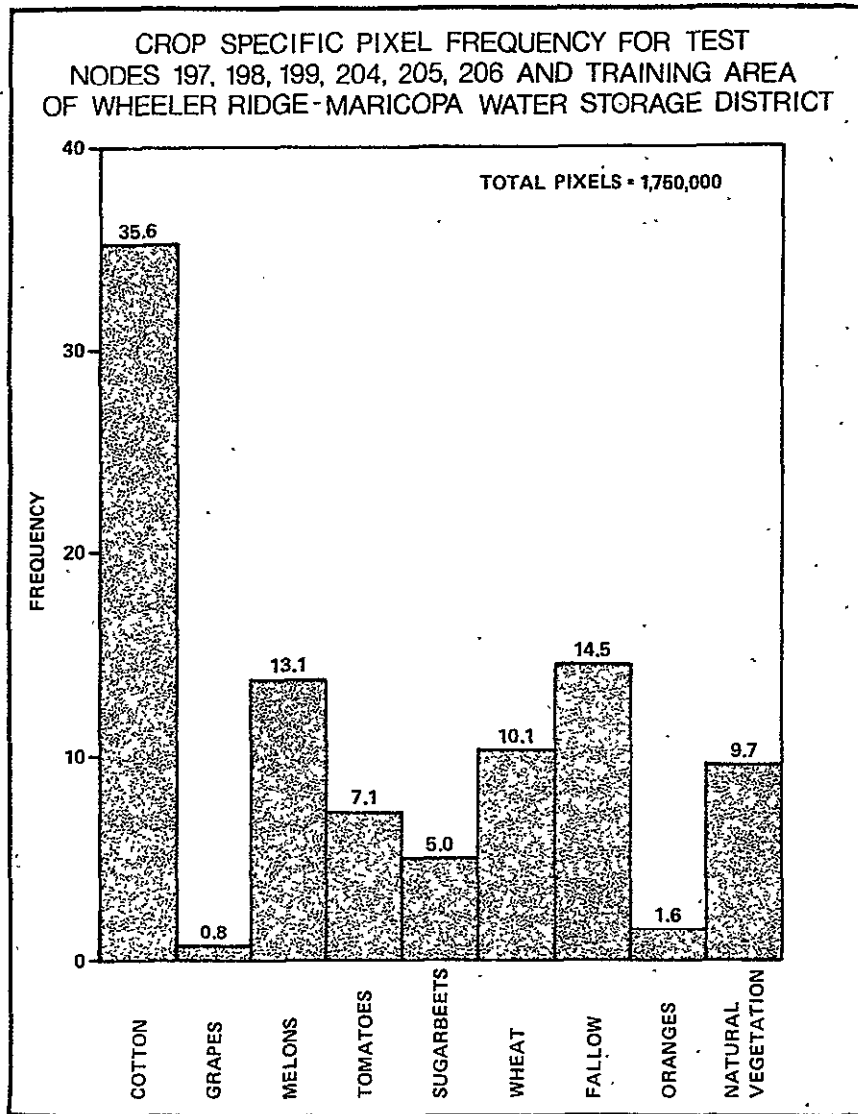


Figure 4-19A. LANDSAT per pixel classification map of the training and test (197, 198, 199, 204, 205, 206) areas in the Wheeler Ridge-Maricopa Water Storage District in Kern County, California.



Geography Remote Sensing Unit, University of California, Santa Barbara

Figure 4-19B.

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Table 4-15

DIGITAL ACREAGE WEIGHTED
LANDSAT MULTIDATE-MULTIBAND CROP CLASSIFICATION AND WATER DEMAND PREDICTION
NODES 197, 205, 206 OF THE WHEELER RIDGE - MARICOPA WATER STORAGE DISTRICT 1974

R.S. CLASSIFICATION (AC)	DISTRICT GROUND TRUTH (AC)	% ACCURACY	DIGITAL ACREAGE WEIGHTED												
			COTTON	GRAPES	MELONS	TOMATOES	SUGARBEETS	WHEAT	FALLOW	ORANGES	NATURAL VEGETATION	OTHER	TOTAL		
COTTON	98	7020			10	180		20							7230
GRAPES	1		55	190					445		470				1160
MELONS	35	140		120	80										340
TOMATOES	48		24	75	330	90	185								704
SUGARBEETS	11	60			80	35		155							330
WHEAT	42						65	90							155
FALLOW	76	40						380	80						500
ORANGES	51			65		30			100						195
NATURAL VEGETATION	100										280				280
OTHER	90	30								12			853		945
TOTAL	78	7340	79	460	670	155	270	1082	180	750	853				9238 11839
R.S. WATER DEMAND PREDICTION (CFS FEET)	90	24222	245	1380	2010	543	297	0	540	0	2883				32120
ABS \ REL	80	23166	171	360	990	123	72	0	300	0	3211				28426
DISTRICT TRUTH	100	23859	3596	1020	2112	1155	171	0	585	0	3194				35692

Table 4-16

DIGITAL ACREAGE WEIGHTED
LANDSAT MULTIDATE-MULTIBAND CROP CLASSIFICATION AND WATER DEMAND PREDICTION
NODES 198, 199, 204 OF THE WHEELER RIDGE - MARICOPA WATER STORAGE DISTRICT, 1974

R.S. CLASSIFICATION (AC)	DISTRICT GROUND TRUTH (AC)	% ACCURACY	DIGITAL ACREAGE WEIGHTED												
			COTTON	GRAPES	MELONS	TOMATOES	SUGARBEETS	WHEAT	FALLOW	ORANGES	NATURAL VEGETATION	OTHER	TOTAL		
COTTON	97	8495			140	30			80						8795
GRAPES	0			15											15
MELONS	0	160		80		220	220								680
TOMATOES	88			600		30									630
SUGARBEETS	27				160	160	180	100							600
WHEAT	100						630								630
FALLOW	100							600							600
ORANGES	0											45			45
NATURAL VEGETATION	100										320				320
OTHER	70	80					60	160					700		1000
TOTAL	86	8735	0	155	920	160	1090	1240	0	320	745				11505 13365
R.S. WATER DEMAND PREDICTION (CFS FEET)	92	28826	0	465	2760	560	1199	0	0	0	2518				36328
ABS \ REL	85	28034	0	0	1800	560	693	0	0	0	2360				33453
DISTRICT TRUTH	100	29024	47	2040	2040	2100	693	0	135	0	3380				39459

Table 4-17

DIGITAL ACREAGE WEIGHTED
 LANGSAT MULTIDATE-MULTIBAND CROP CLASSIFICATION AND WATER DEMAND PREDICTION
 NODES 197, 198, 199, 204, 205, 206 OF THE WHEELER RIDGE - MARICOPA WATER STORAGE DISTRICT 1974

R.S. CLASSIFICATION (AC) DISTRICT GROUND TRUTH (AC)	% ACCURACY	COTTON	GRAPES	MELONS	TOMATOES	SUGARBEETS	WHEAT	FALLOW	ORANGES	NATURAL VEGETATION	OTHER	TOTAL
COTTON	97	15515		150	260		20	80				16925
GRAPES	5		55	205				465		470		1175
MELONS	12	300		120	160		220	220				1020
TOMATOES	67		24	75	930	90	185	80				1384
SUGARBEETS	21	60			240	195	180	255				930
WHEAT	86						695	90				785
FALLOW	89	40						980	80			1100
ORANGES	42			65		30			100		45	240
NATURAL VEGETATION	100									600		600
OTHER	80	160					60	172			1553	1945
TOTAL	82	16075	79	615	1590	315	1360	2322	180	1070	1598	20743 25204

R.S. WATER DEMAND PREDICTION (acre feet)	91	53048	245	1845	4770	1193	1496	0	540	0	5401	68448
ABS \ REL	82	51200	171	360	2790	683	765	0	300	0	5249	61518
DISTRICT TRUTH	100	52833	3643	3060	4152	3255	864	0	720	0	6574	75151

Table 4-18

SUMMARY OF MANUAL AND DIGITAL CROP CLASSIFICATION AND WATER DEMAND PREDICTION
 WHEELER RIDGE-MARICOPA WATER STORAGE DISTRICT

CLASSIFICATION METHOD	PRIMARY	SECONDARY	TOTAL AREA	ACREAGE WEIGHTED PRIMARY	ACREAGE WEIGHTED SECONDARY	ACREAGE WEIGHTED TOTAL AREA	PRIMARY WATER DEMAND ACCURACY	SECONDARY WATER DEMAND ACCURACY	TOTAL WATER DEMAND ACCURACY
MANUAL HIGH ALTITUDE	72	60	66	71	63	66	73	65	70
MANUAL LANDSAT	76	67	71	76	70	73	78	70	73
DIGITAL LANDSAT	63	86	73	78	86	82	80	85	82

Performance of 2 interpreters (1 high altitude, 1 LANDSAT) from a group of eight interpreters (4 high altitude, 4 LANDSAT). Acreage weighted accuracies and water demand predictions approximate using a single interpreter's results.
 Geography Faculty Spring Unit, University of California, Santa Barbara

digital performance. An 82% accurate crop identification yielded an 82% absolute water demand prediction. The 91% accurate relative water demand prediction is 3% lower than the manual LANDSAT (Table 4-14) and 7% lower than the manual high altitude (Table 4-9). This suggests that although the relative water demand accuracies are high, it would not be advantageous to conduct a water demand survey hoping that if misclassifications occur they will correspond to similar water demanding crops. As shown here, there may be a decline in this relative water demand accuracy which could be more pronounced in other environments. The ideal is to base a water demand prediction on crop inventories which the user feels are absolutely accurate.

Table 4-18 is provided to summarize the manual and digital crop classifications and water demand prediction results presented thus far. Note that there is a hierarchy with the LANDSAT digital approach being the most effective and manual high altitude the least. Of course, the user must carefully evaluate the tradeoff between technique costs and possible returns. Analyses of the equipment and implementation costs for the specific techniques in Appendix I enable the user to make a decision.

4.46 Digital Crop Identification of Multidate LANDSAT Transparencies Using a Point Densitometer and Discriminant Analysis Classification Algorithm (C).

The previous LANDSAT digital crop identification procedure requires substantial hardware and programming expertise. Also, the cost of computer compatible tapes (CCTs) at \$200 per date is a serious constraint to many users. Consequently, considerable research has gone into the development of procedures which allow agencies with modest equipment expense and a "packaged" discriminant analysis program available at many computer facilities to conduct repeatable, computer assisted crop identification. A 1973 crop identification and water demand prediction for node 199 in the Wheeler Ridge-Maricopa Water District will be demonstrated using this technique.

LANDSAT Image Inventory, Assessment, Acquisition, and Formatting: These procedures are adequately defined in the manual LANDSAT crop identification procedure. The only difference here is that instead of color composites, each individual channel available throughout the growing season is ordered in a positive transparency format. For example, Table 4-19 lists the available 1973 MSS imagery of node 199 purchased. The 1:1,000,000 scale transparencies are already in a suitable format as this technique does not require geometric rectification if reasonable (5 square miles) test regions are under investigation.

Ground Truth, Field Boundary Overlay and Crop Phenology Information: Each of these previously discussed components is necessary, however, the field boundary overlay (Figure 4-14) is of critical importance in this

Table 4-19

Inventory of 1973 LANDSAT Imagery for Node 199
in the Wheeler Ridge-Maricopa Water District

<u>Date</u>	<u>Bands Available</u>
January 2	4 5 6 7
January 20	6 7
February 7	clouds
February 25	4 5*6*7*
March 14	4 5 6 7
April 2	4*5*6*7*
April 20	4*5*6*7*
May 7	4*5*6*7*
May 26	4 5 6 7
June 12	4*5*6*7*
June 30	4 5 6 7
July 18	4*5*6*7*
August 6	clouds
August 23	4*5*6*7*
Sept 11	4 5 6 7
Sept 29	clouds
October 17	4*5*6*7*
November 4	4 5 6 7
November 22	clouds
December 9	clouds
December 28	clouds

* bands purchased

procedure. The task of identifying individual fields on 1:1,000,000 LANDSAT transparencies is accomplished by producing field boundary maps for each node or group of nodes and then photographically reducing these outline maps to the exact scale of the LANDSAT imagery (see rightmost image on Figure 4-22). The inclusion of permanent features on this field boundary map such as canals, highways, etc., makes alignment of the reduced overlay upon the transparencies a relatively simple task. The most important requirement for this approach is that precision photographic facilities be available to insure accurately scaled field boundary reductions.

Training and Test Field Selection and Data Extraction: As each field in a region is assigned a specific number, the selection of training and test fields becomes a straightforward matter when used in conjunction with a limited amount of field verified data. The field boundary overlay provides its most important function as a method for multiple image correlation with data extracted on a per-field basis from successive images. This data extraction may be accomplished in a variety of ways including the use of an inexpensive optical or video point densitometer (see Figures 4-20 and 4-21 respectively). An added advantage of the video densitometer is its potential for computer controlled point data extraction if digitization hardware and software can be appended. Nevertheless, the simple optical densitometer can be used to manually extract point density measurements for training and test fields for all bands desired.

Important elements of this capability are apparent. Instead of being restricted to just a few dates in the growing season due to CCT costs, the user now has the option of analyzing all potential channels and then selecting an optimum subset for crop identification.

Crop Classification and Water Demand Prediction: With training and test data extracted on a per field basis and an intuitive evaluation made concerning optimum channels to be used in the classification, the dataset is ready to be interrogated. There are numerous discriminant analysis "packaged" programs available. Output presented here documents the Statistical Package for the Social Sciences (1976) whereas previous research used UCLA's Biomedical Statistical Package BMDP-Biomedical Computer Programs (1975). The variables used in these analyses are the density values for the LANDSAT bands selected. The groups are the croptypes under consideration. By training the computer on known fields a contingency table showing training performance is produced. Table 4-20 documents such results for the 24 training fields in the node 199 example. Except for discriminating melons, the training data appears to be adequate. With the classifier trained on these 24 fields it can now be applied to the 52 test fields which are not given a class code (i.e. croptype) when input to the classifier. The discriminant analysis algorithm assigns each "unknown" case to that group of which it has the highest probability of being a member. When using these packages the user must manually evaluate classified

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Figure 4-20. Macbeth point densitometer. (Macbeth Corporation, Newburgh, New York.)

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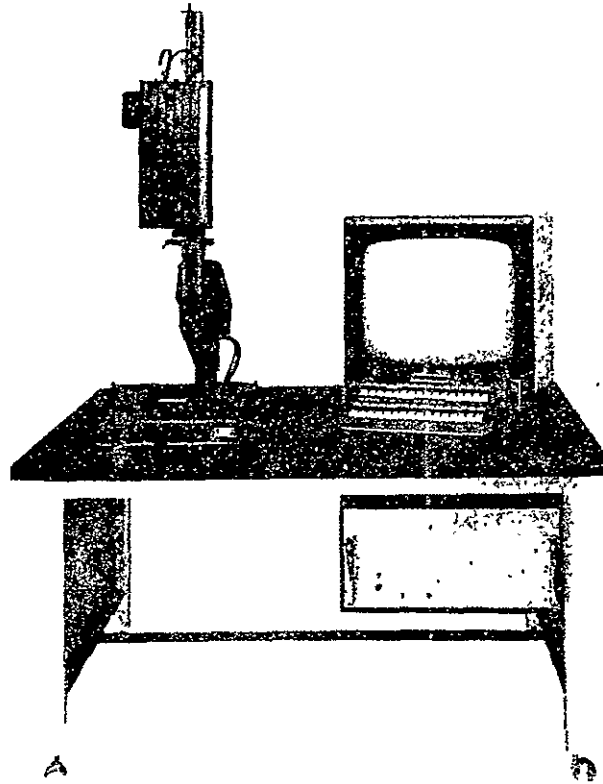


Figure 4-21. Spatial Data video densitometer. (Spatial Data Systems, Inc., Goleta, California.)

Table 4-20

DIGITAL LANDSAT TRAINING FIELD CROP CLASSIFICATION:
NODE 199 OF THE WHEELER RIDGE-MARICOPA WATER STORAGE DISTRICT, 1973

R.S. CLASSIFICATION \ DISTRICT GROUND TRUTH	% ACCURACY	BARLEY	COTTON	MELONS	SUGARBEETS	SAFFLOWER	TOTAL
BARLEY	80	4	1				5
COTTON	100		5				5
MELONS	40	1	1	2		1	5
SUGARBEETS	60				3	2	5
SAFFLOWER	100					4	4
TOTAL	75	5	7	2	3	7	18 24

Table 4-21

DIGITAL LANDSAT TEST FIELD CROP CLASSIFICATION:
NODE 199 OF THE WHEELER RIDGE-MARICOPA WATER STORAGE DISTRICT, 1973

R.S. CLASSIFICATION \ DISTRICT GROUND TRUTH	% ACCURACY	BARLEY	COTTON	MELONS	SUGARBEETS	SAFFLOWER	TOTAL
BARLEY	60	3		1		1	5
COTTON	100		35				35
MELONS	0				3	2	5
SUGARBEETS	67				2	1	3
SAFFLOWER	100					4	4
TOTAL	85	3	35	1	5	8	44 52

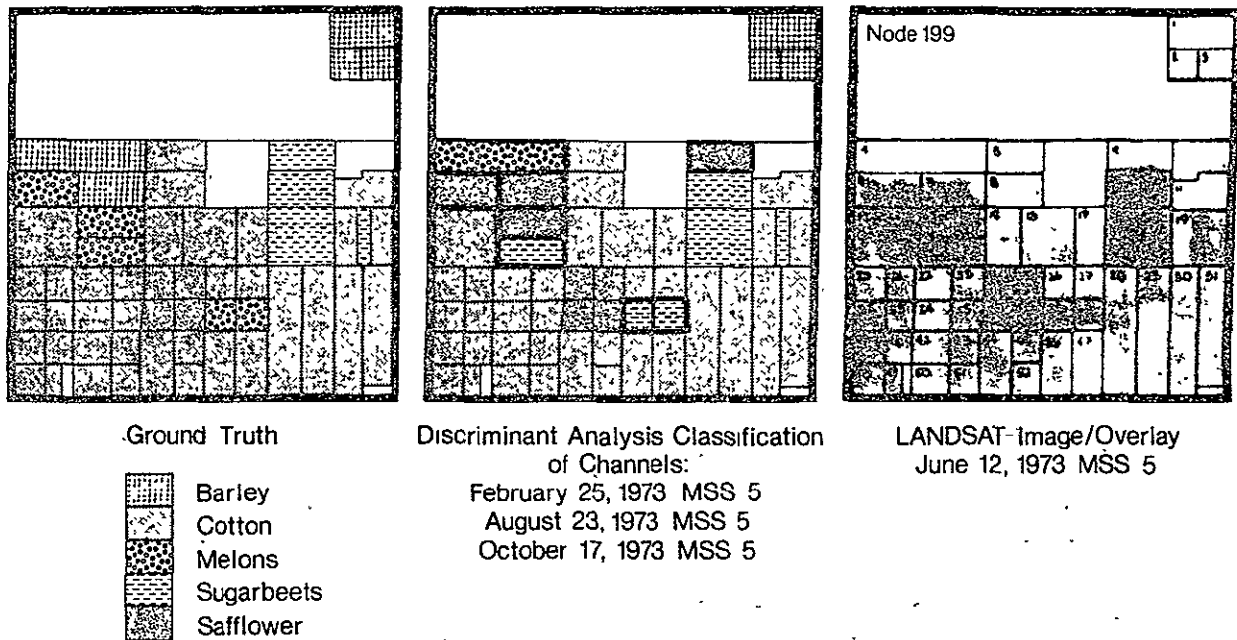
Table 4-22

DIGITAL LANDSAT TEST FIELD ACREAGE WEIGHTED CROP CLASSIFICATION
AND WATER DEMAND PREDICTION
NODE 199 OF THE WHEELER RIDGE-MARICOPA WATER STORAGE DISTRICT, 1973

R.S. CLASSIFICATION (AC) \ DISTRICT GROUND TRUTH (AC)	% ACCURACY	BARLEY	COTTON	MELONS	SUGARBEETS	SAFFLOWER	TOTAL
BARLEY	40	160		160		80	400
COTTON	100		2520				2520
MELONS	0				160	160	320
SUGARBEETS	75				240	80	320
SAFFLOWER	100					160	160
TOTAL	83	160	2520	160	400	430	3080 3720

R.S. WATER DEMAND PREDICTION (acre feet)	95	176	7338	458	1140	1593	11260
ABS. \ REL.	87	176	7838	0	684	533	9231
DISTRICT TRUTH	100	440	7883	915	912	533	10688

LANDSAT MULTIDATE CROP CLASSIFICATION FOR NODE 199
 WHEELER RIDGE - MARICOPA WATER STORAGE DISTRICT
 KERN COUNTY, CALIFORNIA



Geography Remote Sensing Unit, University of California, Santa Barbara

Figure 4-22. A discriminant analysis classification map of the three most optimum channels (as specified by divergence statistics) compared with the ground truth map. Note the LANDSAT image/overlay which facilitates registration and data extraction of multidate images on a per-field basis. Crop identification and water demand accuracies associated with this inventory are given in Table 4-22.

test data in order to derive the test region contingency table illustrated in Table 4-21. The results of the Node 199 classification are presented in map format in Figure 4-22. With a small amount of programming the per field statistics can be manipulated to yield both the acreage weighted crop identification and water demand prediction desired (Table 4-22). In this instance, the user must provide per field acreages and local water application rate statistics.

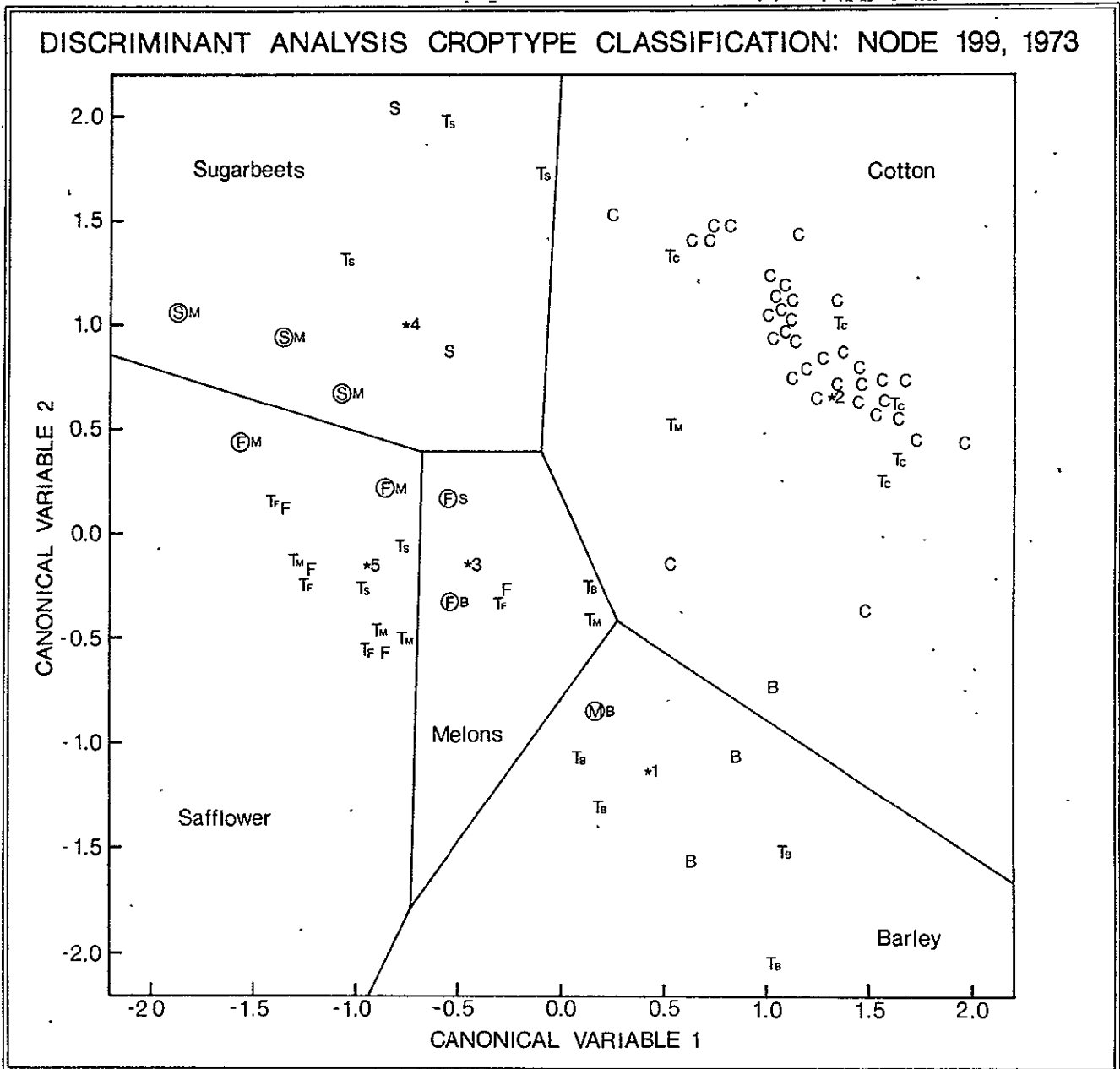
The "packaged" discriminant analysis programs normally plot the location of the cases according to their scores on the first two canonical variables. This is valuable because one can visually identify those fields which are incorrectly classified and analyze them in relation to their cluster location (Figure 4-23). In the Node 199 example it is apparent why the cotton classification was so high. Most all of the cotton training and test data exhibit signatures which cluster in a region separate from all other classes. Conversely, by re-evaluating the training class statistics in Table 4-20 in conjunction with Figure 4-22 we realize why melons are misclassified. Most melon training fields are located in other croptype regions. An iteration of the entire classification procedure with new melon training data might improve the test region melon classification.

While this technique is tailored to users with little equipment and software, it has a great potential for maximizing CCT digital classification techniques previously discussed. Agencies capable of doing CCT interrogation often have image digitization capabilities. Consequently, computer controlled digitization and per field data extraction could take place for training fields in each channel throughout the growing season. This data could be input to the LARSYS statistical separability analysis termed "divergence." Divergence rank orders subsets of images (i.e. all combinations of channels as specified such as two, three, or four at a time) in terms of their class identification capability. Consequently, by investing a relatively small amount of dollars in transparencies and data extraction, the agency could make improved CCT purchases by knowing the optimum dates beforehand.

4.5 SUMMARY

The agricultural water demand prediction procedures were developed for a representative semi-arid region in central California. They may be applied to other water demanding regions if careful attention is given to the following procedural steps:

Empirically identify the regionally important nature of the water demand prediction variables, i.e. which parameters account for the most variance in the prediction procedure.



Geography Remote Sensing Unit, University of California, Santa Barbara

Figure 4-23. LANDSAT based discriminant analysis crop classification of Node 199 (Wheeler Ridge-Maricopa Water Storage District), 1973 growing season. Plotted are the first two canonical variables derived from 2/25/73-MSS 5, 8/23/73-MSS 5, and 10/17/73-MSS 5 imagery. Decision boundaries separate the five fairly distinct clusters, each representing a different croptype. Training fields from surrounding nodes are identified by letters T = barley, T = cotton, T = melons, T = sugarbeets, T = safflower; class means are shown as *1, *2, *3, *4, and *5 respectively. Test data (B, C, M, S, F) represent individual fields of Node 199. Fields misclassified are circled and correct classification, according to Water District crop map, are subscripted.

- * Evaluate information sources and identify those parameters which due to temporal or accuracy constraints should be inventoried using remote sensing techniques. Based on previous research, it is assumed that the agricultural landcover will be a major model driver.
- * Select one of the inventory techniques by evaluating the level of information detail required and the agency's hardware, software, and collateral information resources.
- * Conduct the agricultural landcover inventory.
- * Develop spatially accurate water demand predictions by interrogating the landcover dataset in conjunction with average irrigation rates.

The water demand estimates may then be used to make short and long-term water resource management decisions regarding groundwater recharge, taxation schedules, and/or intra-regional water transfer.

4.6 FUTURE WORK

The proposed research for the period beginning May 1, 1977 will be to perform a total resource complex inventory of the valley portion of Kern County, California. As the Geography Remote Sensing Unit has continually interfaced with public user agencies to identify information requirements and, in addition, has acquired a substantial amount of collateral information on this region in the past, we feel that the only viable method of modeling the total resource complex is to develop an analytical geobase information system. The most significant driver of this information system will be the use of digital LANDSAT thematic products which will monitor dynamic topics. Such data will be merged with other collateral information such as soils, groundwater, census, etc., to yield higher order integrative data which is spatially accurate and useful for Kern County decision makers. By April, 1978, GRSU will document the procedural manner in which other regions can initiate and successfully operate a total resource complex information system such as that developed for the Kern County study area.

APPENDIX I
MANUAL (A) AND DIGITAL CCT (B) CROP IDENTIFICATION
TECHNIQUES COST AND EQUIPMENT ANALYSIS

This section summarizes the cost and equipment requirement for conducting the manual and digital CCT crop identifications for the entire six node study area of the Wheeler Ridge-Maricopa Water District. This six node agricultural region has 408 fields totaling approximately 27,700 acres.

Manual:

The statistics presented in Table 4-23 represent:

- * The costs of the physical materials and labor required to produce the image/crop calendar keys.
- * The interpretation cost for classifying both the primary and secondary test areas.

Results indicate that for operational considerations there is no appreciable difference in cost between the highflight and LANDSAT approaches i.e., only \$42 separates them. Since there was no significant difference in the classification accuracy of the manual high altitude and LANDSAT interpretations, we consider it interesting that the costs are also very comparable. This suggests that resource managers may take maximum advantage of either medium i.e., high altitude photography or LANDSAT imagery, when available for their particular study area and that comparable accuracies and costs could result.

Also of importance is the very minimal amount of capital equipment required to conduct manual crop identifications. Table 4-24 identifies the only major item as being a photographic laboratory capable of enlargement/reduction and modest color production. However, an agency could use standard commercial processing if necessary.

Digital:

The statistics presented in Table 4-25 represent the costs of:

- * Computer compatible tapes (CCT)
- * Geometric rectification and registration
- * Channel selection divergence
- * Classification, and

* An image analyst (programmer).

Compared to the mean cost of the manual techniques, the digital LANDSAT approach was approximately 3 times more expensive. A major factor associated with the processing of the digital LANDSAT data is the cost of tape acquisition from the EROS Data Center, Sioux Falls, South Dakota. This cost alone is nearly twice the amount required to conduct the entire analysis using either of the manual techniques.

Digital image processing required to accomplish the crop identification goals set out in our analysis necessitates access to sophisticated computer hardware and software such as the types seen in Table . This table shows the characteristics of a minimum and desired computer configuration for digital crop identification and those facilities used in our analysis. The minimum computer capability required for a low-cost data system is shown in the third column. If a computer of the minimum capability is used, the data processing time will be longer. It may be necessary to process the imagery through the computer two or more times to classify the data. Addition of computer memory is recommended where high throughput rates are required. The fourth column shows an adequate computer configuration for most potential users of remote sensing, even for state-sized survey areas.

Table 4-23 . Cost of Manual Crop Identification for the Primary and Secondary Test Areas of the Wheeler Ridge-Maricopa Water District Kern County, California*

High Altitude:

Original positive transparencies from EROS	4 @ \$12	=\$ 48.00
Cibachrome paper prints	8 @ \$ 7	=\$ 56.00
Image and Crop Calendar key creation	60 hrs @ \$ 5	=\$300.00
Interpretation time	8 hrs @ \$ 5	=\$ 40.00
		<hr/>
		\$444.00

LANDSAT:

Original positive transparencies from EROS	16 @ \$ 5	=\$ 80.00
Color Combiner 8X10" Ektacolor film	4 @ \$ 3	=\$ 12.00
Develop 8X10" negatives	4 @ \$ 3	=\$ 12.00
Paper prints	8 @ \$ 6	=\$ 48.00
Image and Crop Calendar key creation	60 hrs @ \$ 5	=\$300.00
Interpretation time	8 hrs @ \$ 5	=\$ 40.00
		<hr/>
		\$482.00

* The costs reported include the cost of image acquisition from readily available sources, but does not include the cost of aircraft or satellite mobilization.

Table 4-24. Equipment Required for Manual and Digital Crop Identification

Manual:

- Photographic laboratory for making field boundary overlays (i.e. enlargement & reduction of images)

Digital:

CATEGORY	FACILITIES USED IN OUR ANALYSIS	MINIMUM	DESIRED
Central Processor Unit with Operators Console	yes	yes	yes
Memory	yes	16K, 16 bit words	64K, 16 bit words
Tape Drives (CCT)	yes	Two 7 or 9 track	Two 9 track, 3.05 MPS (120 IPS), 315 Byt/cm (800BPI)
Disc (Rotating Memory Device)	yes	12M, 16 bit words	46M, 16 bit words
Line Printer	yes	yes	yes
Electrostatic Printer	no	no	yes
Card Reader	yes	yes	yes
Floating Point Hardware	yes	no	yes
Micro Programmable Writable Control Storage	no	no	yes
Operating System	yes	no	yes
FORTRAN Compiler	yes	yes	yes
Optical Mechanical Scanner	yes	no	yes
APPROXIMATE COST		\$75-80K	\$200-250K

Table 4-25. Cost of Digital Crop Identification for the Primary and Secondary Test Areas of the Wheeler Ridge-Maricopa Water District Kern County, California

LANDSAT:

Computer Compatible Tapes from ERTS	4@ \$200	= \$ 800.00
Geometric Rectification and Registration		
16 Channels x 5 min cpu @ \$100/hr (JPL)		= 133.00
16 channel divergence: combinations of 4 channels		
58.3 min cpu (UCSB) + 2000 Disk I/O		= 71.00
4 channel classification		
76.3 min cpu (UCSB) + 6000 Disk + Tape I/O		= 203.00
Image Analyst (programmer)		
30 hrs @ \$10./hr.		= 300.00
		<hr/>
		\$1507.00

CHAPTER 5

WATER DEMAND STUDIES IN SOUTHERN CALIFORNIA

Co-Investigator: Leonard W. Bowden, Riverside Campus
Contributors: Claude W. Johnson, David A. Nichols,
and Richard A. Bartko

Chapter 5

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Chapter 5

WATER DEMAND STUDIES IN SOUTHERN CALIFORNIA

Co-Investigator: Leonard W. Bowden, Riverside Campus
Contributors: Claude W. Johnson, David A. Nichols
and Richard Bartko

5.1 SUMMARY

Efforts on the grant by the Riverside Campus the past year have been directed toward refining some of the parameters utilized in estimating water demands and documentation of land use mapping procedures. The parameter studies involve irrigated agriculture differentiations and techniques for inter-censal population estimates. The Procedural Manual for Land Use Mapping is being written to provide public and private agencies step by step procedures in some of the newer methods developed in connection with the Water Demand Studies.

The differentiation between irrigated and non-irrigated agriculture has been a concern of the State of California Department of Water Resources (DWR) in their land use mapping program for years. There has been no cost effective method of detecting the two types of agriculture other than actual field inspection. The cost effectiveness restriction strongly suggests the use of Landsat imagery to provide a multi-date data base. Working in conjunction with the EROS data center and the Jet Propulsion Lab (JPL), we are investigating image processing techniques to provide such data.

The inter-censal population studies are directed toward providing the ability to accurately estimate the population, and more specifically, the actual location (as opposed to census area) so that DWR is better able to apply their per capita water demand models in their estimating procedures.

Our experience and generation of new techniques developed from the Water Demand Studies has enabled us to write a Procedural Manual for Land Use Mapping. Initial reaction to the preliminary draft has been that more detail is required for each of the several steps in the outline. One specific area of expansion that has been recommended deals with automated processing. Therefore, we intend to document and publish the necessary users' manual for these programs in the coming year. Comments about the manual by DWR are included in Appendix 5-I.

With this report we are making an initial overall evaluation of what we feel is the effect we have had upon the DWR as a result of the water demand studies conducted over the past several years. A discussion of the two current water demand studies directed toward refining specific parameters is also included. A section is included to provide a detailed outline of the Procedural Manual for Land Use Mapping with several of the illustrations that will appear in the manual. The report concludes with anticipated studies for the coming year.

5.2 CURRENT STUDIES: WATER DEMAND INVESTIGATIONS UTILIZING REMOTE SENSING

5.2.1 Preliminary Evaluation of the Impact of the Water Demand Studies on DWR.

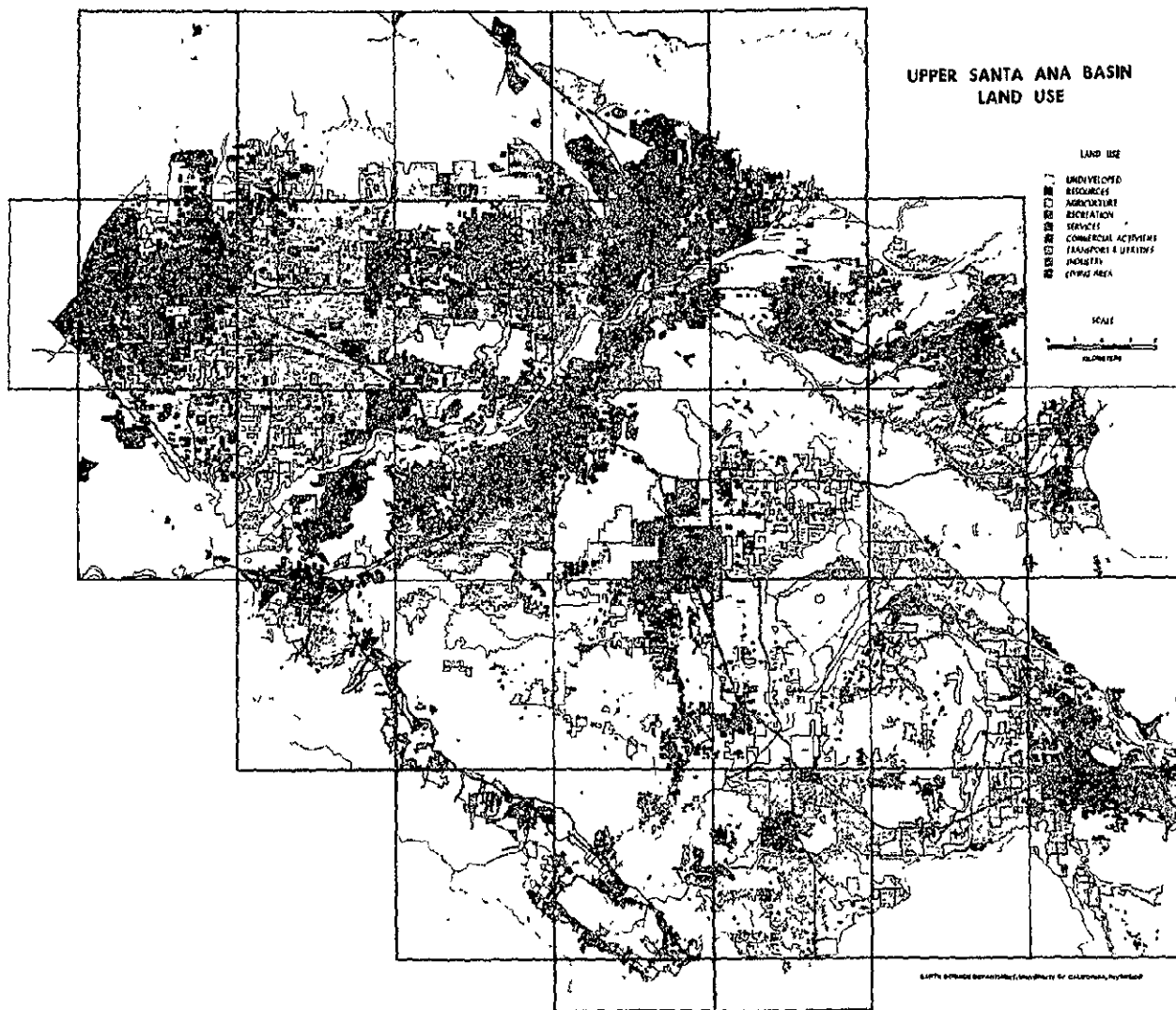
One of the primary objectives of the water demand study was to determine if remote sensing could provide a more cost effective means of determining water demand. In consulting the State of California Department of Water Resources (DWR) it was found that land use was considered the driving parameter in their water demand model. Using land use as the central theme we proceeded with the study producing an automated map display (figure 5.1) of the 586,618 hectares (1.5 million acres) of the Upper Santa Ana River Drainage Basin. Details of the study have been previously discussed in our annual reports. As a result of the study we have been able to reach the following selected conclusions:

1. Without the use of remote sensing, DWR does not have the physical resources to collect the data necessary to estimate water demand in each of various regional basins.

The current DWR schedule of land use mapping of the 11 hydrologic study areas (each containing two or more sub-units) is to update the information once each decade. The DWR has been able to maintain the decade schedule (considered by many analyst as grossly inadequate because of the rapid conversion of land to urban use) with an acceptable degree of accuracy by assistance from available NASA imagery. Over the past few years DWR analysts have spent many weeks utilizing the NASA imagery in the university film libraries.

2. The degree of cost-benefit or the extent of the cost effectiveness of establishing water demands utilizing remotely sensed data depends upon:
 - a. The type and scale of imagery being utilized, and
 - b. The extent to which the actual user is able to automate the data reduction and storage techniques.

In performing the study an attempt was made to provide land use data to the same detail which is currently being used by DWR. The detail required ground resolutions of 6 meters (20 ft.) and, therefore, increased both image acquisition cost and data reduction cost. We question that DWR requires the detail of land use they are currently obtaining. With the fine resolution of the present land use mapping procedures being utilized by the DWR the major savings can be made by automating the data reduction, storage, and display techniques. To establish the total areas (acreages) of each type of land use DWR expends many man hours to manually cut and weigh specially prepared maps. Financial constraints prevent the DWR from automating the process to establish area total within a few minutes, as has been developed by this study. To update a map DWR must redo all work manually. Our automated system allows updating in less than eight man hours. Cost benefits can be realized in making water demand estimates



5-3

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Figure 5.1 General Land Use Map of the Upper Santa Ana River Drainage Basin.

from remotely sensed data by using lower resolution imagery (mapping land use in grosser detail) and by instituting automated procedures.

3. The DWR has altered some of their land use mapping techniques in line with the recommendations and findings presented in this study over the past few years.

The availability of large format color infrared imagery acquired by NASA (at no cost to DWR) has enabled the department analysts to obtain much of their recent land use data by means of remote sensing. This has been in lieu of extensive ground surveys and many small format (including 35mm slides) images in black-and-white and color. By using the large format, small scale, and lower resolution imagery, the DWR can still obtain the desired detail at lower acquisition costs. In addition, some of the newer transfer techniques (Cronoflex image and/or map overlays) as outlined in section 5.3.2 (Land Use Mapping Techniques) are being adopted by the DWR.

4. The availability of U-2 and Landsat imagery and the development of automated geographic information systems and land use mapping displays under the water demand study are leading DWR to consider both of these alternatives in their long range planning.

There has been no apparent immediate impact on personnel of the DWR resulting from our Water Demand Study. However, a gradual trend has been noted in the thinking of DWR management in considering future adaptation of some of the advanced techniques being developed. Landsat imagery may be used to establish areas of concern due to rapid change and then to make a detailed update from other imagery. The possibility of obtaining contracted high altitude imagery of 1/10 or 1/5 of the state each year has also been suggested. This would provide complete coverage of the 100 million acres at least every five to ten years.

5.2.2 Irrigated Agriculture Change Detection Utilizing Landsat Imagery

Introduction

Approximately 85% of total water use in California is for agriculture. It is essential that accurate and timely figures relating agricultural land use to water consumption be made available to water resource planners. The California Department of Water Resources (DWR) maps land use on a ten year cycle. The maps include agricultural uses and provide the basis for agricultural water demand estimates. Changes that occur between mappings go undetected. These changes are substantial where rapid urbanization is taking place.

One of the primary concerns in estimating water demand is the determination of irrigated vs. non-irrigated agriculture. The Riverside Campus has been requested by DWR to investigate methods by which irrigated and non-irrigated agriculture can be mapped and monitored on a more timely basis than present. The temporally regular and large area coverage of Landsat is believed a suitable data source for this purpose. The investigation is directed toward an understanding of Landsat capabilities within the context of DWR's agricultural water demand estimation procedures.

and to provide a method for updating agricultural irrigated and non-irrigated classifications on a yearly basis. A study area has been selected in which a wide variety of agricultural and urban land uses exist and intermingle. Figure 5.2 shows an entire Landsat scene (June 1974) with the study area bounded by a rectangle.

Description of Study Area

Agriculture in southern California is quite varied and includes irrigated and dry-farmed grains, vegetable crops, permanent tree crops, and improved and unimproved grazing lands. Multiple cropping (raising more than one crop per year on a given field) is a common practice, especially with the vegetable crops. Dry-farmed grain fields are usually left fallow every other year. Some grains are prematurely cut (green chop) for hay. A wide variety of cultural practices combines to present complex agricultural patterns. Nowhere in southern California is this entire milieu of cultural practices better represented than in the Perris Valley.

Figure 5.3 is a location map of the Perris Valley. The Perris area is sited on what is commonly referred to as the Perris Block, a relatively homogeneous surface that has been uplifted by faulting. The San Jacinto Fault and the Elsinore Fault delineate the Perris Block with their traces trending northwest-southeast. The northeast and southwest borders are defined by the Santa Ana River and a low upland complex, respectively.

Agriculture in Perris Valley is confined primarily to areas of alluvial fill. Irrigated and non-irrigated agriculture are mixed throughout the area with the non-irrigated lands being found primarily on the more rolling topography. In the northwest part of the Perris Block, granitic outcrops of the southern California batholith preclude significant agriculture; citrus, however, is found in the more favored areas.

Experimental Design

There are essentially two methods by which updating can be performed. Each method has different accuracy as well as data processing costs. A long established tradition of the Riverside campus is that, to be successful in transferring applications of remote sensing, the methods employed must be within the general technological capabilities of the user.

The first method which may be applied to updating procedures is to reclassify the entire area in question at each point in the update cycle. To do this by traditional ground survey methods would result in no expansion of capabilities because the update cycle could not be compressed further. An automated classification of Landsat data presents an alternative to ground survey methods. However, the DWR has specific classification requirements relating to water use which are difficult to accommodate with a data base which is essentially a record of ground cover. Costs of the better automated classifiers are prohibitive for classification accuracies of 90% or more. Perhaps at some point DWR can reconcile their data needs with that which is supplied by satellite sensing. In combination with decreasing data processing costs, a systematic reclassification may be both acceptable and cost effective.

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Figure 5.2 Landsat scene as displayed on the Image-100.
The Perris Valley study area sub-scene is shown by
the rectangle.

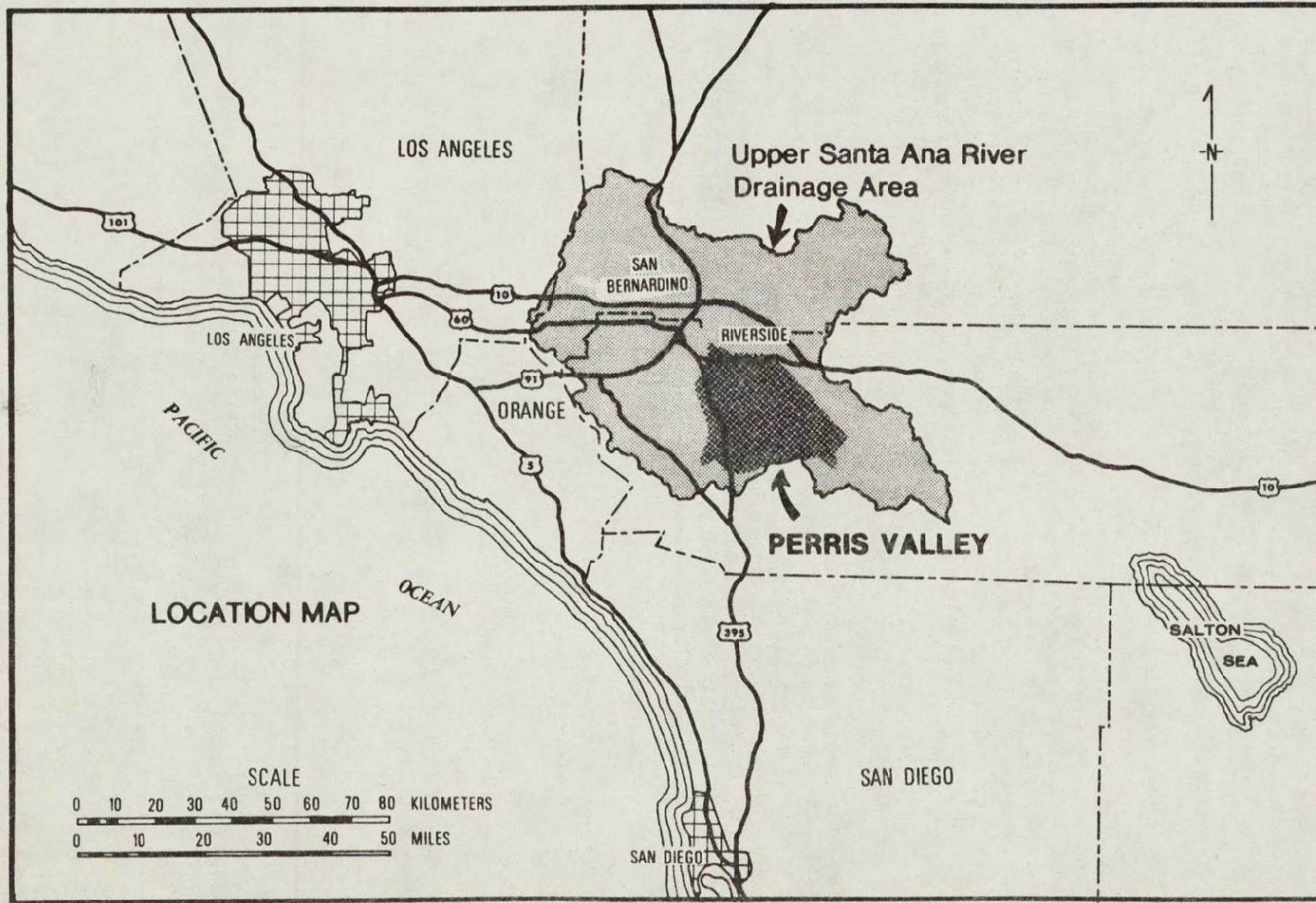


Figure 5.3 Location map of the Perris Valley area within the Upper Santa Ana River Drainage Basin.

A second method of updating relies on the interpretive powers of a ground surveyor but utilizes Landsat to focus the activities of that surveyor in areas where change is taking place. This leads to a maximization of the field worker's time. In this method, multi-temporal Landsat data are processed so as to detect change. When change is mapped the surveyor can then go into the field and evaluate the nature of that change. Change detection is the approach taken in this experiment.

The change detection method leads to a two-fold consideration of accuracies. First, if a change is detected, what is the probability of there being a change that is significant enough to be mapped? It is possible that accuracies on the order of 50% are acceptable, maybe even less. The inverse is whether or not the change detection system detected all the change that is significant. Much higher accuracies would be required in the latter case. Because we do not have to be concerned with misclassifications, it is likely that high accuracies are more achievable than that required for a complete reclassification as described above. Therefore, in evaluating change detection for irrigated and non-irrigated classifications one must ask: 1) what percentage of all detected change is actually significant, and; 2) has all significant change been identified?

The data being utilized for this investigation consist of Landsat, 4-band, digital data for June 24, 1974 and June 10, 1975. The data for these scenes were windowed using a 512 x 512 pixel subscene. Figure 5.2 shows the entire June 1974 scene with the subscene window represented by a rectangle. Due to different coverage on the two satellite passes, the subscene coverages are different. The 1975 subscene is shifted south relative to the 1974 subscene. After windowing, the data were contrast enhanced for the two subscenes (Figures 5.4 and 5.5). The subscenes were then registered so that multi-temporal overlay analysis could be performed.

Additional remote sensing data are being utilized in the form of high altitude U-2 aircraft imagery. Recent flights for the Perris Valley study area are:

- | | | | |
|----------|------|--------------|--------|
| 1) March | 1974 | NASA Mission | 74-041 |
| 2) June | 1974 | " | 74-091 |
| 3) Oct. | 1974 | " | 74-181 |
| 4) Nov. | 1974 | " | 74-201 |
| 5) Dec. | 1975 | " | 75-201 |

The June 1974 data are being used as 'ground truth' for the June 1974 Landsat scene. 'Ground truth' for the Landsat 1975 scene is in the form of land use maps prepared by DWR in the summer of 1975. No U-2 imagery is available for spring or summer of 1975.

After pre-processing of the Landsat data, band 5(.6-.7 μ) and band 7(.8-1.1 μ) were ratioed as follows:

$$\text{Band 5 1975} \div \text{Band 5 1974}$$

$$\text{Band 7 1975} \div \text{Band 7 1974}$$

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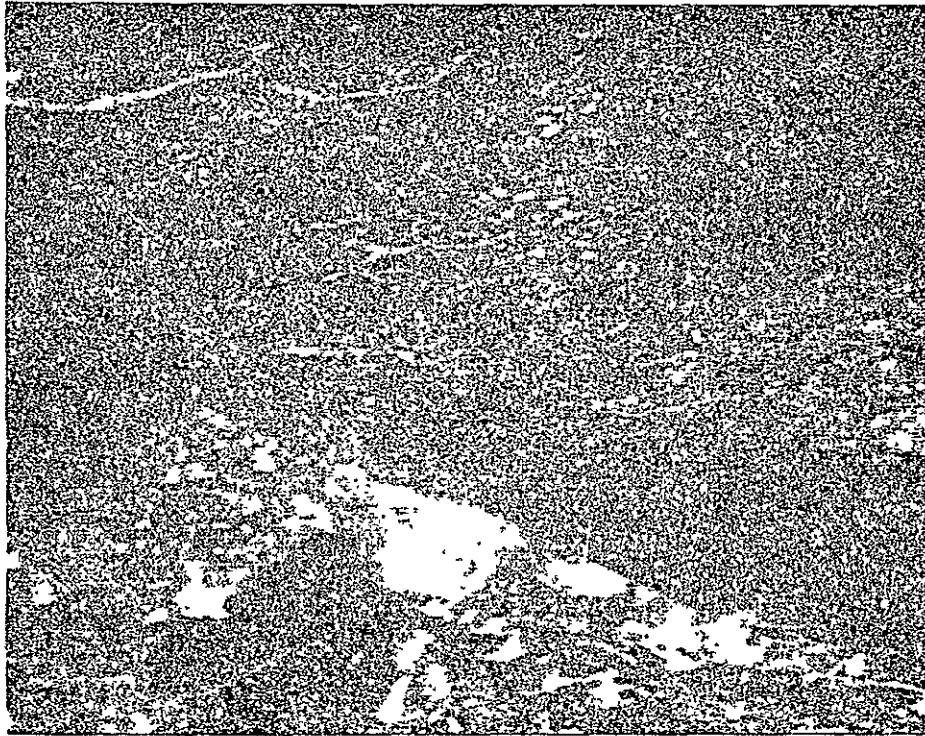


Figure 5.4 Subscene of the Perris Valley study area for June 1974. The image has been contrast enhanced.

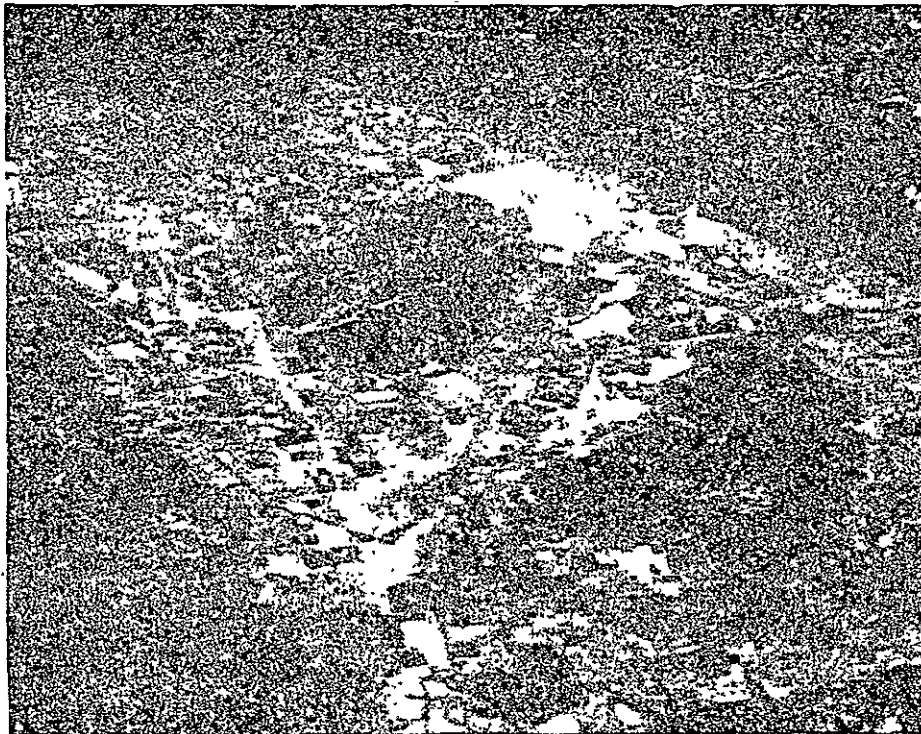


Figure 5.5 Subscene of the Perris Valley study area for June 1975. The image has been contrast enhanced.

The basic tenet of this procedure is that high or low ratios indicate changes in spectral response and therefore in land use. A ratio of 1 would of course be no spectral change.

The extreme highs and lows of both ratio operations were visually identified and parameterized for execution of a parallelopiped classifier. The net result is four maps or images which represent:

- | | | |
|---------------|-----------------|------------|
| 1) High ratio | Band 5 ÷ Band 5 | Figure 5.6 |
| 2) Low ratio | Band 5 ÷ Band 5 | Figure 5.7 |
| 3) High ratio | Band 7 ÷ Band 7 | Figure 5.8 |
| 4) Low ratio | Band 7 ÷ Band 7 | Figure 5.9 |

Preliminary Results

Detailed analysis of the nature of change detected above has not yet been carried out. Preliminary inspection of the images indicates the following:

1) High ratio, bands 5 - Represents a change from irrigated agriculture to either a non-cropped or non-irrigated field. Spectral response for band 5 has increased.

2) Low ratio, bands 5 - Represents a change to irrigated agriculture from either a non-cropped or non-irrigated field. Spectral response for band 5 has decreased.

3) High ratio, bands 7 - Represents a change to irrigated agriculture from either a non-cropped or non-irrigated field. Spectral response for band 7 has increased.

4) Low ratio, bands 7 - Represents a change from irrigated agriculture to either a non-cropped or non-irrigated field in some cases. Changes from non-irrigated to irrigated but non-cropped fields also tend to be detected. Spectral response for band 7 has decreased.

While initial results from this analysis are encouraging, it is difficult to systematically evaluate the postulated changes with respect to the accuracy considerations described above. The major difficulty arises as a result of interpretation of the concept of irrigated versus non-irrigated fields and the effect on acquiring useable 'ground truth'. As stated above, 'ground truth' for 1974 and 1975 consists of U-2 high altitude imagery and DWR land use maps, respectively. Classification based solely on imagery is impossible because comparable imagery does not exist for both 1974 and 1975. Duplication of the 1975 DWR classification from the 1974 imagery is difficult because of the way in which DWR views the irrigated/non-irrigated dichotomy, as explained below.

Mapping performed by DWR with respect to irrigated or non-irrigated classification may take into account cultural practices which are known or strongly suspected but not in evidence at the time of survey. DWR does not take a

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Figure 5.6 High change ratio, bands 5. Irrigated agriculture to no-crop is represented by red. Note: red does not mean high Infrared reflectance.

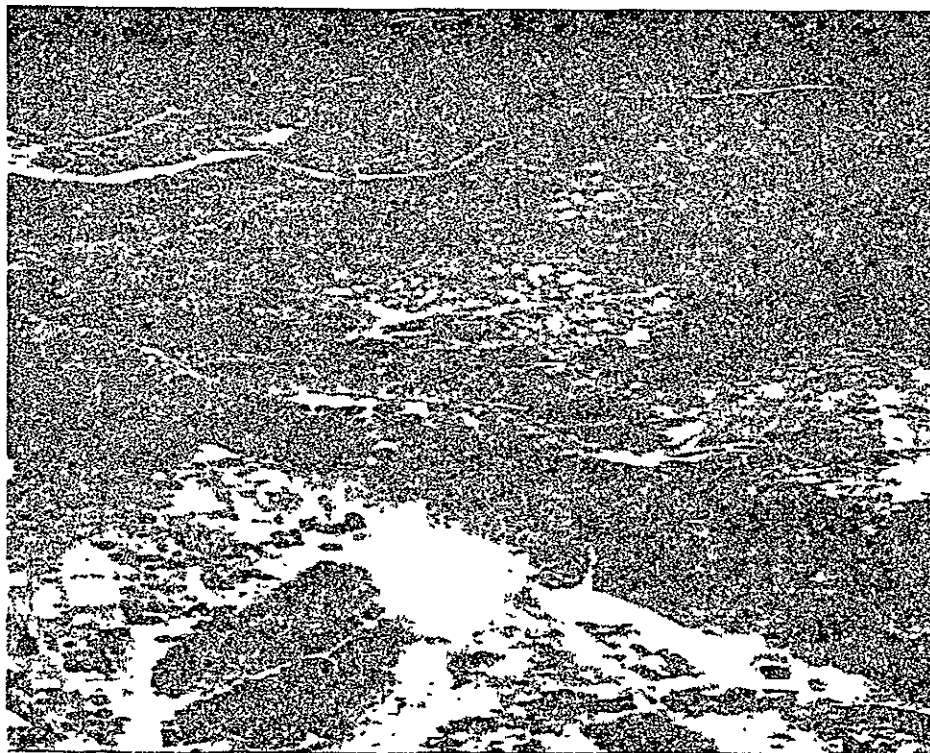


Figure 5.7 Low change ratio, bands 5. No-crop changing to irrigated crop is represented by blue.



Figure 5.8 High change ratio, bands 7. No-crop changing to irrigated crop is represented by yellow.

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Figure 5.9 Low change ratio, bands 7. A change from irrigated agriculture to a non-cropped or non-irrigated field is represented by cyan (in some cases). Changes from non-irrigated to irrigated-non-cropped fields tend to be detected and represented by cyan as well.

"time slice" approach to mapping, as would be the case with remote sensors, but allows the field worker to "integrate", over time, knowledge of field conditions. For example, the following excerpt is taken from the "Field Manual of the Land and Water Use Section, Southern District".

"At times it is difficult to determine whether grain and hay crops are irrigated. The presence of an irrigation installation is not a final determining factor. Often it may be necessary to make a decision based on local practices in order to expedite the survey. For example, if pre-irrigation seems to be a common practice in an area, all of these crops, except those which are obviously non-irrigated, are considered to be irrigated..."

In order to carry out a systematic analysis of the nature of change and resultant accuracies, methods are being investigated which will bypass these difficulties. Presently being explored is the possibility of using an unsupervised classification on the subscenes to define change in terms of the resulting information classes. Using this technique will assure a relatively consistent set of information classes from one year to the next. Additional methods will be explored as they are deemed appropriate.

In conclusion, it should be noted that for an operational change detection system, systematic characterization of change types would not be necessary as that would be carried out in the field. It is only required for evaluating the detection method for a particular region to determine efficacy.

5.2.3 Current Study: Utilization of Remote Sensing to Provide Inter-Census Population Estimates

Water demand can be divided basically into urban and agricultural uses. For estimating present urban water consumption, DWR utilizes population data and water delivery data for service districts to arrive at a per capita water use statistic. Over time these statistics yield water consumption trends which may then be used to extrapolate future water demand. This technique cannot be applied to agricultural water use because population has no relevance. For purposes of urban water demand estimation, however, this procedure is proving quite useful but has limitations for some planning purposes because of the aggregated nature of the data.

5.2.3.1 Urban Per Capita Water Demand Estimation

The urban per capita water use estimation method is a set of procedures which establishes a gallons-per-capita-per-day (gpcd) figure for urban and industrial water uses in each water service district. Its applicability is limited to those service districts where reliable population and delivery estimates are available. Procedures employed by DWR are: 1) Annual deliveries are calculated and include metered municipal and industrial use plus system losses minus agricultural use and water sold to other utilities; 2) Population for a given year is calculated by deriving persons per water service connection and/or persons per dwelling unit from census data, which is interpolated between census years and multiplied by the number of water service accounts or dwelling units. Where census data are not available population estimates are provided by the water agency itself. Therefore, annual water production

in terms of gpcd is given by the following equation:

$$\text{gpcd} = \frac{\text{Annual Production (gal/yr)}}{\text{Population}} \times \frac{1}{\text{days/yr.}}$$

Straightaway one may see that the above procedure relies heavily on population data and/or dwelling unit counts for accurate estimates. On the whole, DWR analysts feel that intercensal population estimates, which are made by the State Department of Finance, cities themselves, and water service districts on a new connections basis, are adequate for most highly aggregated long-term projections. However, these analysts have expressed a need for knowing where this population exists so that proper estimates can be made in the context of DWR's hydrological sub-unit planning areas, as well as other arbitrary aggregation units. In order to accomplish this disaggregation the spatial patterns of population must be established. This is accomplished most readily by remote sensing techniques.

5.2.3.2 Estimation of Population Using Remote Sensing

One study currently in progress addresses the need to analyze water use on a per capita basis and demonstrates the combination of data from the decennial census and high-altitude color infrared imagery. At least one value of this combination of data is the amplification of its geographic component. For example, it would be useful to show not only the extent of each census tract and its population aggregate but the actual area within each census tract that is occupied by various forms of land use. Specifically, remotely sensed data provides information which can be used to delineate land area used for housing and land area used otherwise.

Making a few assumptions about population dynamics it is possible to depict the changes in population for a small area in both positive and negative amounts. The first assumption is that the per dwelling unit population density within a census tract will not change rapidly. The second assumption is that the population density is proportional among the contiguous residential land use areas of a particular census tract. The utility of these assumptions is that by defining a density population statistic the total population of any planning unit, i.e. hydrologic sub-unit, fire district, school district, etc., can be obtained by summing the populations of all of the residential areas contained within that planning area. For residential areas which are split by planning area boundaries the per capita density figure will reveal the expected number of persons in that part of the residential unit which occurs within that planning area; information which can only be estimated relative to area. Also, intercensal population can be estimated by simply evaluating an image of the area taken at the time in question and by applying the old population density to the more recent housing pattern.

In order to test the above assumptions and the accuracy of inter-censal population estimation an experiment was carried out utilizing 1970 and 1975 census data for a portion of San Bernardino, California. The 1970 census data were derived from U.S. Census Bureau sources. The 1975 census data, which were used to check accuracies, were available as a result of a special census carried out by San Bernardino County. The study area covers twenty-seven census tracts which include high and low density housing, commercial

and industrial uses as well as areas of housing expansion and housing abandonment. Figure 5.10a is a U-2 image of the study area.

The methodology employed involved the comparison of 1970 and 1975 housing areas as mapped from high altitude NASA imagery and the extrapolation of population density from 1970 to 1975. Three maps were produced, one of census tract boundaries from an existing basemap and two from the housing interpretation. Housing was delineated from CIR 1:130,000 scale transparencies. In order to insure registration accuracy these frames were enlarged to a nominal scale of 1:62,500 and black-and-white Cronaflex images were produced. The housing area boundaries were then transferred to mylar sheets overlaid on the Cronaflex. Census tract boundaries were established on the same basemap. All three maps were then digitized for computer overlay processing. After creating a grid cell image of each map the cells were aggregated into housing and non-housing counts for each census tract for both years. Figure 5.10b shows the census tract boundaries overlaid on the 1970 housing image. The acreage value per grid cell was multiplied by the cell counts to give acreage tallies. Census data for 1970 were used to calculate density values at the tract level. The density values were then applied to the calculated 1975 housing acreages to produce a 1975 population estimate for each census tract. Two different density statistics were used as depicted in Figure 5.11. Table 5.1 contains data pertinent to the model. Estimates are contained in Table 5.2.

From the data it can be concluded that, for this experiment, population estimates are poor. This may be attributed to several causes. First, the assumption of little housing density change through time may be erroneous. However, no correlation could be found between per cent population change and per cent change in persons per occupied dwelling unit or persons per acre. Secondly, it was discovered that the grid cell approach tended to overestimate housing area. If the error is consistent in both years the impact is minimal. Another reason for poor performance, and the most compelling one, is that the 1970 and 1975 census counts were taken utilizing different enumeration methods. Therefore any estimating procedure based on change data may yield spurious results. Although the estimating procedure does not work, no reason can be found as to why it does not work.

Further redefinition of the experiment is being carried out in an attempt to control for data inconsistencies. If the reason for poor performance can be discovered, steps can be taken to improve accuracy. There is no evidence at this stage to suggest that the basic approach of utilizing remote sensing for population estimation would be fruitless.

5.3 CURRENT STUDIES: RESOURCE PLANNING DATA ANALYSIS TECHNIQUES

5.3.1 Conversion of Digitally Classified Images to a Polygon Data Structure

In the past the Riverside Campus has been concerned with the display of spatial information as derived from remotely sensed data. In particular, common output devices such as the X, Y plotter have been utilized for display of remote sensing information in a form well understood by resource planners--the choroplethic map. In addition, remote sensing has been continually evaluated, in terms of both its potential and problems, for input to geographic information systems.

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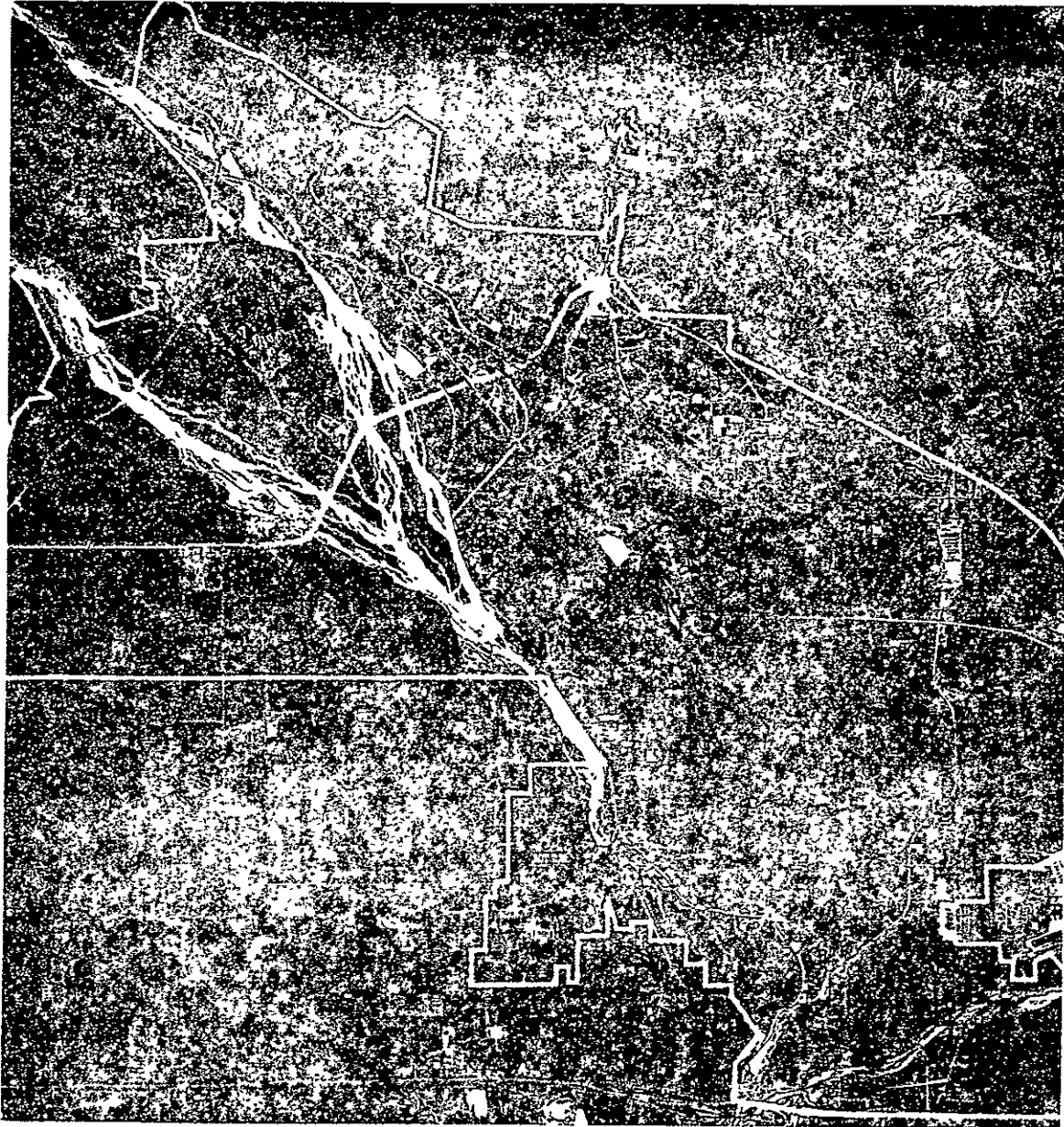


Figure 5.10a U-2 Image of San Bernardino, California showing the outline of the Inter Censal Population study area.

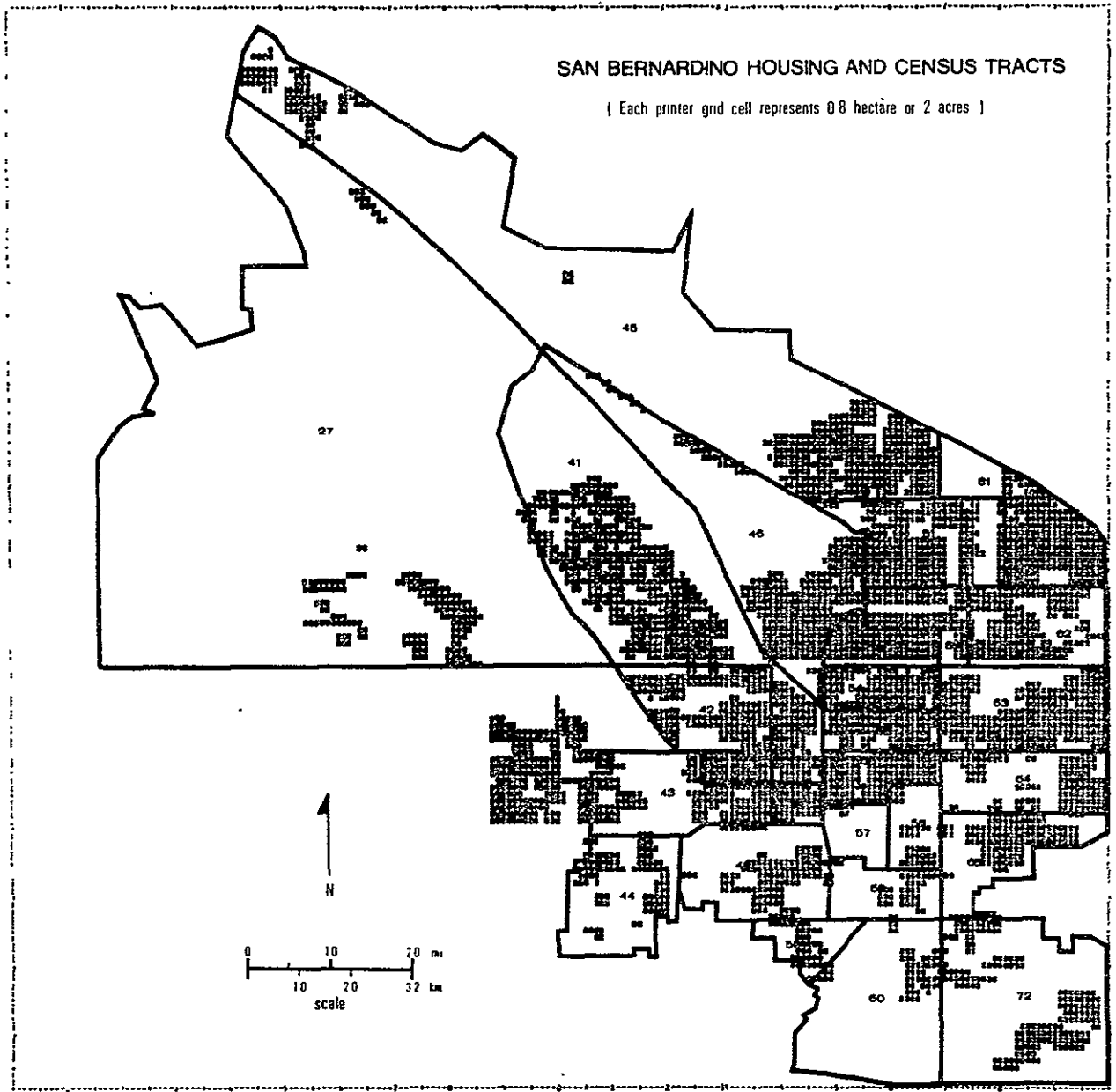


Figure 5.10b 1970 census tract map of San Bernardino, California superimposed on a map of the housing units. (Compare to figure 5.10a).

CENSUS TRACT NUMBER	POPULATION	1970			1975			CHANGE 1975-1970			
		ACRES OF HOUSING	PERSONS PER ACRE	HOUSING TOTAL ACRES	ACRES OF HOUSING	PERSONS PER ACRE	HOUSING/ TOTAL ACRES	ACRES OF HOUSING	PERSONS PER ACRE	HOUSING/ TOTAL ACRES	PERSONS PER D.U.
27	3743	490	7.64	.0300	592	6.54	.0363	102	-1.10	.0063	-.37
41	9264	1572	5.89	.3861	1746	4.38	.4288	174	-1.51	.0427	-.34
42	9714	722	13.45	.6224	810	10.33	.6983	88	-3.12	.0759	-.48
43	7375	520	14.18	.4602	562	11.49	.4973	42	-2.69	.0371	-.35
44	5093	324	15.72	.2727	336	12.01	.2828	12	-3.71	.0101	-.40
45	11139	1396	7.98	.1824	1466	7.01	.1916	70	-.97	.0092	-.40
46	8059	814	9.90	.2889	904	8.12	.3208	90	-1.78	.0319	-.16
47	4974	376	13.23	.7402	388	10.85	.7638	12	-2.38	.0236	-.38
48	2755	192	14.35	.8496	202	11.77	.8938	10	-2.28	.0442	-.28
49	4061	382	10.63	.3162	390	9.92	.3228	8	-.71	.0066	-.09
50	1971	130	15.16	.3714	138	11.59	.3943	8	-3.57	.0229	-.27
51	6842	828	8.26	.6656	798	8.03	.6415	-30	-.23	-.0241	-.30
52	3304	350	9.44	.7353	360	8.88	.7563	10	-.56	.0210	-.37
53	3997	394	10.15	.8603	370	9.70	.8079	-24	-.45	-.0524	.20
54	3681	374	9.84	.8348	370	9.89	.8259	-4	.05	-.0089	-.03
55	4767	372	12.81	.8304	372	11.91	.8304	0	-.90	0	-.10
56	4775	386	12.37	.7942	376	10.97	.7737	-10	-1.40	-.0205	-.09
57	912	48	19.00	.1500	52	16.23	.1625	4	-2.77	.0125	.03
58	2204	166	13.28	.3756	204	10.34	.4615	38	-2.94	.0859	-.69
59	1253	154	8.14	.2628	96	10.54	.1638	-58	2.40	-.0990	-.22
60	1013	164	6.18	.0873	192	4.27	.1022	28	-1.91	.0149	-.21
61	8953	876	10.22	.7180	872	9.44	.7148	-4	-.78	-.0032	-.38
62	7349	642	11.45	.6114	674	10.99	.6419	32	-.46	.0305	-.41
63	10942	942	11.62	.7009	924	10.18	.6875	-18	-1.44	-.0134	-.13
64	4813	468	10.28	.4286	472	9.70	.4322	4	-.58	.0036	-.41
65	3662	420	8.72	.4555	436	7.21	.4729	16	-1.51	.0174	.06
72	4508	634	7.11	.2548	736	6.23	.2958	2	-.88	.0410	-.24

TABLE 5.1

Census Tract Data for Selected
San Bernardino Census Tracts

TRACT NUMBER	1975 POPULATION*	METHOD 1			METHOD 2		
		ESTIMATED POPULATION	ERROR	PER CENT ERROR	ESTIMATED POPULATION	ERROR	PER CENT ERROR
27	3869	4523	654	16.9	3766	-103	-2.7
41	7649	10284	2639	34.5	9660	2015	26.4
42	8364	10894	2530	30.2	10451	2087	25.0
43	6456	7969	1513	23.4	7649	1193	18.5
44	4034	5282	1248	30.9	5144	1110	27.5
45	10272	11699	1427	13.9	11241	969	9.4
46	7341	8950	1609	21.9	8316	975	13.3
47	4209	5133	924	22.0	5091	882	21.0
48	2377	2898	521	21.9	2876	499	21.0
49	3870	4145	275	7.1	4087	217	5.6
50	1599	2092	493	30.8	2016	417	26.1
51	6410	6591	181	2.8	6677	267	4.2
52	3195	3398	203	6.4	3373	178	5.6
53	3589	3754	165	4.6	3788	199	5.5
54	3660	3642	-18	-0.5	3648	-12	-0.3
55	4432	4767	335	7.6	4767	335	7.6
56	4124	4651	509	12.3	4677	553	13.4
57	844	988	144	17.1	923	79	9.4
58	2109	2709	600	28.4	2393	284	13.5
59	1012	781	-231	-22.8	1129	117	11.6
60	820	1187	367	44.8	1028	208	25.4
61	8230	8912	682	8.3	8924	694	8.4
62	7408	7717	309	4.2	7573	165	2.2
63	9407	10737	1330	14.1	10795	1388	14.8
64	4579	4852	273	6.0	4830	251	5.5
65	3145	3802	657	20.9	3726	581	18.5
72	4587	5233	646	14.1	4693	106	2.3
		RMS=1018.41 \bar{x} =15.62			RMS=811.29 \bar{x} =12.54		

*Source: San Bernardino Co. Special Census

TABLE 5.2

Estimated Population and Error for Selected
San Bernardino Census Tracts

61-9

POPULATION ESTIMATION FLOW DIAGRAMS

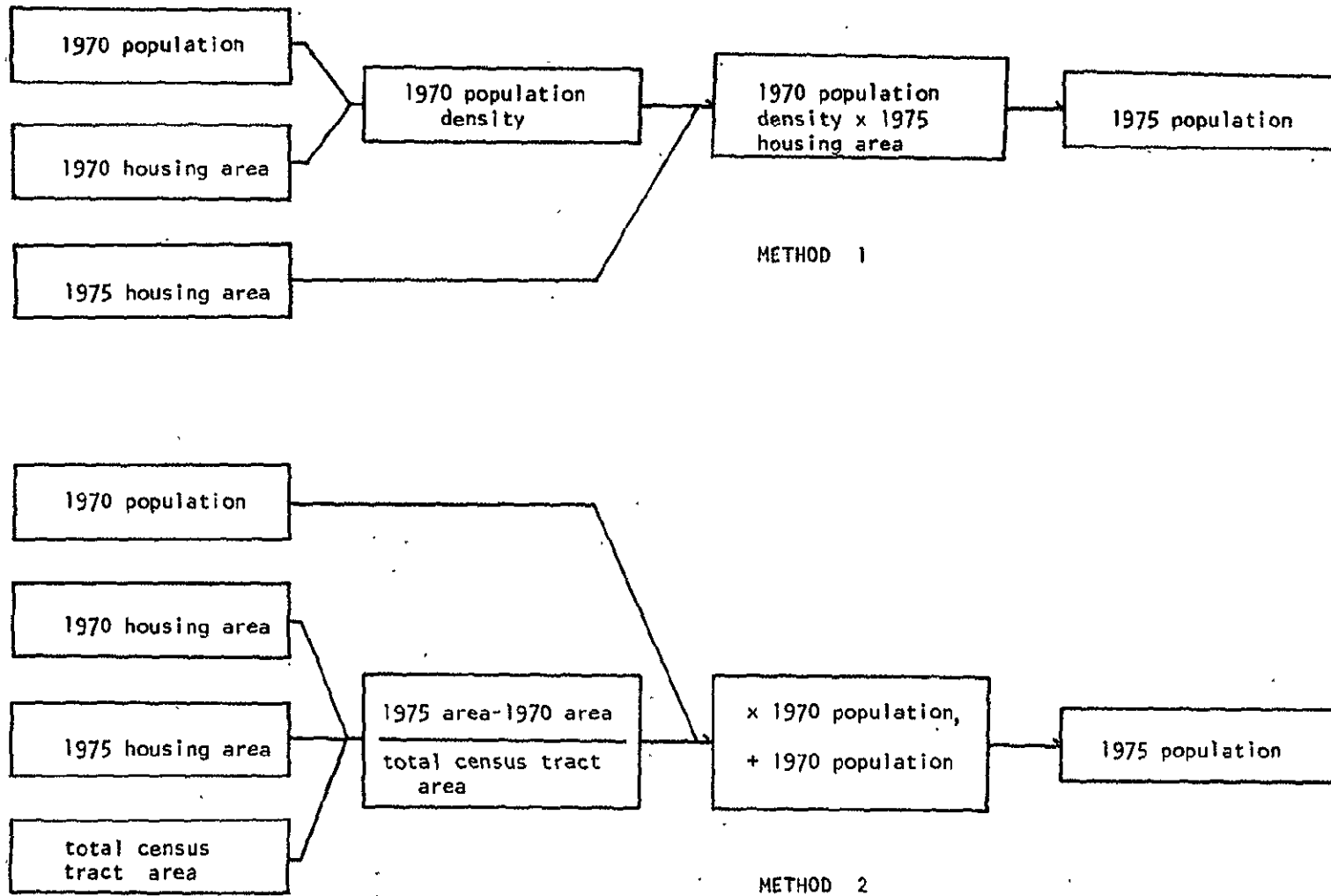


Figure 5.11 Population Estimate flow diagrams for the two different density statistics.

The analogue nature of photographic films led to the development of mapping procedures which were essentially polygon oriented. Areas with homogeneous spectral and classificatory characteristics were delineated by manually drawing lines to represent boundary conditions. At the same time, geographic information systems shifted from grid cell based files to polygon oriented cartographic data bases with linkages to attribute files. In the early 1970's remotely sensed data utilization and polygon based geographic information systems with optional graphic output on X,Y plotters were complimentary. At that point in time, the non-automated portions of a data gathering and data analysis/display system were manual photo-interpretation and cartographic digitization.

When we now consider Landsat as a viable general purpose data source for resource planning, a different set of conditions is obtained. An important condition is that Landsat data is most usable in digital form. In digital form, the process of classification can be carried out quickly and systematically using numerical algorithms. The upshot of the present situation is that resource planners are faced with the capability of generating thematic maps of earth resource information which is in line and sample (or 'grid') form. To input grid information to existing or future polygon based information systems requires digitizing the maps (a manual process) as produced on a film recorder (which is not widely available). Thus, for many resource planners the classification process has been automated but not the data input process. Little work has been done on the automated conversion of line and sample format classified maps to polygon data structures. Providing software were available to produce polygon data structures from line and sample data structures, planners would be able to utilize the increasingly common X,Y plotter for mapping purposes as well as input directly to polygon based information systems.

Making no assumptions as to the relative merit of polygon or 'grid cell' based information systems and assuming that digitally classified maps will be in increasing demand by planners, a program was developed which creates polygons from pixels. Presently this program is referred to as POLYGRIP (POLYgon from GRid Input Program). The program has been written and debugged but tests are underway to assess performance characteristics under different data configurations. Smoothing algorithms are being investigated which will significantly reduce superfluous coordinates as well as eliminate the 'step' effect of diagonal boundaries. Figure 5.12 is an example of a classified image of net radiation (from Skylab data) which was converted using POLYGRIP and mapped with CHORMAP (see section 5.3.1 step 14).

Program Description

The POLYGRIP program consists of two basic operations. First, line segments are created on boundary conditions and the right and left attributes are stored. Only vertices which represent a change in direction are kept. This gives a line representation of boundary conditions but does not define polygons. Present efforts on the conversion of line and sample data structures for X,Y plotting stop at this point. The second operation involves the cycling of polygons. Each homogeneous area is constructed from the line segment information. Right and left attributes are replaced by right and left polygon numbers with links to their attributes. All island polygons

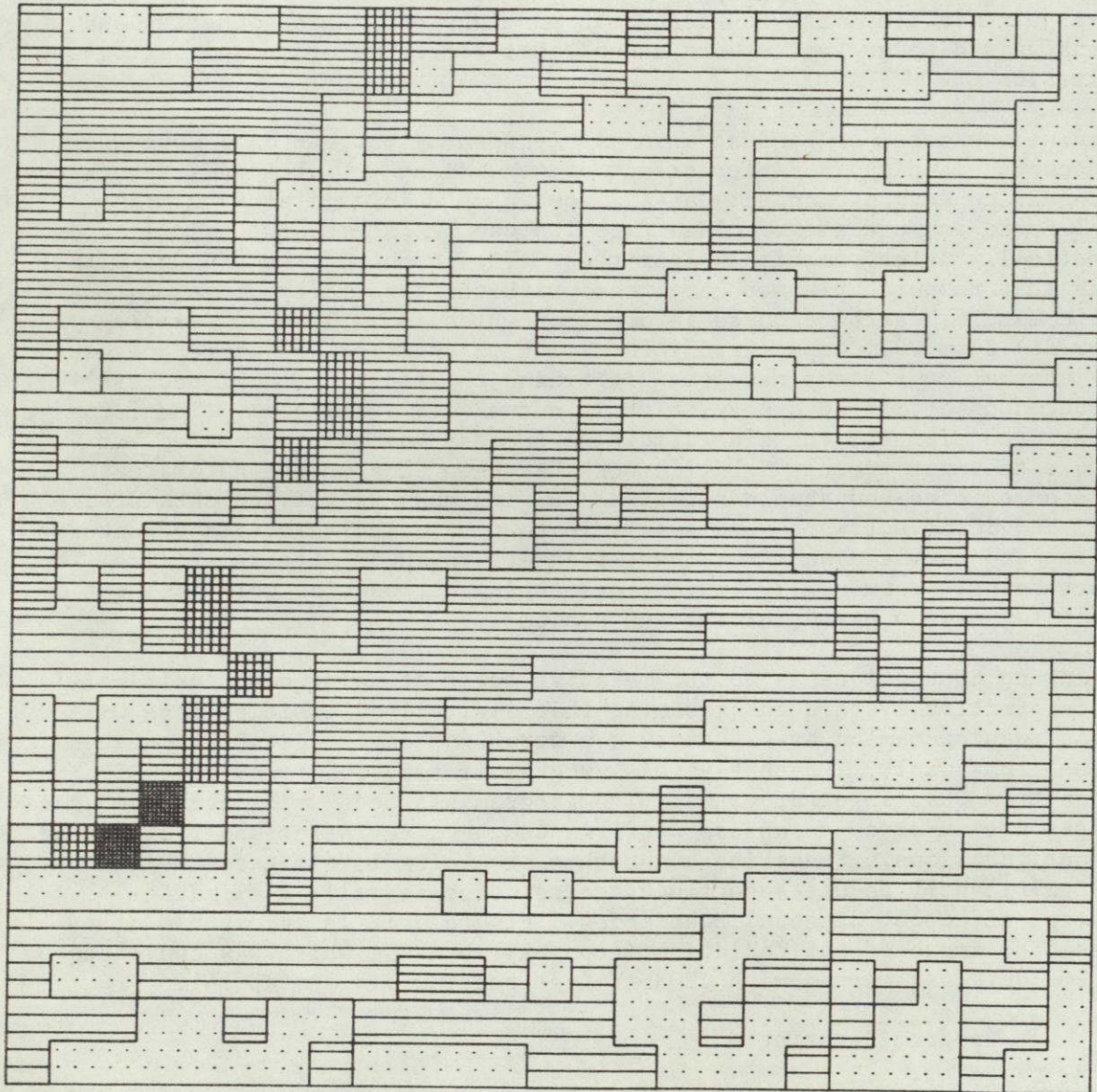


Figure 5.12 Map showing distribution of net radiation for a portion of Central Atlantic Regional Test Site. Net radiation was calculated and a line and sample file with the interval level for each pixel was created. This file was converted to a polygon data structure, linking all islands, by the POLYGRIP program. Mapping was done on an X,Y flat-bed plotter using the CHORMAP choroplethic mapping program.

are detected and inserted into their containing polygon. An infinite level of island nesting can be accommodated.

The polygon cycling operation yields an unambiguous encoding of polygons. It also allows direct entry into polygon based information systems as well as choroplethic mapping on X,Y plotters with conventional software and graphics media.

5.3.2 Procedural Manual - Techniques for Mapping Land Use from Remotely Sensed Imagery

5.3.2.0 PREFACE

A procedural manual containing the details of the techniques developed in conjunction with the water demand studies will be published under separate cover. The complete preliminary text was included in Chapter 5 of our semi-annual report dated 31 December 1976. For the purpose of this report only a brief outline of each of the steps will be listed along with some of the figures which will appear in the separate manual.

5.3.2.1 INTRODUCTION

The production of a land use map involves carrying out a series of tasks which result in an end product of pre-defined quality. The quality may be only a simple sketch map of a designated area with written or coded notations of the land use. On the other hand the quality may be a very elaborate four-color shaded map prepared by an automated drafting machine. Obviously the tasks will vary in detail and effort according to the desired quality of the end product. Most land use mapping efforts have general tasks in common. These include planning, data acquisition and mapping, and data compilation and display. Because the general tasks normally follow one another chronologically, they may be referred to as 'phases'.

Before any land use or thematic mapping is begun, a planning phase should be carried out in which objectives are defined and quality control parameters are established. The objective may be to provide data from which the water demands of the region can be predicted for the next thirty years. Such an extensive objective would require accurate detail of boundaries of land use as the driving parameter in the water demand model. Likewise the quality of the final product (map display and statistical compilation) should be of such quality that it can be reproduced and utilized in publications that have a lifetime of several years. The objectives of an urban planner may be for a land use map to be used in a general plan to assist in making zoning decisions. To insure the final product meets the pre-defined objective the planning phase must include consideration of how, where, when, and what type of information is to be acquired.

The second or production phase includes data acquisition and mapping. Information is transferred from the actual site by either a field survey, or from remotely sensed data to a draft map. Normally this involves categorization of the data (i.e. housing, industry, agriculture, water areas, etc.), scale change (image scale may be 1:130,000 and final desired scale be 1:12,000), and positional control relative to a planimetric base map (area calculations require that points or intersection be located on the map with sufficient

accuracy that computed map area is equal to actual ground area).

The production of a planimetrically correct draft land use map represents the completion of the production or information phase. However, two major tasks remain in order for the work to be useful to the planner. First, the map must be prepared suitable for presentation and its readability enhanced (e.g. an inked final copy with color or shading either manually or automatically drawn), and second, the map information must be compiled so as to answer the question of "how much?" as well as "what?" and "where?" (e.g. How many hectares of agriculture and where is it located?). Area measurements and summaries are therefore a requisite part of any major land use mapping effort. This is termed the data compilation and presentation mapping phase.

5.3.2.2 PLANNING PHASE

5.3.2.2.1 Step 1: Define Goals and Objectives

a. Establish the Purpose of the Land Use Map

The decision to be made in each phase is totally dependent upon the purpose or final use of the map. If the map is to be used to estimate water demands, then it will dictate to what detail land use must be classified (e.g. Can housing be grouped as one or does it need to be categorized into single and multiple residential, transient, rural?). For water demands, housing as a general classification may be sufficient but for the city or county planner that is to use the map for establishing a zoning ordinance, the map must be in greater detail.

b. Establish the Temporal Baseline

The prime reason for the recurring need to map land use is rapid change. If the data needs to be acquired for a large area at an instant of time--such as an agricultural crop inventory--the acquisition problem is greater than if it is for a slowly changing central business district. The large agricultural area may require an instantaneous image taken at a particular time of the growing season. The data for an unchanging urban area may be adequate from imagery taken a year ago.

5.3.2.2.2 Step 2: Establish Classification System

Land use has a variety of real-world expressions. Theoretically, it would be useful to attempt to identify each of these expressions unambiguously. However, such effort would require gathering and handling an inordinate and superfluous amount of data. For convenience, land use expressions are categorized and classified.

One does not classify land use to any degree of specificity greater than required for operational applications. However, one does not want to be so general as to lose information that is essential for operation and planning purposes. The end purpose of the land use information must dictate the classification system. Because most land use classification systems are hierarchical in nature, the specificity or refinement of the system

is usually indicated by user needs.

Four levels of land use classification types are generally recognized. In agriculture, a fifth level has been developed to specify certain types of food crops. An example of the hierarchical structure to four levels is provided in Table 5.3.

Table 5.3

Excerpt from land use classification system showing hierarchical structure (C.P.O., 1968)

First level.....	<u>5000</u>	Trade
Second level.....	<u>5100</u>	Wholesale trade
Third level.....	<u>5130</u>	Dry Goods and Apparel
	<u>5140</u>	Groceries and Related Products
Fourth level.....	<u>5141</u>	Groceries (general line)
	<u>5142</u>	Dairy Products
	<u>5143</u>	Poultry and Poultry Products

Resource managers who must work with both urban and rural regions (e.g., managers of water resources or forest managers) prefer a dichotomous classification system (urban/rural) with hierarchical breakdowns under those two headings. Interpreters extracting general land use data from high altitude aircraft and satellite imagery often create a system that fits what can be observed from the image. This latter approach, if followed rigorously, has the tendency to confuse the final user of the map. Therefore, either the interpreter or the user must modify his mode of operation.

The primary concern in constructing a land use classification system to be used with an image data base is to provide at least some level of classification for all necessarily detectable land uses. Land use types that are to be differentiated, but are non-detectable from imagery, must be identified from some other data source. Fortunately, data from multiple sources are easily mixed so that the best land use information can be used.

5.3.2.2.3 Step 3: Establish Accuracy Parameters

To save time, effort, and maintain a certain degree of uniformity, throughout the mapping project it is necessary to establish resolution, classification, and positional accuracies. Resolution refers to the smallest area on the ground that is to be mapped. Classification accuracy refers to what hierarchical level different categories of land use will be listed. Positional accuracy refers to the relation of delineated boundaries with some specific geographic reference system relating to actual physical location on the ground.

5.3.2.2.4 Step 4: Select Data Source

Land use data may be obtained by either actual inspection on the ground (field survey) or from remotely sensed imagery or by a combination of the two. Remotely sensed imagery is available from many government and private film libraries or may be contracted for from sources. A little time spent at the beginning of the project to determine the availability of imagery for the region under investigation may pay off in savings of both time and money. Use of available imagery may require a compromise in some of the planning parameters but the savings may justify the use.

5.3.2.2.5 Step 5: Select the Scale and Type of Imagery

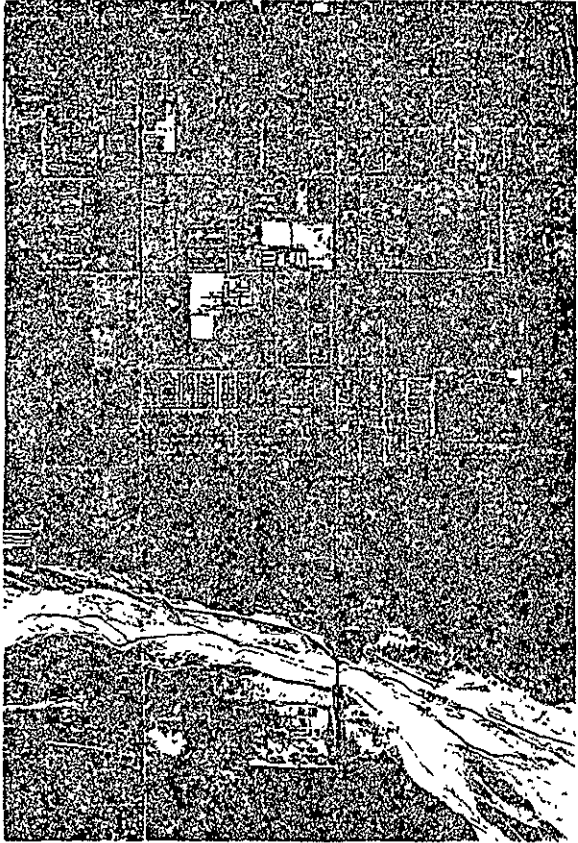
The ground resolution (dimensions of the smallest object on the image that can be detected) desired and the target being imaged usually dictate the scale and type of imagery to be obtained. Because of the contrast found on some imagery (such as color infrared) a lower resolution may be possible. If vegetation detection is a prerequisite, color infrared film is suggested; however, for some types of resource mapping other films are desired. (Note: The procedural manual will devote several pages to this subject). The ramifications of film type and resolution are too extensive to elaborate in this discussion. The reader is referred to the American Society of Photogrammetry's Manual of Remote Sensing for detailed information on the subject. Figures 5.13 show three different scales of imagery and give an indication of the resolution obtainable from each.

5.3.2.2.6 Step 6: Establish a Base Mapping System

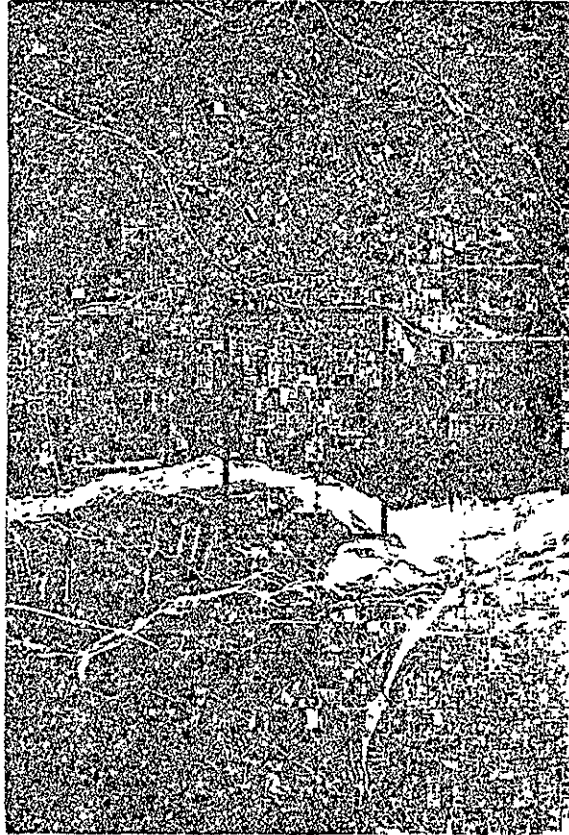
The choice of a base map to be used in controlling the drafting of the work map is dependent upon the required accuracies. The base map should contain cultural details (i.e. roads or other significant points) that can be related to features detectable on the image. The features should be spread throughout the map so that the image detail can be rectified to the planimetric map base. If cultural features are not available on the map it is sometimes possible to use natural features that maintain a high degree of stability. Many stream beds are found to hold their positions over the period that USGS topographic maps are updated.

In the United States it has been found that the most suitable base maps are published by the United States Geological Survey. Three series of topographic maps (Figure 5.14) are published at scales of 1:24,000; 1:62,500; and 1:250,000 (USGS, 1969). At a cost of \$1.25 per sheet the maps are relatively inexpensive and can be obtained for any area in the United States in at least one of the three different scales. Distribution centers are located throughout the U.S. including the Map Distribution Center, USGS Denver Federal Center Bldg 41, Denver, CO 80225.

If area calculation is not a concern, then base map selection is not critical. In this case a suitable base map may even include an ordinary road map, or a map included in a standard atlas. However, the latter maps create a copyright problem and cannot be reproduced without permission. Most government maps are not copyrighted, which makes the choice of USGS maps perhaps the most acceptable for all cases.



a



b



c

Figures 5.13 Three scales of imagery showing the Redlands, California area. Figure a is a U-2 CIR at an original scale of 1:32,500 with a ground resolution of approximately 1.5 meters (5 feet). Figure 2 is a U-2 image at a scale of 1:130,000 with approximate ground resolution of 6 meters (20 feet). Figure c is a Landsat image with original scale of 1:3,300,000 with a ground resolution of 80 meters (262 feet).

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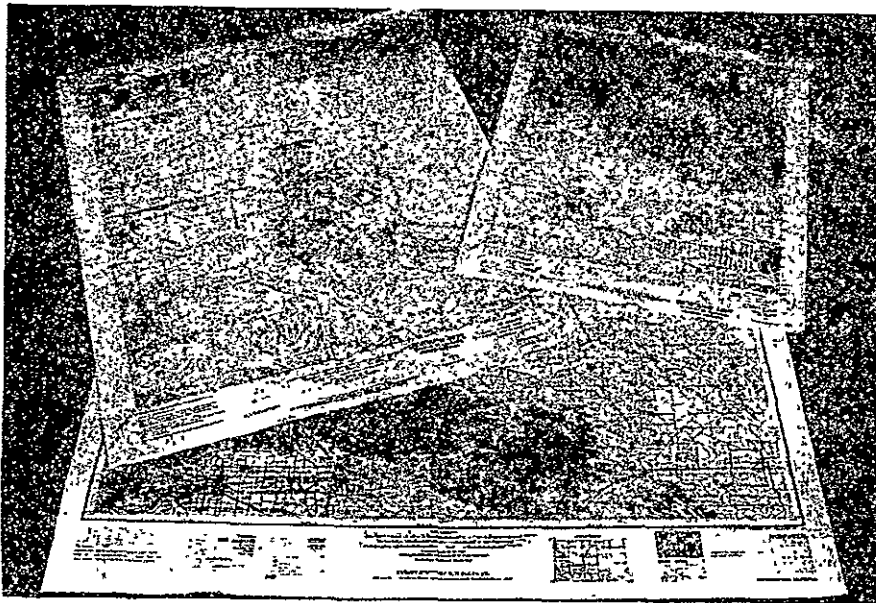


Figure 5.14 Typical U.S.G.S. topographical map sheets that may be used for controlled base maps. The three common scales represented are: 1:24,000; 1:62,500; and 1:250,000. Almost complete coverage of the United States is available in at least two of the scales. The maps are available from U.S. government Map Distribution Centers.

5.3.2.3 MAPPING PHASE

The actual production of the work map involves the transfer of the relevant data from the image to the initial work map. If a planimetric map is required, the data transfer process must be controlled by utilizing an accurately prepared base map such as a USGS topographic map. Planimetric control is normally obtained manually by overlaying the work map (a sheet of frosted mylar drafting film) on the base control map. Lines drawn on the mylar work map can then be controlled by the cultural features seen on the base map. Automated systems have been developed that maintain accurate planimetric control by utilizing a procedure called electronic resectioning (Tewinkel, 1966). The data transfer process involves the procedures of: scale change, image rectification, boundary interpretation, land use interpretation, and a random field check for verification of accuracy and correction of uncertain interpretations.

5.3.2.3.1 Step 7: Method of Scale Change, Rectification, and Data Transfer

Imagery seldom is available or obtained that is the same scale as the scale of the base work map. Also images contain distortions that must be rectified to the planimetric scale of the base map. The conventional method of data transfer has been to visually detect the data boundaries on the image and manually outline the same area on the base map (Figure 5.15). Another recently developed method has been to project the image onto the base map by one of several types of projectors (Figure 5.16) and by moving the map slightly, to adjust for distortion, trace the correct boundaries on the base map. Another recent development, adopted during our recent water demand study, is to use a matte surface photo film and either reduce the base map photographically to the scale of the image for tracing (Figure 5.17) or enlarge the image photographically to the base map scale for transfer of data on a one-to-one correspondence (Figure 5.18). Either of the latter two methods requires some slight shifting of the map to provide planimetric transfer of the distorted image data.

5.3.2.3.1 Step 8: Conduct Random Field Check of the Completed Work Map

To provide a basis of establishing the accuracy of the data on the map, a random field check should be conducted to verify the various land uses identified from the image. Also, any areas that could not be identified from the image can be visually verified from the ground survey.

5.3.2.4 DATA COMPILATION AND PRESENTATION PHASE

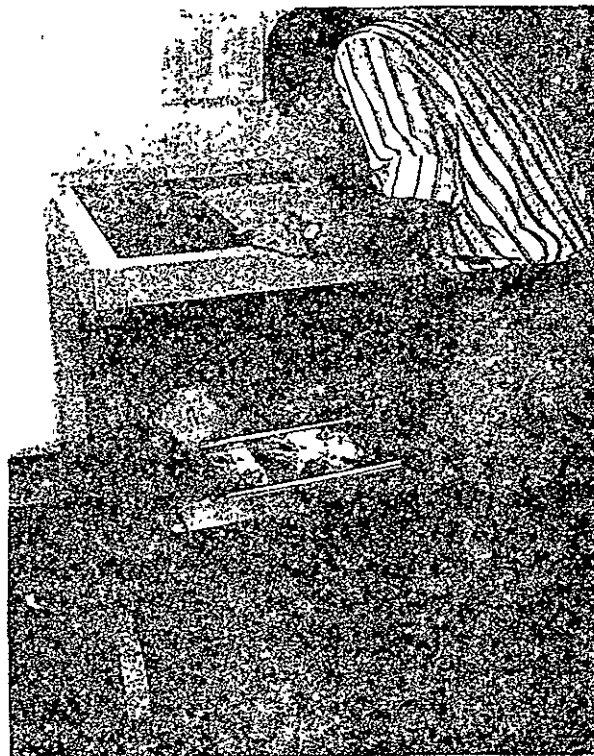
The data on the work map is now verified and the working map is planimetrically correct. The work map consists of a set of connected boundaries (polygons) and associated land use attributes. We are now faced with the decision as to what method should be used to prepare a final map that meets the previously determined quality.

5.3.2.4.1 Step 9: Select Method of Final Reproduction

The work or 'draft' map may be all that is required by the user and the map is completed. However, most users desire a map where each land use type on the



Figure 5.15 Conventional method of data transfer from an image to the base work map. The image is visually inspected and the boundary lines are manually drawn on the work map.



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Figure 5.16 Another traditional method of data transfer is to project the image from the rear through a transparent base work map. Several front projection systems are also available.



Figure 5.17 An example of scale change from map scale to image scale. The original topographic map (on the left) has been reduced from a scale of 1:24,000 to the image scale of 1:32,500. The reduced map (on the right) has been photographically reproduced on a matte surfaced film. The reduced scale map may now be overlaid on the image (upper center) and land use boundaries traced directly onto the map.

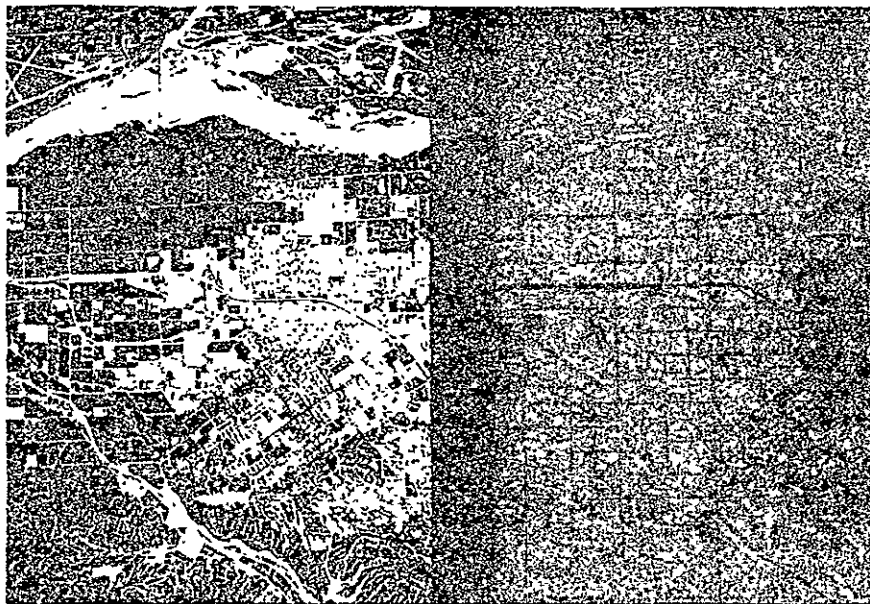


Figure 5.18 Another method of scale change is to produce the image (in black-and-white) at the map scale on matte surface photographic film. This process also permits a magnified view of the image.

map is colored or shaded the same legend. If only one final copy that is not intended to be changed or updated is desired then the final work probably should be accomplished manually. However, if area calculations are required for the various types of land use and/or the map data is to be periodically updated, or the land use data is to be combined with other information for a composite type presentation, it may be worth the time and effort to encode the data into computer compatible format and reproduce future maps and changes automatically.

5.3.2.4.2 Step 10: Prepare a Clean Copy of the Land Use Map

Whether the final map is produced manually or by machine procedure, a "clean" map will be required for further processing. In manual production the "clean" copy often is obtained by inking in the boundary lines and cleaning up the other areas with various drafting techniques. In machine processing there are several considerations. The degree of cleanness depends upon the method of data conversion.

If the work map was produced on mylar film with all the shades of gray of the original image, or all the topographic features of the contour lines, then the line work must be extracted from the background. In many cases the only reasonable solution is to redraw the boundary lines on a clean mylar overlay. Using a light table this procedure can be accomplished rapidly.

In addition to removing unwanted detail on the work map it is also necessary to provide additional data conversion information for machine processing. One method of data conversion is for an operator to digitize each line segment of the work map. If each polygon is digitized independently the result is double digitizing. That is the line segments are digitized twice; once for each adjacent polygon. This presents no problem at the intersection of lines. However where a line segment bends the operator must know where to locate a vertex point for that bend so that he digitizes the same location for both adjacent polygons. Hence, the preparation of a "clean" map copy for machine conversion may also include placing tic marks on any line segment that changes direction other than at the intersection of two or more lines. Figure 5.19 is an example of a land use map prepared for digitizing.

5.3.2.4.3 Step 12: Convert "Clean" Work Map to Machine Format

The remainder of discussion in this phase considers the problems of machine production of land use maps because manually produced maps would be completed at the end of Step 9.

a. Machine Digitizing

The conversion of a map to machine format can be accomplished in several ways including manual conversion utilizing a coordinate overlay, or through the use of any one of the many machine scanners or line followers which have been developed. The discussion will be limited to manual conversion procedures using a coordinate table.

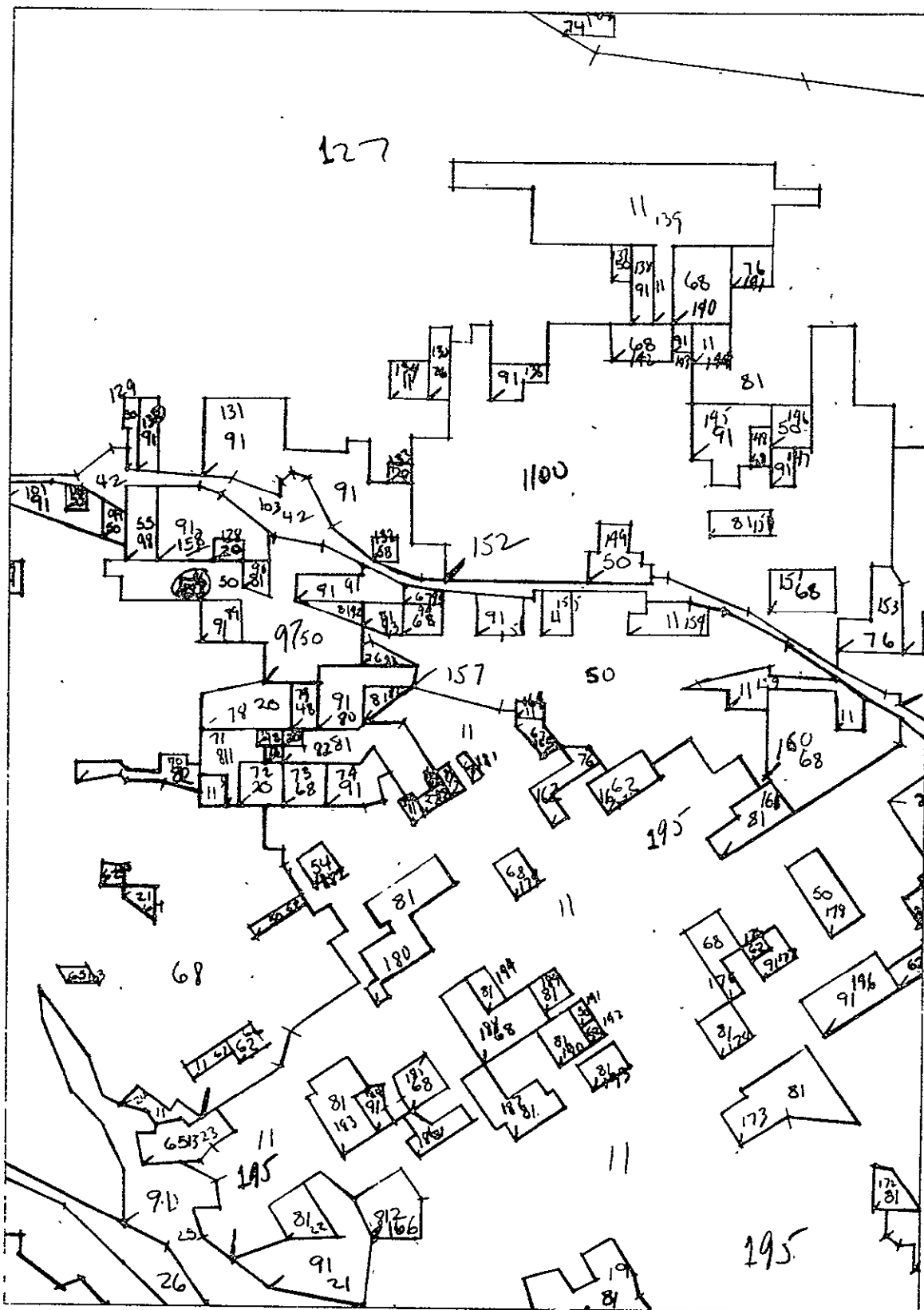


Figure 5.19 Example of a 'clean' work map ready for conversion of data to computer format (digitizing). Tic marks must be placed at all angles greater than 90° so that operator may relocate the point when digitizing the adjacent polygon. Land use codes (two digit numbers) are entered prior to digitizing the map. The polygon numbers (three digits) are entered in red.

A commonly used device for map data conversion is a coordinatograph (Figure 5.20). This is a table and associated electronics that will measure the X and Y coordinates of a point from a pre-set origin to accuracies of one-hundredth (0.01) of an inch to one ten-thousandths (0.0001) of an inch. The finer the resolution of measurement the costlier the machine. Most land use or thematic map data conversion can be accomplished with a resolution of one-hundredth (0.01) of an inch. By means of mechanical and optical encoders the analog map data are transferred to electronic equipment that converts the analog measuring signal to a digital machine readable form.

b. Procedural Error Editing

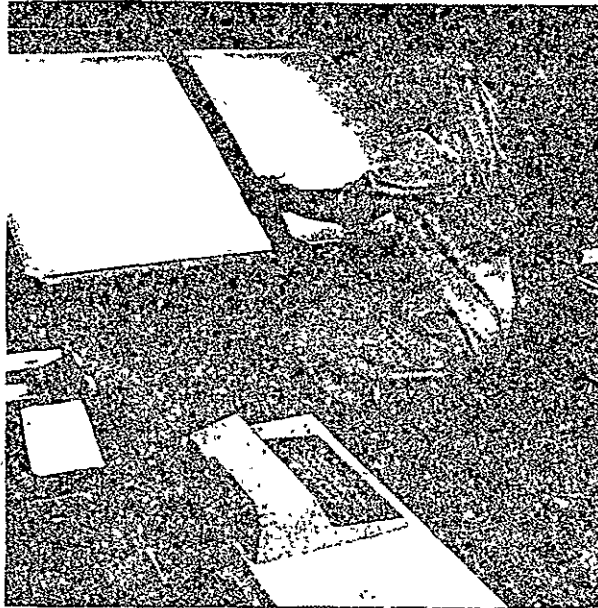
Both time and money can be saved if the raw converted map data is subjected to a preliminary edit procedure. The edit is designed to detect procedural errors that are caused by the human operator. Most of the human errors are excusable because digitizing is a tedious task and requires close concentration with considerable eye-strain occurring during the process. The visual editing of converted data is laborious, time consuming and inaccurate. A computer editing program performing the same operations takes about 30 seconds time (even for a detailed map) and detects all procedural errors. For example, if the operator failed to close a polygon (return to the original starting point) the program will detect that condition, which would otherwise lead to an ambiguous situation. The operator must then correct the errors (Figure 5.21). Manual edit of the same data may take one to two hours and not necessarily detect all the errors.

c. Geometric Editing

Once the raw data has been edited and corrected a test map must be plotted (Figure 5.22). The test map is then edited for geometric errors in digitizing that occur either through machine failure or operator error. If the operator fails to locate the same point within a set selected tolerance (0.01" to 0.03") a double line may be created bordering adjacent polygons. This error is apparent on the test map as a double line. Overlaying the test map on the "clean" work map will detect the error. The double line may also create a calculation error in determining the area of a polygon. Occasionally the conversion equipment will malfunction and not record the correct X or Y coordinate, or the computer will be unable to read a coordinate and substitute a zero value. A "spike" will be created which causes the plotter to draw a line from its last position to some distant point on the map. When all the geometric errors are corrected then final map production can begin.

5.3.2.4.4 Step 13: Produce Statistical Tabulation of Land Use Data

One purpose for machine production is to be able to accurately compute the land use areas. Once the final edit and corrections have been made, the area data can be generated with assurance of accuracy (i.e. less than 1% error in computed area). Digital computers permit rapid computation of areas for individual polygons (Figure 5.23a). In addition, a more useful tabulation is a compilation of total area for each land use classification present on the map (Figure 5.23b).



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Figure 5.20 An example of a digitizer, a device used to convert map data to computer format. The cursor (either fixed arm as shown, or floating) is moved over the table called a coordinatograph. The X,Y coordinates of each point measured to resolutions up to one-thousandth of an inch are converted electronically to digital computer format. The data is recorded on either machine cards or magnetic tape.

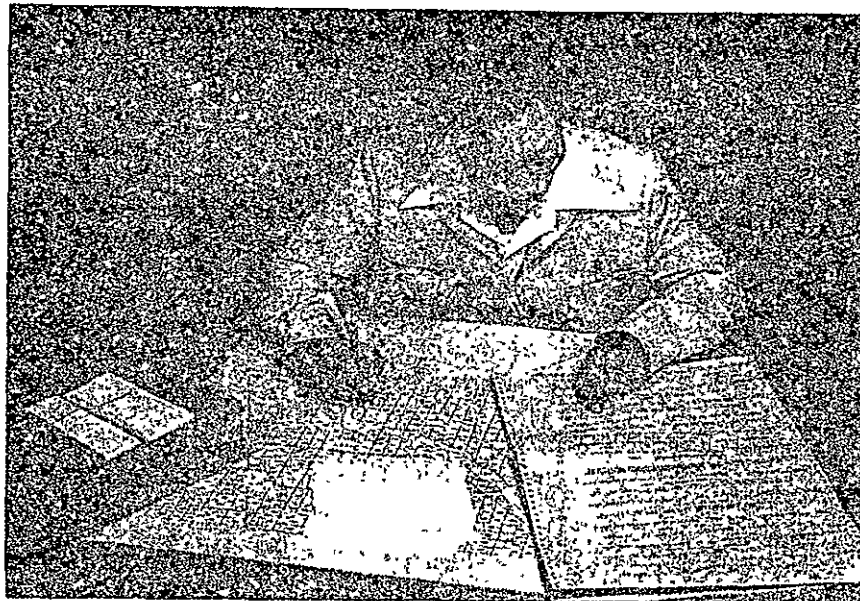


Figure 5.21 Procedural errors created during the digitizing process are detected by a computer program. A computer printout of the errors is reviewed and manual corrections are made to the digitized data.

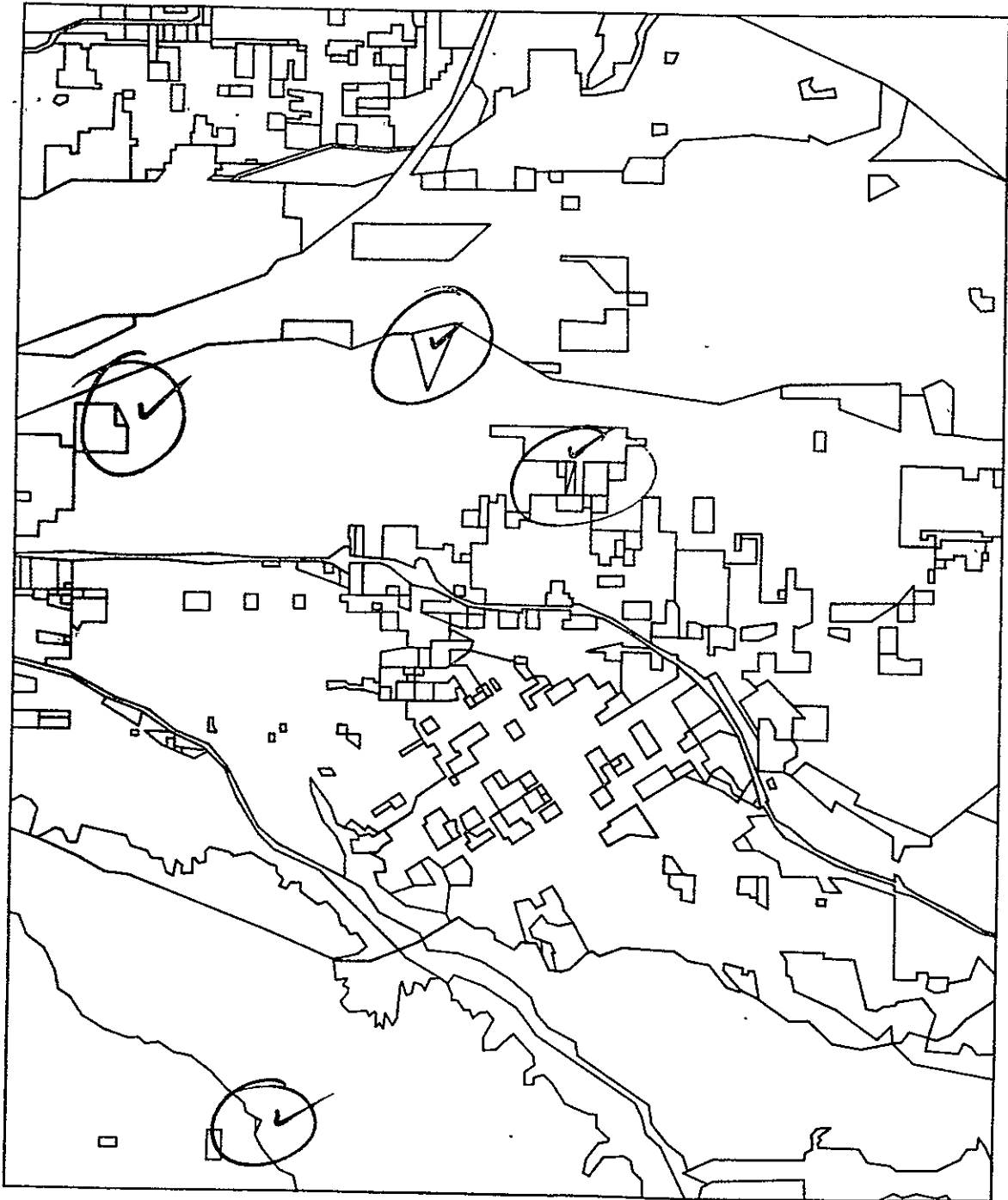


Figure 5.22 Geometric errors in the computer data are detected by plotting a test map of the polygon outlines. The example test map shows errors in digitizing that did not follow the correct path around the polygons. Three of the depicted errors were caused by the omission of one vertex. The fourth error was created by the insertion of an erroneous point, probably at the time of manual correction of procedural errors.

AREA CALCULATIONS

SCALE FACTOR IS 9.58

POLYGON	TYPE	ACRES	HECTARES
1	1100.	5.33	2.16
2	1100.	14.70	5.95
3	9100.	1379.04	558.08
4	9100.	3350.67	1355.97
5	8100.	140.43	56.83
6	8160.	359.57	145.51
7	9300.	197.44	79.90
8	9100.	65.88	26.66
9	9100.	10.60	4.29
10	8100.	336.93	136.35
11	7400.	72.67	29.41
12	1100.	63.36	25.64
13	9100.	2074.59	839.56
14	7400.	193.86	78.45
15	6800.	9.43	3.82
16	9100.	320.72	129.79
17	8100.	6.29	2.55
18	6200.	55.64	22.52
19	8100.	47.95	19.41
20	9100.	9.16	3.71
21	9100.	52.24	21.14
22	8100.	13.51	5.47
23	6500.	19.84	8.03
24	1100.	7.68	3.11
25	9100.	127.78	51.71
26	9300.	121.70	49.25
27	9100.	441.73	178.76
28	9100.	26.67	10.79
29	9100.	15.61	6.32

Figure 5.23a Table of area calculations for each polygon produced by the computer program.

AREAS BY TYPE

TYPE	ACRES	HECTARES
1100.	6461.34	2614.81
1400.	170.31	68.92
2000.	103.30	41.81
2100.	4.23	1.71
2400.	77.09	31.20
2700.	3.34	1.35
3400.	9.97	4.03
3900.	6.52	2.64
4200.	232.60	94.13
4300.	101.04	40.89
4700.	2.62	1.06
4800.	223.15	90.30
5000.	568.12	229.91
5400.	5.88	2.38
5500.	19.16	7.76
5800.	13.25	5.36
6200.	95.64	38.70
6500.	22.94	9.28
6700.	41.02	16.60
6750.	1207.33	488.59
6800.	555.20	224.68
6900.	1.57	0.64
7200.	27.27	11.03
7400.	410.73	166.22
7600.	68.33	27.65
7900.	1.39	0.56
8100.	2555.65	1034.24
8110.	3352.25	1356.61
8120.	6400.10	2590.03
8160.	359.57	145.51
8200.	27.84	11.26
8500.	143.39	58.03

Figure 5.23b Table summarizing the total area by land use type. Also compiled by the computer.

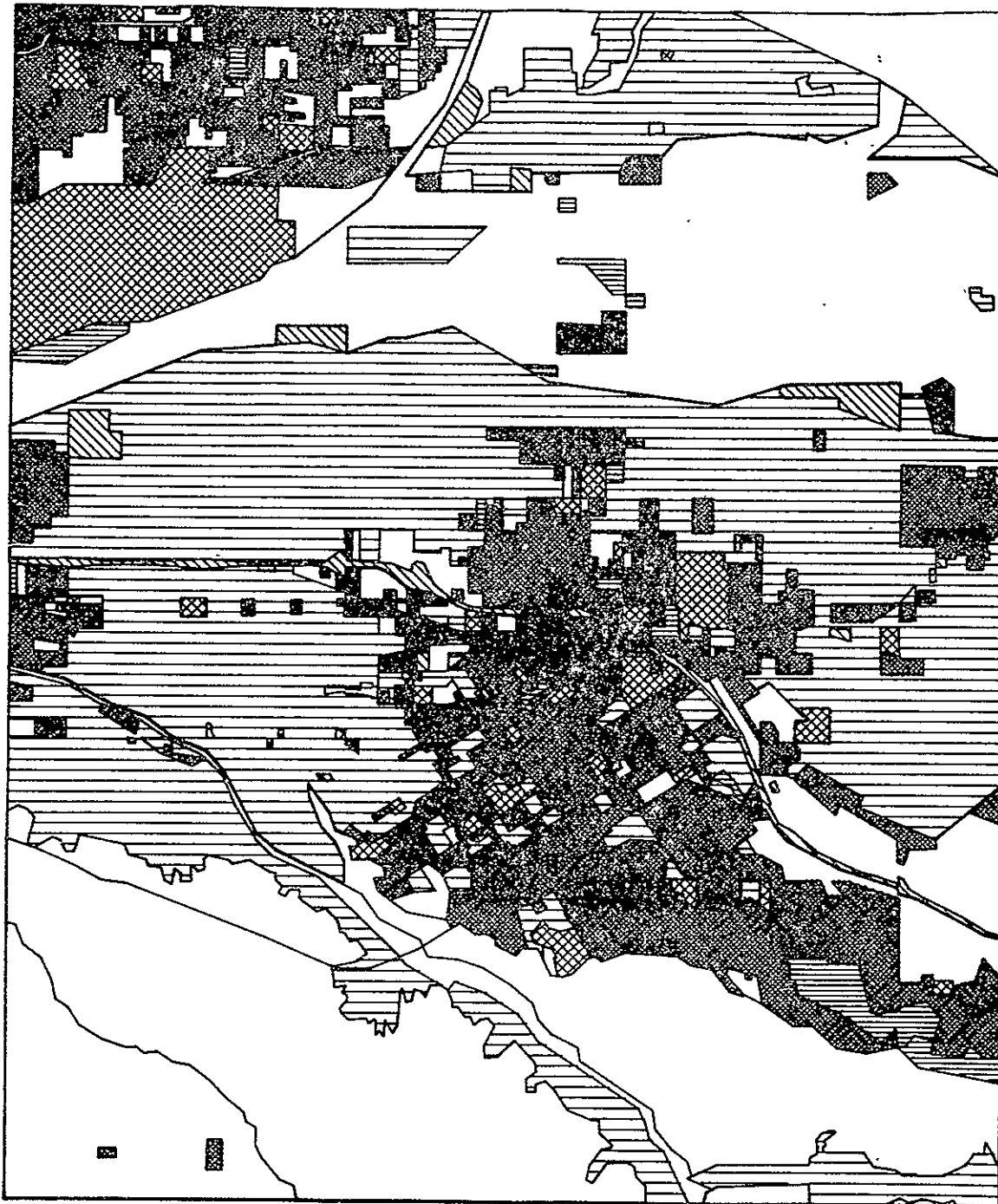


Figure 5.24 Shaded land use map of Redlands, California. After the final edit of the test map the data is processed through the CHORMAP program to add the shading for each land use type as indicated by the legend.

5.3.2.4.5 Step 14: Produce Final Land Use Maps

The final step in land use or thematic map production is to draw or plot a shaded or colored map commonly called a choroplethic map. The computer must be instructed as to which shade and/or color is to be placed in each polygon. Reference should be made to any one of several standard cartography textbooks for the theory of shade and coloring techniques.

Some computer programs will produce part or all of the map legend, otherwise legends must be added manually. Titles and subtitles are an essential part of a map. Each map should have a scale. If the map is to be photographically changed in scale then a graphic bar is the only scale that can be placed on the map. Other types of scales (e.g. representative fractions) lose their meaning when the map is photographically reduced or enlarged.

There can be several overlay features added to the final map, either manually or by computer. If a user needs a road network for a reference system, it can be drawn in by machine or manually. Other reference areas such as place names can be similarly added. Figure 5.24 is an example of a land use map generated by the CHORMAP program and plotted on a flat-bed plotter.

5.4 FUTURE STUDIES

During the next year we will be concluding our work on the Water Demand Studies. Our efforts will therefore be directed to finishing our last project and documenting the various programs and techniques that have been developed over the past few years.

5.4.1 Irrigated Agricultural Change Detection Utilizing Landsat Imagery

Section 5.2.2 reports on our recent efforts to utilize the digital MSS data from Landsat to develop a system to detect change in irrigated agriculture. A successful effort would provide DWR with a capability to distinguish irrigated agriculture from non-irrigated agriculture and provide a cost effective means of updating the agricultural areas of their land use maps. A possible "spin off" is that a technique will evolve to pinpoint areas of recent change which can then be studied in more detail by DWR to make spot changes in their land use data.

5.4.2 Documentation of Automated Land Use Mapping Programs for Use by Resource Planners

Section 5.3.2 outlines the procedural manual on techniques of land use mapping developed during the water demand studies. Parts of the manual discuss the use of automated mapping systems, but there are no details of these programs in the manual as it now exists. We, like most developers of computer programs, are hesitant to release our mapping programs without thorough documentation and a users' manual. If the documentation is not properly accomplished, the potential user requires much individual training and many phone calls before he is able to use the programs on his own computer.

We plan to document the programs, develop a users manual for each program and provide a program listing. It should be noted that the publication of these programs can in no way imply continued support or extensive assistance, should a user decide to implement them.

DEPARTMENT OF WATER RESOURCES

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April 13, 1977

Professor L. W. Bowden
Department of Earth Sciences
University of California at Riverside
Riverside, CA 92502

Dear Professor Bowden:

Thank you for the opportunity to review your "Procedural Manual for Land Use".

The procedures you have outlined will be of value to any agency setting up a land use program. Your manual covers the steps needed to develop such a program. However, the amount of detail required depends on the expertise of the novice about to implement an entire land use program. A good reference for providing a comprehensive background for the neophyte is contained in a report prepared by the Association of American Geographers for the USGS, which is:

Wiedel, Joseph W., Kleckner, Richard,
A User Guide: Using Remote Sensor Data
For Land Use Mapping and Inventory.
July 1974; Interagency Report No. USGS 253,
Contract No. 14-08-0001-13702

In review of your manual, please note the following comments:

Resolution Accuracy -- Resolution accuracy should be maintained at a consistent level of detail throughout an entire survey; otherwise photo interpretation will be affected as a result of excess aggregation and/or differentiation. Inconsistent resolution accuracy can result in land use maps and data that are not truly representative of reality. Parcel delineation of the final map will be the most obvious feature affected. The visual display will tend to be skewed in the areas of inconsistent resolution accuracy.

Classification Accuracy -- It should be noted here that classification accuracy can be improved by careful selection of training sites. This can be done by the photo interpreter carefully correlating ground truth with the chosen imagery.

Machine Digitizing -- The Department of Water Resources does not utilize the data conversion system presented in your manual. Therefore, a critique of this section was not conducted. Digitizing does appear to provide a data system

Professor L. W. Bowden
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that can handle large amounts of data that must be updatable and easily assessed. The Department is currently looking into the acquisition of this type of system.

In summary, the manual does the job it was intended for. Each land use mapping system is normally developed for a specific purpose, to study a unique phenomenon. This concept must be kept in mind when presenting a procedure manual dealing with a land use mapping system.

Recapping the items noted:

Wiedel and Kleckner's User's Guide would be a useful addition to your bibliography.

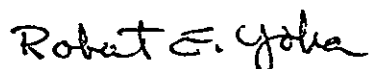
Resolution must be consistently maintained at whatever level of chosen detail.

Classification by the photo interpreter can be maximized and enhanced through careful use of training sites.

Interfacing the human photo interpreter with machine digitizing appears to be the most cost efficient land use mapping system.

Thank you again for asking our Department to comment on your "Procedure Manual".

Sincerely,



Robert E. Yoha
Land and Water Use Analyst

CHAPTER 6

IMPACTS OF THE DROUGHT ON WATER MANAGEMENT IN CALIFORNIA
-- A SOCIOECONOMIC VIEW

Co-Investigator: Ida R. Hoos
Contributor: James M. Sharp

IMPACTS OF THE DROUGHT ON WATER MANAGEMENT IN CALIFORNIA
-- A SOCIOECONOMIC VIEW

6.0 Introduction

Even when viewed from 570 miles away, signs of the prolonged dry period are strikingly apparent. Landsat's four multispectral "eyes" reveal jagged strips of bare soil around the perimeters of California's vast water storage facilities. Figure 1 shows how the State's largest reservoir, Lake Shasta, appeared last autumn. A corresponding view later this year will show even more exposed lakebed.

Of course, satellite imagery is hardly needed to discover that California is facing an increasingly chronic drought. But the synoptic viewpoint does help underscore the severity of the situation. In normal years, state-wide water use would total about 41 million acre-feet, with 85% consumed by agricultural uses. This year, state officials are expecting a shortfall of some 10 million acre-feet. This anticipates roughly equal availability of surface and ground water supplies, around 15 million acre-feet for each source. The San Joaquin Valley promises to be the most seriously affected region with a projected shortage of some 6 million acre-feet.¹

Federal and state water managers alike have announced reductions in water deliveries. The Bureau of Reclamation this year is cutting back its deliveries to 3.4 million acre-feet, less than half of normal. Most of the Bureau's agricultural customers will receive only a quarter of their usual Central Valley Project water. The Westlands Water District in Fresno County, the Bureau's largest customer, last year received about 1.3 million acre-feet of CVP water. This year Westlands deliveries will be reduced to 250,000 acre-feet, and the district has almost no available ground water. Similarly, California's Department of Water Resources will limit deliveries to its 24 State Water Project contracting districts to 1.8 million acre-feet, considerably below the projected demand of 3.4 million acre-feet. Kern County Water Agency the State's largest agricultural customer, will receive less than half of the 890,000 acre-feet it obtained last year.

Exposed lakebeds and reduced water supplies are some of the more obvious of the drought-induced changes. The cumulative effects of two critically dry years are uncovering other dimensions of California's socioeconomic landscape as well. In this progress report we explore how the drought is working to expose three such areas: (1) the relationships between different physical resources and sectors of the economy, (2) the assumptions and pressures behind

¹ Ronald B. Robie, "California Perspective", presented at the Governor's Drought Conference, March 7-8, 1977, Los Angeles.

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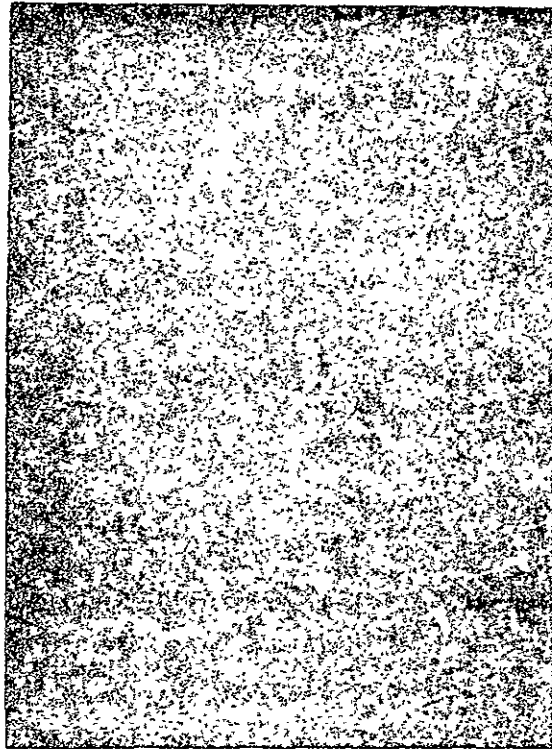


Figure 1. Drought-related low water levels at Lake Shasta are clearly evident in this Landsat image, taken October 4, 1976. The Sacramento River flows southeast through the City of Redding and agricultural areas. The average storage in Lake Shasta on October 1st is usually about 75% of its capacity of 4.5 million acre-feet. On October 1, 1976, the Bureau of Reclamation reported 1.3 million acre-feet of storage; by October 1, 1977, the Bureau projects this will drop to 585 thousand acre-feet.

existing water management philosophies, and (3) the possible long-term consequences of a prolonged dry period in the West.

6.1 Resource and Economic Interdependencies

The intertwined nature of California's water, water-related resources, and water-dependent organizations has been described in earlier progress reports. A drought has the effect of stretching thinner this fabric of relationships and more clearly revealing the interconnections. The water-energy connection is particularly instructive. Reduced surface supplies represent a dual energy drain through hydropower reductions and increases in groundwater pumping. With the amount of stream flow available for hydroelectric generation estimated to be the lowest on record, the 1975 water year tactic of releasing more water from reservoir storage cannot be repeated this year. A reduction in hydroelectric generation from 32 billion kWh to 12 billion kWh would require the consumption of an equivalent of 33 million barrels of oil in steam generating plants at a cost of about \$495 million. With most of the State's hydroelectric generating capacity situated in the northern part of the State, the drought seems to be having its most marked effect on the Pacific Gas & Electric Company. Besides imposing a succession of rate increases, the company advances the water shortage as an argument in favor of continued operation of the Rancho Seco nuclear plant and as leverage for commissioning of the Diablo Canyon reactor.

In Southern California, the drought affects the energy situation indirectly. As a means of compensating for reduced availability of water from the Owe Valley, the City of Los Angeles plans to pump ground water in the San Fernand Valley and to purchase water from the Metropolitan Water District of Southern California. The result is a reduction of energy generation by hydroelectric plants along the Los Angeles Aqueduct and an increase in the amount of energy needed for groundwater pumping and for delivery of water by the Metropolitan Water District. As dismal as hydroelectric power prospects are in California they are worse in the Pacific Northwest. Effects of the dry 1976-77 winter promise to be particularly devastating there since 80% of the region's power is produced hydroelectrically. A recent report to the governors of Oregon, Washington, and Idaho warned that if there is no recovery, their region "will experience a critical shortage of electricity", possibly emptying power-producing reservoirs by the spring of 1978.²

Closely tied to decreases in water supplies are corresponding decreases in air and water quality. Substitutions of petroleum-derived power for hydroelectric deficits are likely to accelerate air quality degradation, a result that will also occur when natural gas shortages force utilities to burn fuel

² William Endicott, "Northwest May Face Rationing of Power", Los Angeles Times March 9, 1977, p. 8.

oil. Deterioration of water quality, measured in terms of increased salinity, increased biological and chemical pollutants, and increased water temperatures, is also a problem associated with reduced stream flows. The Sacramento-San Joaquin Delta region epitomizes the intermingled array of environmental and economic factors. As the principal artery through which water from Central Valley rivers and aqueducts returns to the sea, the Delta is central to California's water management problems. A recent report provides an apt description of that area's importance:³

If you were to take California's water pulse, you'd put your finger on the Sacramento-San Joaquin Delta. Through the Delta passes water for crops, people, fish, and factories. These needs are competitive. Sorting them out and meeting them is a monumental task.

Protection of the Delta has long been a central factor in the myriad of management decisions and actions vis-à-vis water in this state. Its web of waterways supports a lucrative recreation industry, boating ranking high on the list of activities. In addition to the many varieties of game fish that attract sportsmen in large numbers, the Delta supports a wealth of marine life and wild fowl as part of its ecological system. While preservation of all these assets has long been a public concern, with responsibility for protection a matter of prolonged litigation between federal and state agencies, the concern remained largely in the legal domain because levels of export of water from the Delta were low and supplies replenished by ample rain and runoff. Discussions about the definitions of what constituted a dry year and, thus, the occasion for imposition of certain standards and controls remained conjectural but not particularly pressing matters -- always useful for debate between conservationists and special interests and, interestingly, a meeting ground for often otherwise warring factions. Since 1965, when the Interagency Delta Committee, made up of the Department of Water Resources, U.S. Bureau of Reclamation, and U.S. Corps of Engineers, recommended the Peripheral Canal concept, public positions have become strongly polarized, with environmentalists voicing anxiety over not only the ecological balance of the Delta but also the state of the San Francisco Bay and its environs.

The critically dry years of 1976 and 1977 have dramatically highlighted the Delta dilemma. Reduced fresh-water outflows will allow a greater influx of saltwater against the fragile hydraulic barrier that protects existing fish, wildlife, agricultural, industrial, and municipal water supplies. Almost prophetically, the drought is providing a glimpse of possible environ-

³ Donald E. Owen, "Delta Alternative Review Status", draft, February 1977, p. 1.

mental problems to come. So far, salt intrusions into the Delta have been controlled reasonably well by releases from upstream dams. But as state and federal aqueducts divert greater amounts of fresh water from the Delta, maintenance of the Delta's natural salt barrier will become increasingly difficult -- especially during dry periods. In the 1990's, when both the Central Valley Project and the State Water Project are scheduled to be operating at near capacity, environmentalists fear a series of dry years could inflict irreversible damage on the Delta's ecosystem as well as inhibiting the flushing mechanism in San Francisco Bay.

To many people, the drought's economic impacts are far more immediate than gradual environmental degradation. Seriously affected is California's \$9 billion agriculture industry, with drought-related losses estimated unofficially at anywhere between \$790 million and \$2 billion, with \$1.3 billion the generally-used figure. By way of illustration, we might cite the plight of livestock producers whose estimated damages last year exceeded \$465 million with more anticipated this year. Herds which usually graze on non-irrigated pasture land must now be fed with hay or alfalfa pellets trucked in at ever-rising cost to ranchers. The price of feed has increased from the low of \$60 in 1976 to a current high of \$110. Compounding the dire uncertainties is the possibility that the U.S. Bureau of Land Management might rescind the long standing privilege, extended to ranchers, of grazing their livestock on the public lands under its jurisdiction. The reason for such a move is drought-derived, in that preservation of forage for wild horses, burros, deer, etc., is the objective. The state's livestock industry, with cash receipts in 1975 of \$1.2 billion, accounted for a major part of the state's agricultural economy. Experts estimate a loss of more than \$500 million in 1977 and predict even bleaker times ahead because of the increasingly unfavorable competitive condition with respect to imports from Australia, New Zealand, Canada, and Argentina.

Shortage of irrigation water will cause crop reductions in the Central Valley; cutbacks of deliveries to the west side of Fresno County will affect such crops as cotton and tomatoes; Kern County, with some 900,000 acres of irrigated farmland in 1975, will probably leave unplanted some 10 per cent of that acreage; falling water tables are raising concerns about salinity and even availability of water in the wells of San Joaquin County; other counties, such as Madera, Tulare, and Kings, still rely heavily on their wells and may suffer little if any hardship. Not unexpectedly, some areas can expect to benefit, in that shortages elsewhere will put a premium on their output. Thus, the Imperial Valley, drawing on reservoirs still full from the Colorado River, will probably produce more cotton and alfalfa than usual to take advantage of the market situation. Business is also booming for welldiggers, tank truck owners, and water witches. Welldiggers are reporting order backlogs of up to six months, a problem for farmers who are counting on new wells to compensate for reduced irrigation supplies.

Adversely affected by the drought are the interrelated web of industries dependent on California agriculture. Especially hard hit is the canning industry, where losses can be anticipated not only because of possible shortages of produce but because of the dearth of water for the processing. Some two million gallons of fresh water are required daily for the operation of a single large cannery. Food processors, truckers, the farm machinery and tool industry -- all aspects of agri-business -- are bound to be affected. And caught in the ripple effect will be the job holders and consumers. According to some estimates, one dollar in gross farm receipts translates into three dollars in spending capability for related goods and services. Consumers across the nation can expect to pay more for their groceries since California supplies 40% of the nation's summer fruit and vegetable crop. The California Farm Bureau recently predicted that by late summer the price of fresh vegetables will have risen by 10% to 15%.⁴ Rice, lettuce, sugar beets, cucumbers, onions, and tomatoes are among those vegetables whose prices will be most affected by drought-related losses. Similar water shortages are causing reduced harvests of apples, pears, almonds, and walnuts.

The drought has also dried out other forms of vegetation. After two dry winters, the California Division of Forestry regards the fire danger in the state's brushlands and forests as "disastrous".⁵ Weakened by lack of water, many plants are more susceptible to disease, insects, and air pollution. A buildup of dead leaves and brush from afflicted plants has further increased fire hazards, an occurrence that will affect fire seasons in California for several years to come. In addition, diminished water supplies are likely to hamper efforts to fight the fires that do materialize. Some timber companies, in fact, are curtailing their logging activities because of the extremely dry conditions. Commercial and governmental tree-stocking programs are also suffering setbacks. The cumulative effects of fuel buildup and additional fires eventually will impact nearby soil and water resources, as erosion accelerates and debris washes into streams.

6.2 Water Management Philosophies

Along with subjecting the fabric of water resources relationships to greater scrutiny, the drought also is focusing attention on the "social resources" involved -- i.e., the institutions, capital, skills, and information that are combined in the process of developing and managing the natural re-

⁴ Judith Frutig, "Drought Points to Higher Food Costs", The Christian Science Monitor, May 4, 1977, p. 5.

⁵ Anne Jackson, "How California Life Will Change as a Result of Two Parched Years", California Journal, April 1977, p. 111.

sources. Many of the assumptions and exigencies underlying water management in California are now more clearly visible. The responses of federal and state water managers to the conditions of 1976, the first of the critically dry years, is illustrative. Last year, the Bureau of Reclamation delivered 6 million acre-feet to Central Valley Project customers under the assumption that 1977 would be a normal water year.⁶ It was not. So this year, the Bureau intends to supply only about a quarter of contracted CVP water, with none available next year to agricultural customers if the drought continues. The State Department of Water Resources has fared slightly better. In 1976, DWR's California Water Project delivered more than 2 million acre-feet, an increase of almost 15% over the record delivery of 1975. The Department's operating assumption was that 1977 would be as dry as 1934, the third driest year on record. Since 1977 has turned out considerably drier than 1934, the DWR is reducing deliveries of SWP water to its agricultural customers by 60% over last year. This blow is softened, however, by an exchange of 320,000 acre-feet with the Metropolitan Water District of Southern California. The DWR is now assuming the low water conditions of 1977 will prevail next year also, a prospect that would reduce 1978 deliveries to SWP agricultural customers to near zero.

How can water delivery capabilities dry up so fast in a state with billions of dollars invested in massive water storage and conveyance facilities? California's \$2.3 billion State Water Project was originally designed to enable customers to survive a prolonged dry period as severe as the record drought of 1927 to 1934. The Bureau of Reclamation's Central Valley Project, representing a potential federal investment of over \$3 billion, was also inspired by the 1930's drought. Some 40 years later, after only two dry years, the security offered by these vast projects has all but disappeared. What has happened? Aside from the cruel reality of consecutive record dry years, most of the answer lies within the management dynamics that guide such capital intensive systems. Ironically, the enormous investment tied up in these vast projects helps undermine their ability to insure against unexpected crises. Every distributing agency that uses water from these projects is locked into a repayment plan that allows little maneuvering room in times of crisis. When the occasional disaster does strike, agencies are forced to borrow repayment money. The reality is that no major user can afford to allow much of the system to

⁶ Increasingly, such "normal year" assumptions are being recognized as tenuous bases for planning. Secretary of Agriculture Bob Bergland, for example, recently ordered USDA economists to stop basing forecasts "on the assumption that we will have normal weather". Instead, the Department is developing a new forecasting system that uses weather records to project alternative price structures likely to arise under different weather conditions. Robert C. Cowen, "Weather, a New Kind of Challenge", Christian Science Monitor, February 25, 1977, p. 17.

go unused in anticipation of the next drought -- the water must be constantly used and paid for. Large-scale dams and reservoirs, in other words, are not very useful for handling the occasional large-scale crisis. Long-term financial arrangements require that they be operated "efficiently", a practice that leaves little margin for rare events.

In addition to exposing the dynamics of underlying management constraints, the drought places in sharp perspective the relations between those interested in water management issues. What becomes immediately apparent is the galvanizing effect of crisis. Just as the drought years from 1927 to 1934 served as the impetus to planning and construction of most of the state's major water projects, so the current dry period has underscored the urgency for action and has provided leverage for decisions that for a multiplicity of reasons, have met resistance. Old differences do not, however, fade away under the pressure of exigency, and the ghosts of earlier controversies over the system that moved water from north to south are being revived to haunt the new generation of planners. Moreover, while environmentalism, which is a relatively new movement, did not hamper earlier project construction, it now tempers markedly the enthusiasm for harnessing and diverting waters through as many dams as Congress (and President Carter) might be willing to finance. Indeed, retrospective cost/benefit analyses and impact assessments of major projects undertaken in the past forty years would shed interesting light on the relationship between prospect and reality. In any case, all of the carefully contrived calculations missed an essential point made by Ronald Robie, Director of the Department of Water Resources, in his statement before the House Subcommittee on Water and Power Resources: "None of the theoretical plans contemplated the psychological effect of the economic and other very real adverse impacts of taking shortages."⁷

For anyone interested in the formal analysis of decision-making, there is much to be learned from the current California experience of coping with serious shortages of vital resources. To begin with, "need" is not being defined in customary, strictly short-term economic terms. Thus, methodological tools that have become the textbook "Bibles" are notably absent. This situation may be of short duration, depending on how the Rand Group, now engaged in a two-year study, financed jointly by the Assembly Rules Committee and the Rockefeller Foundation, interpret their assignment. Titled, "Long-Term Implications of California Water Policies: A Study to Promote Efficient Water Use", the Rand Corporation is charged with "examining California's water policies primarily to ascertain the long-term social, economic, and environmental implications emerging from these policies".⁸ In the past, most studies of this kind have fallen far short

⁷ Ronald B. Robie, Statement before the U.S. House of Representatives Committee on Interior and Insular Affairs, Subcommittee on Water and Power Resources, March 5, 1977.

⁸ Ronald B. Robie, Report of Activities of the Department of Water Resources, March 4, 1977, pp. 26-27.

of providing useful and reliable guidelines especially as to longterm social and environmental implications. Constrained by the methodology, eclectic as to inputs, the output of many research projects on water policy has been of limited value. In the current emergency, cost-benefit analysis is not invoked and therefore no attempt is made at the "rational trade-offs" that could justify certain courses of action to the possible detriment of the state's future quality of life. Emphasis is, instead, on such human and social activities as conservation and personal sacrifice. There are, to be sure, ideological as well as factional differences and personal feelings vis-à-vis inequities in allotments, pricing, and longer-range policies. Certain industries are at a singular disadvantage and face possible extinction; many families feel that they are unfairly burdened under rationing systems current and proposed. By and large, however, the climate of public opinion about the drought and about official responses to it seems to indicate a degree of confidence notably lacking in its reactions to the energy crisis and the measures proposed by President Carter.

How to mitigate adverse affects, how to apportion limited supplies wisely, how to provide for an uncertain future -- these are matters of concern, and many of the State's drought period activities⁹ are directed to them:

- ° Reactivating and expanding the Drought Information Center
- ° Requesting contingency plans from water agencies
- ° Distributing guidelines on urban and agricultural conservation
- ° Encouraging and developing water exchange contracts to reallocate water from areas with sufficient supplies to water-short areas
- ° Providing emergency low interest water supply loans
- ° Extending disaster relief through State requests to federal authorities
- ° Modifying Delta water quality standards for the dry year
- ° Establishing a commission to review and recommend changes in California's water law

⁹ Ronald B. Robie, Report of the Activities of the Department of Water Resources, presented to the California Water Commission, April 1, 1977, pp. 3-4.

- Developing and supporting legislation on drought-related problems
- Holding fact-finding meetings in key areas of the State to consider drought problems and to hear directly from those affected what should be done
- Working with local agencies to develop specific remedial measures
- Forming an advisory group on irrigation practices
- Constructing temporary facilities to alleviate water quality problems
- Incorporating water saving practices in operations of State agencies
- Providing emergency water supply equipment
- Streamlining procedures for water rights in the dry year

One important phase of the action plan depends on acceptance of the concept of exchanges, which Robie articulates as being a keystone in his management philosophy. This is the point at which crisis may have a galvanizing effect. Under conditions of business-as-usual, water districts tend to be "insular and provincial".

Especially in times of shortage, these artificial barriers must come down in the interests of the common good. I believe the State should serve as a catalyst and coordinator in breaking down such barriers. California is one state, and sharing agreements are essential if we are to husband limited supplies.¹⁰

An example of the unifying effect of the drought situation may be seen in the exchange agreement under which the Metropolitan Water District of Southern California made available 320,000 acre-feet of water for allocation to areas of need. About 10,800 acre-feet of this water would be available to Marin, which is a particularly stricken area; some of it would be delivered to improve the quality of water in the Contra Costa Canal and to

¹⁰ Ronald B. Robie, Ibid., p. 4.

enable the East Bay Municipal Utility District to receive Central Valley Project water from the Delta. It must be noted, however, that cooperation is not necessarily universal nor voluntary and that long-standing controversy has, in some cases, been exacerbated by the drought. Such, for example, is the situation in the battle between the Los Angeles Department of Water and Power and the ranchers of the Owens Valley. In March, 1977, the California Court of Appeals issued an unusual "memorandum", in advance of any final decision in the suit brought by Inyo County. One of the main intentions was that Los Angeles had been drawing on Owens Valley water because doing so was cheaper than getting it from some other source and that the city had failed to devise and adopt conservation measures. The Court referred to provisions in the State Constitution that not only had bearing on the Inyo-Los Angeles matter but also clearly transcended the question of mere legal title to Owens Valley water: "The waste or unreasonable use of water [must] be prevented and the conservation of such water must be exercised." The "Memorandum", described as a "stern admonition", contained the following:¹¹

In relation to the State's current water crisis, the [Los Angeles] effort at voluntary conservation is inadequate to justify the requested relief. The California Constitution adjures the waste of water and seeks its conservation in the interests of the State's entire population. Reasonable use cannot be quantified in fixed terms but varies with availability. When the State's water resources dwindle, the constitutional demands grow more stringent and compelling, to the end that scarcity and personal sacrifice must be shared as widely as possible among the State's inhabitants. We postulate no fixed mathematical goal and are open to persuasion on that score. [Italics added.]

Unless and until the municipal government of Los Angeles demonstrates a need for water rather than rate preservation, its motion for leave to extract additional water from Owens Valley is not likely to achieve success."

At times, responses to a crisis situation are reminiscent of the philosophy voiced in that song about the Arkansas traveler, who did not bother to fix his leaking roof when the sun shone and could not do so when the rains came. For example, State Senator Ayala of Chino has introduced a bill repealing the 1972 Wild and Scenic Rivers Act, which bans

¹¹ Gladwin Hill, "Valley Gains Water Because of Drought", The New York Times, April 11, 1977, p. 28.

dams on a number of rivers on the North Coast, "I think it is morally wrong to allow water to flow out to sea simply because someone wants to preserve the environment when at the same time agriculture is facing a \$3 billion to \$4 billion loss because of a lack of water If we don't do it now, in wet years, no one is concerned."¹² The legislation proposed here has been regarded with concern by environmentalists who see in it the very kind of opportunism that could force long-range detrimental decisions simply on the basis of current emergency situations. That this mode of behavior is as much to be avoided as the sloth and procrastination of the Arkansas traveler is apparent to the authorities, who have chosen to include the wild rivers issue in a package of federal water legislation being worked out by the State. Official policy in this and other related matters indicates, contrary to impressions conveyed by the media, a disinclination to use the drought as a ramrod.

Not only has the drought "pointed out vividly to all of us the interdependence of all areas of the State,"¹³ but it has also put a special onus on state and federal authorities to resolve some of the controversies long-standing in the history of California's water management. Problems still exist; progress may be ahead; and there seems to be some promise. Ronald Robie prefaced his answers to questions put by a State Committee¹⁴ with the statement:

...I should comment that while the differences in interpretation are sometimes substantial, as a point in fact our day-to-day coordination among operating levels of the Central Valley Project and the State Water Project are extremely good. We share water, energy, and facilities when the need occurs, and adjust the bookkeeping later.

This cordial spirit, which pervades day-to-day operations does not prevail throughout state-federal relationships. In his March 4, 1977 Report to

¹² As quoted in "New Drought Victim -- Free Flowing Rivers?", The Independent and Gazette (Berkeley, California), April 20, 1977.

¹³ Ronald B. Robie, Report to the California Water Commission, April 1, 1977, op. cit., p. 5.

¹⁴ Ronald B. Robie, Statement before the State Senate Committee on Agriculture and Water Resources, February 15, 1977, p. 3.

the Water Commission, Robie¹⁵ commented approvingly on President Carter's decision, in February, 1977, to cut funding by \$289 million for 19 big water projects:

In my opinion, President Carter's action in deleting a number of Bureau of Reclamation projects from the budget on environmental grounds (this does not seem to be the case as to Auburn Dam) illustrates Presidential recognition that in many cases the Bureau's planning efforts have been woefully inadequate and quite narrow. These efforts are almost devoid of any consideration of water reclamation or water conservation, especially in the mid-Pacific region.

The Bureau has been dam and aqueduct oriented in spite of substantial public recognition of other values as expressed, for example, by the National Water Commission. The Bureau's continued and obstinate refusal to accept responsibility for water quality in the Delta -- even at its own diversion point! -- is one manifestation of their narrow approach, and your Commission is aware that the only Bureau projects in California which have been reoriented are those in which the State insisted on new directions.

The Sacramento-San Joaquin Delta, as described earlier, is central to the management of California's water resources. Besides incorporating all the conventional issues, such as the economic, social, political, environmental, and all of the problems of accomodating multiple and conflicting objectives in short- and long-run time frames, the Delta represents the classic clash between federal and state authority and responsibilities. It is here that both governmental entities have equivalent export priority and equal water rights, the one for the Central Valley Project, the other for the State Water Project. Under letter agreement re-negotiated annually between the Bureau of Reclamation and the State of California, both the Central Valley Project and the State Water Project receive water from the Delta for export to their contracting agencies.

The critically dry years of 1976 and 1977 have caused significant changes; the Delta is now a serious issue. Explicitly recognized are a

¹⁵ Ronald B. Robie, Report of the Activities of the Department of Water Resources, Presented to the California Water Commission, March 4, 1977, p. 24.

number of basic Delta needs. They are listed as follows:¹⁶

- Adequate amount of water for Delta agricultural, municipal, and industrial uses (1.6 million acre-feet/year)
- Protection of the fish and wildlife resources
- Control of water quality for all beneficial uses
- Provision for continuing navigation and recreation
- Protection from floods
- A guarantee that the Delta is given priority to the necessary water to meet these needs

Although a draft four-agency fish agreement¹⁷ specifying the needs and means of protecting fish and wildlife has attracted almost unanimous support from the various participants, availability of water to meet the criteria for proper maintenance of fish and wildlife is still a question about which there are some differences. Moreover, the U.S. Bureau of Reclamation still denies salinity responsibility. As part of its effort to develop a realistic working plan, the Department of Water Resources has specified the need for federal participation that would require the Central Valley Project to abide by the same regulations as does the State Water Project. Resolved to maintain water quality and salubrious conditions in the Delta, the State recognizes that federal cooperation is absolutely vital. Hence the effort to attain workable legislation, via the Secretary of the Interior and Congress, to authorize and require protection of the Delta by the Central Valley Project.

Recent personnel changes within the federal government, along with the drought, promise to loosen the state-federal water logjam in California. R. Keith Higginson became the new Commissioner of Reclamation early in April. He replaces Gilbert Stamm, a Bureau veteran who held the commissioner's job for the last four years. Having served as Director of Idaho's Department of Water Resources, Higginson becomes the first outsider to head the Bureau of Reclamation since 1953. Another new appointee is Guy Martin, Assistant Secretary to the Interior for Water and Power. Martin, a lawyer, was director of Natural Resources in Alaska. John Leshy is another major appointee within the Department of Interior, becoming the new Associate Solicitor for Energy and Resources. He was formerly in charge of the Palo Alto office of

¹⁶ Donald E. Owen, Delta Alternative Review Status, *op. cit.*, pp. 5-6.

¹⁷ Agreement participants include DWR, the Bureau of Reclamation, the State Department of Fish and Game, and the U.S. Fish and Wildlife Service.

the National Resources Defense Council and is well known by DWR employees. This infusion of state and local talent into key positions of an agency sometimes described as a feudal kingdom bodes well for states having resource management disputes with the federal government. Secretary of Interior Cecil Andrus himself, the former Governor of Idaho, is well-versed on the water issues of western states as well as with the capabilities of remote sensing techniques.

6.3 Possible Long-term Consequences

If empty reservoirs and declining water tables are exposing more clearly the web of physical and social resources that bind together California's water management landscape, they are also helping to reveal how this mixture is changing. Some of the effects "galvanized" by the drought, in other words, are likely to be more than temporary. At the foundation of these changes are alterations in people's awareness and behavior. The Governor's Drought Conference, held in Los Angeles in March, was one official action designed to call public attention to the drought and the need for water conservation. Nearly 1000 persons --mostly water officials-- attended the first day of the conference. Subsequent regional meetings of the Governor's Drought Emergency Task Force have encouraged similar dialogue amid more localized issues. Establishment of the Drought Information Center (in the offices of DWR's Emergency Flood Operations Center) and a toll-free 24-hour "hot-line" is another attempt to increase public awareness of drought issues.

As might be expected, a wide array of drought-related symbolism reinforces official efforts to encourage a new consciousness toward water and water conservation. Although DWR's "save water" buttons predated most of the current dry period, it is the photos of cracked mud in reservoir bottoms, the brown lawns, and the signs on neighborhood restrooms that provide the strongest symbolic statements. A particularly incendiary symbol for Northern Californians was the news that "their" water was being sent south to fill a man-made recreational lake at Mission Viejo, an Orange County development of condominiums. More positive symbolism is seen in the establishment of a Drought Tolerant Garden Project in Sacramento by the new State Office of Appropriate Technology, and the creation by the East Bay Municipal Utility District of a series of workbooks for schoolchildren featuring water conserving ideas. Figure 2 shows Captain Hydro, a character in the workbooks who, disguised as a mild-mannered fire hydrant salesman, changes his clothes in a laundromat and pursues the wasteful "water bandit". Crop specialists at the Kern County Cooperative Extension in Bakersfield have been involved in creating yet another sort of drought symbolism: figures on water inputs for household food and fiber products.¹⁸ Their calculations show the fol-

¹⁸ Brad Knickerbocker, "What's Using All That Water?", Christian Science Monitor, March 22, 1977, p. 3.

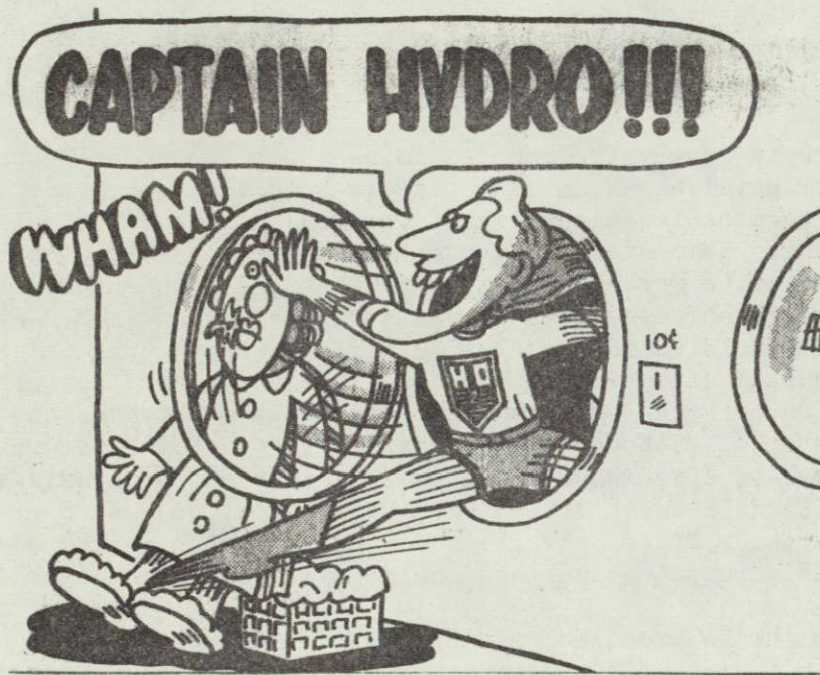


Figure 2. Captain Hydro is the principal character in a water conservation workbook for use in schools, grades 3 to 7, prepared by the East Bay Municipal Utility District. Bob Johnson wrote the story and lessons in the workbook; Ben Akutagawa was the illustrator. East Bay MUD has created a wide variety of educational materials illustrating hydrological principles and promoting water conservation.

lowing results for typical items:

	water input in gallons
loaf of bread	136
cotton pajamas	900
man's shirt	447
quart of milk	223
1 lb. of tomatoes	125
1 lb. of oranges	47
1 lb. of potatoes	23

Whether various changes in public attitude concerning water conservation will persist much beyond the end of the drought remains to be seen. One might reflect on the myriad of conservation practices adopted during World War II --string-saving, grease collection, canning, etc.-- and ask why they did or did not continue beyond the war's end. In comparison, the drought is distinguished by a high degree of interrelation with other basic natural resources (e.g., energy, air, soil, etc.) and future shortage and degradation problems in other sectors are likely to keep water near the forefront of public consciousness. The ties between water and other primary resources is particularly strong in the West, whether it be the dry Southwest, where farmland is only as good as its water supply, or the Northwest, where a water shortage also means a power shortage.

Plans for future energy development, in particular, appear to be on a collision course with existing water supplies in western states. A planned massive power facility near Bakersfield, San Joaquin Nuclear Project, encountered a major setback last December when the Kern County Water Agency broke off negotiations with the Los Angeles Department of Water and Power directed toward county approval of the project.¹⁹ If constructed, the plant would be the largest nuclear power installation in the world, generating enough electricity for a city of 5 million and requiring 20 billion gallons of water per year (about 60,000 acre-feet) for cooling. Local farmers are adamantly opposed to new projects that might usurp their water supplies. Additional agricultural development in southwestern states, plus the expected boom in coal and oil shale development, promises

¹⁹ Gladwin Hill, "Big Atom Plant Threatened by Drought in California", The New York Times, May 9, 1977, p. 18.

C-14

to cause similar problems there. Although water supplies within the Colorado basin were allocated between states by the Colorado River compact of 1922, the division was based on excessive estimates of water supply. This disparity between the legal and physical realities should become obvious in the near future when states such as Arizona begin using their full quota of water. Once again, the finite availability of this resource may disrupt the plans of utility companies who are counting on slurry pipelines to transport their coal from mine site to cities.

The current drought dramatizes the prospects of increased competition for water supplies. What emerges in the West is a picture of an era that is quickly passing. Much of the Southwest's rapid growth has been predicated on cheap and available water, with the assumption that federally-supported irrigation projects would rise as local water tables fell. Resource economists such as Allen V. Kneese of the University of New Mexico expect water supplies in the Southwest to tighten dramatically in the near future.²⁰ This translates into higher prices and a restructuring of the West's agricultural base and industrial production processes, as well as changes in the lifestyles of individual consumers. Depending on market conditions, higher-priced water could mean a displacement of certain crops and industrial processes back toward relatively water-wealthy areas like the Southeast.

The prospect of a major economic dislocation would undoubtedly generate some of its own pressure for water development and conservation. One sees a major mobilization after only two dry years: cloud seeding is invoked as an emergency rainmaking measure; there is a surge of interest in wastewater reclamation, seawater desalinization, and even iceberg towing; groundwater pumping is constrained only by the shortage of well-diggers and equipment; and renewed clamor for additional reservoir construction rekindles new battles between old adversaries. It is this last course of action, damming up new water supplies, through which California's water thirst has been quenched so often in the past. It is also one of the most expensive and difficult alternatives to reverse once started. Commenting on the Teton Dam failure in 1976, California Congressman Leo J. Ryan asserted: "...the root of the problem is in the momentum to build. Once a decision has been made to build, the force of the decision grows with every further decision concerning construction." Ryan believes the same forces are at work in the Bureau

²⁰ In "A Grim Future for the Water-short West", Business Week, May 23, 1977, pp. 111-114.

²¹ Hal Rubin, "The Political Aftershocks of Carter's Auburn Decision", California Journal, May 1977, p. 160.

of Reclamation's controversial Auburn Dam project, a \$1 billion-plus structure under construction near Sacramento, now threatened by seismic problems.

A far less costly alternative to the "momentum to build" syndrome, environmentalists are swift to point out, is that of making better use of existing water resources. But this course of action likewise has its impediments --antiquated water laws that encourage waste provide some of the greatest obstacles. California's water laws, like those of most western states, are based on the "appropriation" doctrine, a concept firmly rooted in the early gold mining era. Under the doctrine, water rights were distributed on a first-come, first-served basis. Users who did not use their full quotas lost them to other users. Furthermore, appropriation doctrine makes the sale of water rights virtually impossible without also selling the land for which they are designated. This is especially conducive to inefficient water use, since landowners have an incentive to use the water they cannot sell, even if it is not needed. Fortunately, there are signs that some states are moving to reduce the inefficiencies of western water law. Governor Brown has appointed a commission to consider possible changes in California's water laws. Nevertheless, change will be difficult due to the political sensitivity surrounding the resource and the state constitutionality issues surrounding water rights law. In the absence of state and federal action, speculates economist Kneese,²² a western water shortage will mean that many holders of inferior water rights simply will not get any water. This in turn could greatly accelerate the long-established custom of buying land solely to gain the water rights. In other words, the newer owners -- often large industrial operations-- could be expected to purchase the land (and water rights) of agricultural users on a massive scale.

Long-run management of California's limited water resources will also require greater attention to cumulative depletion and degradation problems. So far, the State has developed no comprehensive plan for recharging diminishing groundwater tables. In some areas of the San Joaquin Valley, wells in excess of 1,000 feet deep are required to overcome effects of the drought plus years of sustained overdrafts. Agricultural drainage is another unsolved problem in the Central Valley. Accumulations of salts and chemicals in the upper layers of soil or the groundwater has been described in detail by the Geography Remote Sensing Unit at the Santa

²² In "A Grim Future for the Water-short West", op. cit., pp. 112-114.

Barbara Campus. Proposals to solve this worsening situation range from evaporation ponds to the construction of an agricultural cloaca maxima, known as the San Joaquin Drain, which would discharge into the western end of the Delta. Continuing drought conditions will also provide a test for assumptions concerning long-run protection of the Delta as a viable aquatic environment. The DWR already has agreed to temporary reductions in Delta water quality standards to stretch dwindling fresh water supplies further.²³ Yet the Department fears that continued dry weather could make the Delta too salty to provide emergency water supplies to nearby municipal users. Thus, DWR is examining alternatives which include the construction of temporary dams at strategic points within the Delta. Such drastic steps underscore the severity of the current crisis and direct attention to the possibility of Delta degradation problems in the future.

6.4 Role of Remote Sensing

Obviously, no panaceas exist for coping with the intertwined mixture of California's drought-related problems. No spaceage breakthrough can be expected to overcome the myriad financial, legal, and political constraints on managerial action; no single "synoptic viewpoint" will unravel the resource depletion and environmental degradation difficulties exposed by the drought; and no multispectral marvel is going to eliminate the hardships posed by massive social and economic dislocation. All technologies have their limitations. The challenge is to discover the contexts in which they might prove useful for social purposes.

Whether an unprecedented drought offers the optimal context for developing user interest in a new technology like satellite-aided remote sensing techniques is still an open question. Certainly, water managers in California at this time would prefer a technology that instantly produced large volumes of water rather than one that tells them how little water there is. Nevertheless, the drought has stimulated DWR's thirst for a variety of updated information sources by which to monitor the developing crisis. One information area concerns the Department's hydrological modeling efforts. In spring 1976, after the first seriously dry winter, DWR's hydrological models overestimated the amount of stream-flow that would be expected given specified reservoir releases.²⁴ In an effort to better understand the discrepancies, DWR substantially enlarged their summer agricultural land use inventory program to include the entire Sacramento Valley. (Normally, around 10% to 20% of DWR's survey area is updated each year.) Tentative results from the survey showed that early

²³ Ronald B. Robie, Report of Activities of the Department of Water Resources, presented to the California Water Commission, May 6, 1977, pp. 10-12.

²⁴ See DWR Memorandum Report, "Accretion Study Phase of the DWR Coordinated Reservoir Operations Program", April 1972, for a partial description of the model.

irrigation and extremely dry soil accounted for most of the model discrepancies.

Rapidly-changing agricultural patterns, caused in part by the shortage of irrigation water, are another area that DWR wishes to watch more closely. Market pressures and the availability of water --irrigation water or groundwater-- traditionally have been the primary forces affecting cropping patterns in California. If surface supplies dry up, subsurface supplies fall out of reach, and bankers grow increasingly impatient, the landscape of California agriculture will change dramatically. These prospects give DWR incentive to develop methods for assessing statewide changes in agricultural patterns and water usage over a single growing season. Current research using Landsat-aided remote sensing techniques for inventorying irrigated lands in California has shown promising results in this direction.²⁵

Similar interest in updated information has been expressed by other state agencies. Dr. Gordon Snow, agricultural economist in the Department of Food and Agriculture, reports that his department could use improved information to learn about (1) how many acres are planted in different crops; (2) the age and health status of fruit trees; (3) the availability of water from its three principal sources, reservoirs, groundwater, and soil moisture/precipitation; and (4) how much water is being used by different trees and crops. This year, information on soil moisture and groundwater availability would be useful for advising farmers and municipalities on where to dig new wells.

The ubiquity of water-related problems was recently highlighted at the United Nations Water Conference held in Mar del Plata, Argentina, in March.²⁶ Notwithstanding the drought, California's relative water affluence contrasts vividly with a recent World Health Organization survey showing that only 35% of the world population have reasonably safe drinking water, and only 27% have some form of sewage disposal. Delegates to the conference ultimately adopted a plan to give priority to forming national water policies and institutional arrangements. There was also limited commitment to establish joint committees for data collection, pollution control, disease prevention, and flood control. Little progress was made in resolving interboundary conflicts arising from shared rivers, dams, and watersheds.

²⁵ See James M. Sharp, "Evaluating Accomplishments of the Irrigated Lands Project", in Sharon L. Wall *et al.*, An Inventory of Irrigated Lands Within the State of California Based on Landsat and Supporting Aircraft Data, final report, NASA contract NAS 5-20969, January 15, 1977, pp. 34-50.

²⁶ Ian Steele, "Quest for Pure Water", Christian Science Monitor, March 10, 1977, p. 16, and "What Happened on UN Water Parley", Christian Science Monitor, March 30, 1977, p. 9.

derive considerable benefit from study of the conditions impinging on and sometimes impeding, sometimes implementing successful transfer. During forthcoming months, the Social Sciences Group will devote considerable effort to developing a user manual to accompany the technical manuals now under preparation by the Remote-Sensing Group. Ours will be an educational document, designed to help the user understand the dynamics of utilizing technologically advanced data sources in making decisions related to the management of resources.

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CHAPTER 7

SPECIAL STUDIES

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SPECIAL STUDY NO. 1

REACTION TO REFLECTIONS ON THE FIRST CONFERENCE
ON THE ECONOMICS OF REMOTE SENSING INFORMATION SYSTEMS

by

James M. Sharp

Explanatory note: A three-day conference at San Jose State University in January 1977 stimulated several reflections on the sorts of studies often used to evaluate and sometimes to justify various remote sensing applications. These observations, sent to around 50 conference participants, have generated some interesting responses. Presented here are my original critique (exhibit 1), two supportive responses (exhibits 2 and 3), two critical responses (exhibits 4 and 5), and some concluding remarks.

The responses included here are selected from some 15-20 written and verbal reactions. Exhibits 3 and 4 have been retyped from the original handwriting.

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EXHIBIT 1

ON THE VALUE OF EVALUATIVE STUDIES: REFLECTIONS ON THE FIRST CONFERENCE
ON THE ECONOMICS OF REMOTE SENSING INFORMATION SYSTEMS*

James M. Sharp
Space Sciences Laboratory
University of California, Berkeley

The Ingenious Patriot

Having obtained an audience of the King an Ingenious Patriot pulled a paper from his pocket saying:

"May it please your Majesty, I have here a formula for constructing armour-plating which no gun can pierce. If these plates are adopted in the Royal Navy our warships will be invulnerable, and therefore invincible. Here, also, are reports of your Majesty's Ministers, attesting the value of the invention. I will part with my right in it for a million tumtums."

After examining the papers, the King put them away and promised him an order on the Lord High Treasurer of the Extortion Department for a million tumtums.

"And here," said the Ingenious Patriot, pulling another paper from another pocket, "are the working plans of a gun that I have invented, which will pierce that armour. Your Majesty's Royal Brother, the Emperor of Bang, is anxious to purchase it, but loyalty to your Majesty's throne and person constrains me to offer it first to your Majesty. The price is one million tumtums."

Having received the promise of another check, he thrust his hand into still another pocket, remarking:

"The price of the irresistible gun would have been much greater, your Majesty, but for the fact that its missiles can be so effectively averted by my peculiar method of treating the armour plates with a new—"

The King signed to the Great Head Factotum to approach.

"Search this man," he said, "and report how many pockets he has."

"Forty-three, Sire," said the Great Head Factotum, completing the scrutiny.

"May it please your Majesty," cried the Ingenious Patriot, in terror, "one of them contains tobacco."

"Hold him up by the ankles and shake him," said the King; "then give him a check for forty-two million tumtums and put him to death. Let a decree issue declaring ingenuity a capital offence."

Amrose Bierce, 1899

Had he attended, I suspect Mr. Bierce would have regarded the recent conference an assembly of ingenious patriots. Conspicuously absent, however, was a Great Head Factotum to restrain the patriots' ingenuity. Not that a convocation of high technology priests and scholars is any place for a medieval disciplinarian. A more contemporary viewpoint likely would see excessive ingenuity not as a crime, but as a disease to be controlled with ingenuity-suppressant medicines. What follows is one participant's diagnosis of an ingenuity illness manifested in many papers presented at the San Jose conference. The presentations seemed to suffer from three principal afflictions.

* Held 19-21 January 1977 at San Jose State University, San Jose, California.

MISDIRECTED FOCUS

Quantification of the benefits and costs of various remote sensing applications consumed a generous portion of conference time. But for what end? Right from the start, user acceptance has been acknowledged as the sine qua non for the ultimate success of NASA's earth resources applications transfer program. Yet the ability of traditional evaluative studies (i.e., cost-benefit and cost-effectiveness analysis) to facilitate this user acceptance remains to be demonstrated. On the contrary, evidence suggests that potential users are likely to regard independently-performed evaluations with extreme skepticism and occasional hostility: such studies are simply irrelevant to their needs.

The result of all this resembles a spaceage "Nero problem" where NASA investigators fiddle with numbers games while burning issues at the user level are ignored. Preoccupation with the value of remotely-sensed information rather than its use is, in essence, fallout from an earlier generation of studies that sought to justify Landsat to custodians of the federal budget. Fortunately for the user, the GAO, other agencies, and NASA itself have begun to express doubts about the value of these premature evaluations. NASA has entered a new phase in its earth resources program and is shifting its technical research emphasis from performance studies to applications verification testing. The San Jose conference papers notwithstanding, the time seems appropriate to make a parallel shift in socioeconomic research by worrying less about the value of information and by concentrating more on the means for achieving technology utilization.

SIMPLISTIC ASSUMPTIONS

A collection of artificial constructs added to the conference's ingenuity syndrome. Grandiose conclusions seemed to spring full blown from the most primitive of models once they were sprinkled with meager cost data. A rich compost of tenuous assumptions helped produce these miracles. Unfortunately, neither the models nor assumptions bore much resemblance to the real life situations they intended to portray. The problems and decision processes of flesh-and-blood users were obscured by analytical models concerned with homo economus and σ^2 values. This kind of abstraction becomes less relevant when one considers that improved decisions are the ultimate objective of nearly all remote sensing applications. Certainly the users themselves have no reason to be impressed by flimsy models and spurious calculations of net benefits. They are fully capable of performing their own assessments. The consequence for technology developers is an evaluative "boomerang effect" where users perform subjective evaluations and conclude, for reasons often assumed away in the more tidy analyses, that fruits from the new technology are not really worth their price.

PARTIAL ANALYSES

Excessive quantification and reductionistic modeling might be excusable if it is placed in an appropriate context. Most presentations at the conference, however, had no such good fortune. Cost estimates were bootlegged from one investigation to another, many intangibles were overlooked, and results were extrapolated beyond recognition or reason. True, some patriots had their ingenuity called into question, but most escaped without any credibility blemishes. It was the broader themes that escaped attention altogether. Nowhere, for example, were ad hoc evaluations presented within a larger framework of technology assessment. If they had been, considerable frivolity might have been avoided. This is because technology assessments, if well-conceived, cannot occur in a vacuum: they require simultaneous scrutiny of the technology, the surrounding society, and the assessment methodology itself.

* * *

Implicit in the foregoing diagnosis is a prescription for improving the health (and value) of evaluative studies concerned with remote sensing information systems. It is clear that an abundance of ingenuity is going to waste. NASA and other agencies could help by redirecting this talent toward more worthwhile pursuits. Shoddy and meretricious analyses should be put to death; more serious studies, encompassing a full range of technology assessment and utilization questions, should focus on the real life problems of existing and potential users. Only by expanding their horizons can NASA investigators hope to break away from the ersatz of contrived calculations and begin to judge remote sensing technology for what it is really worth.

February 22, 1977

Mr. J.M. Sharp
University of California
Space Sciences Laboratory
Berkley, California 94720
U.S.A.

Dear Mr. Sharp:

Thank you for your recent letter, received February 21, 1977 concerning the value of evaluation studies.

I must say that I fully subscribe to your analysis of the situation as presented at the conference. I would suggest that much the same situation prevails here in Canada. While only recently involved in the evaluation of the outputs of our satellite activities and benefits to the user I have been attempting to isolate the real problems without too much success. Your paper has been of considerable help to me in clarifying my thoughts for which I am grateful.

Sincerely yours,

Mr. James M. Sharp
Space Sciences Laboratory
University of California
Berkeley, Ca. 94720

2 March 1977

Dear Mr. Sharp:

Thank you for your reassuring remarks on the "ingenious patriots"... I was almost convinced of my own ignorance. Perhaps I am not so badly off after all.

I have been highly critical of most federal programs ... a lot of state and local ones, too ... in the fields of remote sensing, information systems and the like, because I think that most of them create more problems than they solve.

I am a career (25 years, plus) professional (planner) in local government, and I am well aware of what has happened to this institution. In light of the technology which is available today ... and which is coming on for the future ... I cannot comprehend why local government, in particular, persists using the same old manual methods. It seems that the only answer to any organizational or technological problem is to hire more people to dilute the problem down, then it won't be so big. I really do know the answer, it's simply that I have been unsuccessful in convincing anyone of influence to undertake the changes.

What good are satellite photographs taken every 18 or so days if it takes upwards of 4 years to receive an interpretation? What good is a census of population whose figures are unreliable three years after the fact ... and if that is the first time you've been able to get the figures? What good is imagery so sophisticated that nobody understands it, or computer compatible data which isn't? What good is high speed, computer graphics capability when it takes months of research to extract the input data ... if it is available at all, which most of the time it isn't? And so on and on. I watch our people, and sometimes participate, re-invent the wheel day in and day out; I have seen enormous sums of money utterly wasted on development programs and technology transfers which were doomed from the start, if one only had sense enough to examine the program for a few minutes.

I have yet to review a program, particularly for geographic data maintenance, which showed any good prospect for survival ... not one of them acknowledges that modern technology is expensive and that somewhere in the program a real ... not a manufactured ... source of cost-effectiveness must be highlighted. I had the feeling that the "ingenious patriots" all manufactured their favorable results.

To be frank about the whole thing, I do not believe that any "patchwork" system will ever do the job ... government as a whole and local government in particular has degenerated into an unintelligible can of worms ... ask anyone that must deal with a building department or an assessor.

The federal establishment could, I think, make an effort to supplant antique, manual technology which has no aim other than survival with modern computer technology aimed at improved efficiency and at the future. USAC, in 1969, made a big show of developing new systems for local government ... which, of course, was a bust. All they did was to patch in some operating business systems and converted the manual operations to machines ... they didn't have nerve enough to undertake geographic data at all ... at least that was the last information which I had.

...well, I could go on like this for days ... suffice it to say that I have some strong feelings about the value of remote sensing and the ability of local government to make use of it. It is strange that of the myriad of people I have talked with who were "selling" modern technology to local government, not one of them had any experience in local government ... not one of them understands the problem for which they are peddling a solution. I see that as a basic fault in the Census, GAP and etc ...!

Thanks again for your ingenious patriots ... gave me a chance to spout off once again.

Sincerely,

16 March 1977

Dear Dr. Sharp:

Enjoyed your views. I fear that I disagree, however.
Please see my crude responses.

(MISDIRECTED FOCUS)

Σ = Technicians should not have to justify expenditures of scarce resources.

(SIMPLISTIC ASSUMPTIONS)

Σ = The models are weak so we should ignore their warnings.

(PARTIAL ANALYSES)

Σ = Same as #2.

(* * *)

Σ = Stop trying.

March 8, 1977

Dr. James M. Sharp
Space Sciences Laboratory
University of California
Berkeley, CA 94720

Dear Dr. Sharp:

One of the foremost "real life problems of existing and potential users" is: how to justify research and development projects involving use of remote sensing information systems. Your remarks on the "value of evaluative studies" reveals that you are (apparently) fortunate enough never to have needed to give this problem much thought. Alternatively, you have emerged unscathed and unshaken from the recession of the early 1970's and retain the naive expectations of the previous decade that R and D funds will flow into Science Laboratories from the federal government whenever the manager asks for them!

Yours sincerely,

General Comments

Positive reactions like those in Exhibits 2 and 3 emphasize the principal assertions in my original critique: in the remote sensing information business, the difference between evaluation and obfuscation all too often is non-existent. At best, the result may be simple confusion; at worst, the result can irretrievably alienate potential technology users.

Critical responses like those in Exhibits 4 and 5 help elucidate some points concerning the content and "clients" of technology evaluations. Of course, technologists have an obligation to justify their expenditures of scarce resources. But what constitutes a fair justification? It is important to not place any greater faith in the supporting models and their conclusions than their assumptions and context allow. In other words, an inadequate justification may be worse than no attempt at justification at all.

A related point involves the intended recipients of such evaluation exercises. It appears that Mr. Exhibit 5 and I are referring to opposite sides of the same federal dollar. One side is concerned with justifying various projects so the funders can establish their priorities; the other side -- the users' orientation -- concerns the end objective of the projects: i.e., how to achieve user acceptance. I am not arguing for an elimination of work on the first side -- just a redress of the balance. Also, I am suggesting that the quality of the work on the first side could be made more relevant to the needs of funders and users alike.

SPECIAL STUDY NO. 2

THE INCREASING NEED FOR WATER RESOURCE
INFORMATION IN CALIFORNIA

By

Robert N. Colwell

Introduction

Because of the fact that California is in the midst of its worst drought in recorded history, there is increasing concern relative to the present adequacy of California's water resources and also of the information that pertains to the supply of and demand for that water.

Concern on the part of the general public is reflected in the daily newspapers of California which contain, in nearly every edition, remote sensing imagery of the types comprising Figures 1 through 4 of this Special Study.

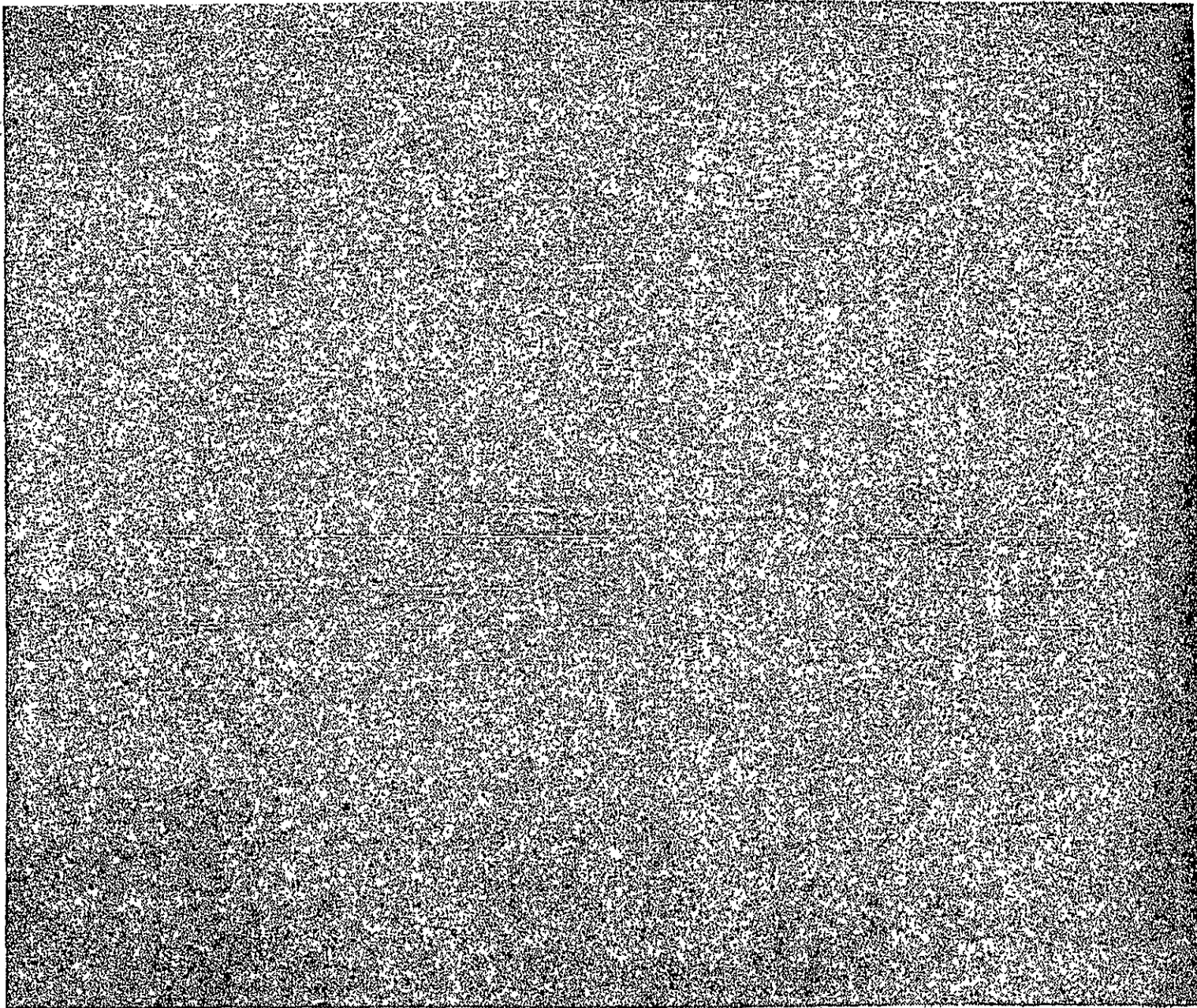
Concern on the part of the California Department of Water Resources has quite properly centered on irrigation water, since more than 80 percent of California's water use is for the irrigation of agricultural crops. That concern has resulted in the conduct, by personnel of the Remote Sensing Research Program on the Berkeley campus of the University of California, of a NASA-funded study for DWR entitled, "An Inventory of Irrigated Lands for Selected Counties within the State of California Based on Landsat and Supporting Aircraft Data".

By way of placing this Special Study in proper perspective, the following points are considered essential:

(1) California receives an annual average of 200 million acre-feet of precipitation.

(2) Because most of this precipitation occurs in the winter months and most runoff occurs in areas with low demand for water, the state of California has built large scale systems, as under the California Water Plan, for the purpose of storing water and eventually of transporting it from areas of surplus to areas of scarcity.

(3) The California Department of Water Resources (DWR) is charged with the "control, protection, conservation, and distribution of California's water in order to meet present and future needs for all beneficial purposes in all areas of the state".



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Figure 1. As shown here, most of the bottom of Folsom Reservoir in the Sierra Nevada Foothills of California is now exposed because of drought conditions. Even the Old Salmon Falls Bridge across the South Fork of the American River has been uncovered. It had not been seen for more than 20 years:

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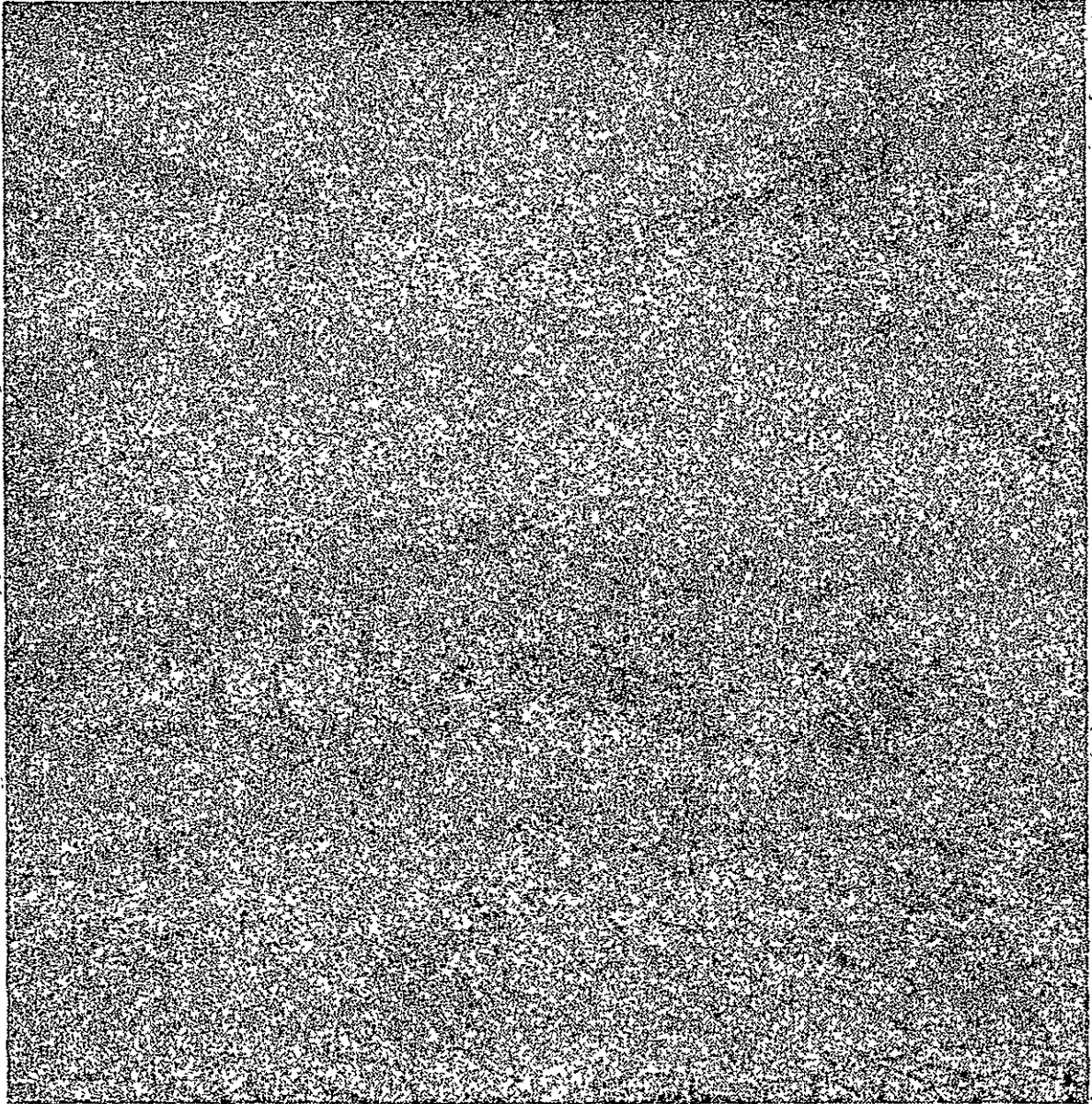


Figure 2. This terrestrial photo shows the Pardee Reservoir, principal water storage facility for the entire San Francisco-East Bay area of California, which has a population that is approaching 2 million. The vegetation "trim line" shows where the water level should be in this reservoir in the spring of the year when this photo was taken. Compare with the aerial photo of Figure 3.

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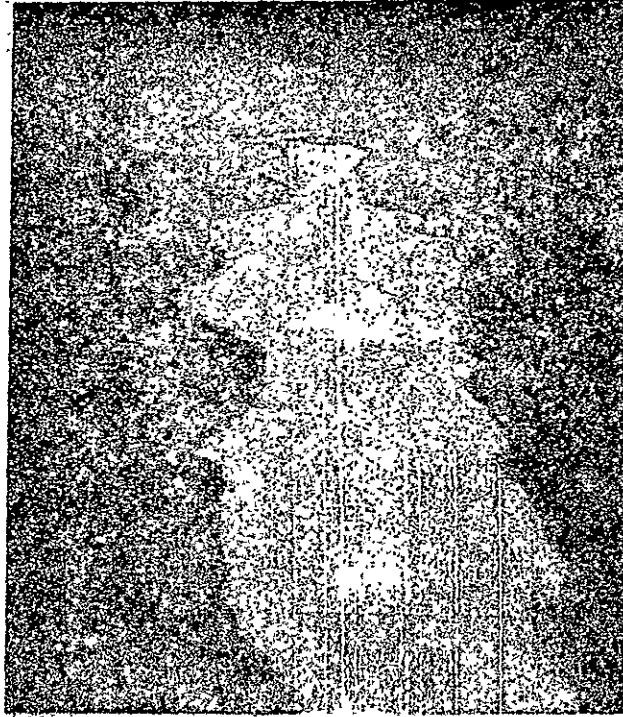


Figure 3. An aerial view of a typical California reservoir as it appeared in the spring of 1977. The terrestrial photo of Figure 2 was taken from the far (upper) end of the reservoir, looking toward the point from which this aerial photo was taken.



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Figure 4. This aerial oblique photo shows a portion of Shasta Reservoir in northern California, taken at about the same time as the Landsat imagery of it was taken that comprises Figure 1 of Chapter 6. The alarmingly low water level is clearly seen in both kinds of imagery.

(4) The DWR carries out this responsibility through a statewide planning program which, in part, includes periodic reassessment of existing and future demands for water and periodic reassessment also of local water resources, water uses, and the magnitude and timing of the need for additional water supplies that cannot be supplied locally.

(5) To meet these needs, the DWR has been performing a continuing survey on a 5 to 10 year cycle to monitor land use changes over the state that will be indicative of changes in water demand.

(6) Because of the costs (an estimated \$150,000 per year) and manpower efforts involved, only a portion of the state is surveyed during a given year. Hence, at any given time water resource data applicable to the various portions of the area of concern have differing degrees of currency, the information having been collected in some areas only recently and in others as much as 5 to 10 years previously. The shifting time base applicable to information from the various components makes it very difficult to compile figures that will reflect water demand throughout the entire state for any given point in time.

(7) Even before the advent of the present study, some remote sensing was used in the DWR data collection effort. Specifically, conventional aerial photography was acquired, in any given year and only on a one-date basis, for each of the counties that were scheduled for an updating of information relative to water demand. From interpretation of the aerial photography and the use of supplemental field inspection, the DWR is able to estimate the acreage of irrigated land in that county as of the date of photography. However, for want of multi-date photography during the growing season DWR is not able to determine either (a) individual types of crops (or crop groupings) that are of significance because of differing demands for irrigation water, or (b) areas in which, through a practice known as "multi-cropping", a given area is made to produce two or more crops in succession in the same growing season, thereby imposing in most instances increased water demands per acre per season.

In view of the foregoing it was considered probable that the repetitive monitoring capabilities offered by the Landsat I and Landsat II vehicles would provide a practical source of information that could become a valuable supplement to the DWR surveys that have just been described. More specifically, the primary objective of the Irrigated Lands Project (ILP) was to develop an operationally feasible process by which the California Department of Water Resources (DWR) could use information derived from the analysis of Landsat imagery, together with supporting large scale aerial photography and ground data to obtain irrigated acreage statistics on a regional basis (i.e., statewide). The methods which personnel of our Remote Sensing Research Program were able to develop preliminarily under this project are now in the process of being demonstrated/tested in a survey of ten California counties (13,745,000 acres). In the 10-county test, three dates of Landsat imagery have been chosen for the estimation: June (when the best insight on small grain acreage is obtained), August (when the maximum canopy coverage for many crops is exhibited), and September (when evidence is best obtained of a multiple cropping sequence). Landsat I color composites, printed at a

scale of approximately 1:154,000, were produced for each of the ten counties on each of the selected dates. County boundaries and areas excluded by DWR from the study (e.g., orchards which, because of their greater degree of permanence are already well mapped) were then annotated on the imagery.

A three-phase sample design with cluster units was chosen for the ILP study, and involved Landsat interpretation, large scale aerial photo interpretation, and ground measurement. The sample units at each phase were a subsample of the sample units at the previous phase. Since estimates are required on a county basis, a stratification by county was also used. A single FORTRAN program was written to compute the three-phase estimates and the associated variance estimates.

Manual interpretation techniques for the Landsat imagery and large scale aerial photography were developed by the RSRP and demonstrated to DWR personnel at several training sessions. With the training provided, DWR became actively involved in interpreting both the Landsat imagery and the large scale aerial photography. A preliminary test based on one of the counties indicates that there is a correlation of 0.951 between the aerial photo interpretation and ground truth data, and of 0.950 between the Landsat imagery interpretation and the aerial photo interpretation.

CHAPTER 8

SUMMARY

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SUMMARY*

Robert N. Colwell

- 8.0 During the one-year period covered by this integrated multi-campus study, California's water resources have continued to be the primary resources investigated. We have concentrated our efforts on determining the usefulness of remote sensing in relation to two aspects of California's water related problems: (1) those pertaining to water supply in northern California (dealt with primarily by personnel of the Davis and Berkeley campuses, as reported upon in Chapters 2 and 3, respectively); and (2) those pertaining to water demand in central and southern California (dealt with primarily by personnel of the Santa Barbara and Riverside campuses, as reported upon in Chapters 4 and 5, respectively). In addition, the socioeconomic, cultural, and political considerations that relate to the management of California's water resources continue to be investigated by the Social Sciences Group on the Berkeley campus, as reported in Chapter 6. Finally, in Chapter 7, an account is given of various special studies which, while being highly relevant to certain of the objectives being sought in our grant-funded studies, were not themselves funded through the grant, itself.
- 8.1.0 The following facts are described in Chapter 1 of this progress report:
- 8.1.1 The rationale for our having concentrated our remote sensing research on California's water resources for the past several years is provided in a four-part statement on page 1-2 of the present progress report. This is followed by an eight-point statement that seeks to place in proper perspective the emphasis that has been placed to date on the use of modern remote sensing techniques in relation to the inventory and management of California's water resources.
- 8.1.2 At NASA's request, the primary focus of our research recently has been changed from one of conducting remote sensing-related research to one of preparing "procedural manuals". The primary objective in preparing such manuals is to achieve technology acceptance. More specifically, the objective is to maximize the prospect that potential user agencies will adopt modern remote sensing techniques as an aid to the inventory and management of water resources, not only in California, but elsewhere as well.

*This summary of our four-campus activities, like that appearing in each of our previous grant reports, is of necessity quite lengthy. The interested reader is nevertheless encouraged to read it in its entirety, the better to appreciate the integrated nature of this multi-campus study and to select portions meriting more detailed reading, depending upon his own specific interests.

8.1.3 Despite this change of focus, we have been able to progress toward the completion of those research aspects which will serve to establish the validity of the various step-by-step procedures which we are in the process of developing for inclusion in the manuals.

8.1.4 The reader will find in this progress report the first iteration of several Procedural Manuals, each describing the specific way in which remote sensing can be used advantageously to inventory some water-related attribute, such as areal extent of snow, water content of snow, water demand in agricultural areas, etc. Thus, the rather sizable overall document will be for use of those concerned with all aspects of water resource management (both the supply and the demand aspects) while each of its various subdivisions, when made to stand alone, will better serve the needs of those concerned with only one limited aspect or another of this management problem.

As an additional aspect of our NASA-approved plan, during the forthcoming one-year period, as we near the time of termination of the grant, we intend to concentrate on the preparation of Procedural Manuals that deal with remote sensing as an aid to the inventory and management of the entire "resource complex" of an area--i.e., not just its water resources, but also its timber, forage, agricultural crops, soils, minerals, fish, wildlife, livestock, and recreational resources.

With respect to the preparation of these more comprehensive Procedural Manuals we recently have had discussions with various resource managers including (1) California's Regional Forester of the U.S. Forest Service; (2) the Supervisors of various U.S. National Forests in California; (3) their counterparts in California's State government; and (4) others concerned with resource management.

8.1.5 Although in some instances it is preferable from the intended user's standpoint for the Procedural Manual to deal with remote sensing as applied to only a single resource, such as water, in other instances it should deal with remote sensing as applied to the inventory and management of multiple resources or, indeed, to the entire "resource complex".

8.1.6 Procedural Manuals of the latter type will be made (during the one-year period beginning on 1 May, 1977) primarily by three components of our multi-campus integrated team: (1) the Geography Remote Sensing Unit on the Santa Barbara campus; (2) the Geosciences Remote Sensing Group on the Riverside campus, and (3) the Remote Sensing Research Program on the Berkeley campus. During that same period our Social Sciences Group also will be assisting in the preparation of the relevant manuals.

8.1.7 By mutual agreement, the remote sensing team at Davis, under the leadership of Dr. Ralph Algazi, will not contribute to the preparation of Procedural Manuals during the one-year period that begins on 1 May, 1977. Instead his grant-funded efforts will be entirely in support of the ASVT that is jointly administered by NASA Goddard and the U.S. Army Corps of Engineers dealing with remote sensing as an aid to the estimation of water supply.

- 8.2.0 The following facts are summarized in Chapter 2 of this report:
- 8.2.1 For reasons indicated above, Chapter 2 constitutes the final report of work done under this grant by personnel of the Davis campus Algazi group. That work has continued to deal primarily with uses of remote sensing in relation to the inventory of water supply. Specific aspects of the work performed by that group during the present reporting period are as follows:
- 8.2.1.1 Implementation and sensitivity analysis of a watershed model. The effect on estimates of monthly volume runoff was determined separately for each of the following parameters: precipitation (i.e., rainfall and snowmelt); evapotranspiration; lower zone and upper zone tension water capacity; imperviousness of the watershed; and percent of the watershed occupied by riparian vegetation, streams, and lakes. The most sensitive and critical parameters were found to be precipitation during the entire year and springtime evapotranspiration.
- 8.2.1.2 Determination as to which of the hydrologic parameters used in the model are amenable to remote sensing inputs. As evidenced by the above findings the two most important parameters to be acquired by remote sensing are precipitation and evapotranspiration. Hence efforts are continuing to maximize the usefulness of remote sensing in measuring these parameters, area-by-area.
- 8.2.1.3 Development of techniques for predicting snowmelt runoff based on digital processing of satellite images. The physical quantities that are of greatest significance in the modeling of basin snowmelt are temperature, albedo, water content, and the areal extent of snow, the latter being further stratified in terms of the elevation, slope, and aspect of the area wherein the snow is present. NOAA satellite returns have been used by Algazi, et al, as the primary source of input data with respect to snow.
- 8.2.1.4 Basic studies of image processing techniques pertinent to remote sensing applications. Emphasis has been given in these studies to the making of geometric corrections of satellite images as necessitated by such factors as panoramic distortion, earth rotation, scan skew, satellite velocity, satellite altitude and attitude changes, and changes in the velocity of rotation of the scanning mirror.
- 8.3.0 The following facts are reported in Chapter 3 of this report:
- 8.3.1 Work performed by personnel of the Remote Sensing Research Program on the Berkeley campus of the University of California, like that of the Algazi group at Davis, has continued to deal primarily with uses of remote sensing in relation to the inventory of water supply. Specific aspects of the work performed by that group during the present reporting period are as follows:*

*Close cooperation with Algazi's group continues on all of these aspects.

- 8.3.1.1 The summarizing of findings to date with respect to the uses that can be made of remote sensing in making estimates of water supply, whether in a local drainage basin or throughout an entire watershed.
 - 8.3.1.2 The development of remote sensing-aided procedures, based on that summary, for estimating various important components that are used as input to hydrologic models dealing with water supply.
 - 8.3.1.3 The preparation of procedural manuals, each of which will describe, for one or more of the above components, the step-wise process which might best be followed by managers of water resources in using remote sensing as an aid to acquiring information with respect to that component.
- 8.3.2 The RSRP group draws the following specific conclusions:
- 8.3.2.1 The methodology that has been developed by RSRP personnel for a remote sensing-aided system to estimate the various components of a water-yield model will give timely, relatively accurate, and cost-effective estimates over snow-covered areas on a watershed-by-watershed basis. (These components are snow areal extent, snow water content, water loss to the atmosphere, and solar radiation. The system employs a basic two stage, two phase sample of three information resolution levels to estimate the quantity of the above-mentioned components of the water-yield model. The input data for this system requiring spatial information is provided by Landsat, by meteorological satellites, by high- and low-flight aerial photography, and by ground observation.)
 - 8.3.2.2 The general concept of multistage sampling, which has been used successfully by RSRP in several other remote sensing research experiments involving manual and automatic data analysis, has governed in large measure the design of this project and has facilitated the performance of valid statistical analyses. This is extremely important so that future results from different approaches can be analyzed with respect to one another and to prior research. Confidence intervals have been applied to all estimates discussed by the RSRP group, thus providing figures relative to the accuracy of results.
 - 8.3.2.3 Sources of input data for use in estimating water supply include the entire spectrum of environmental data gathering systems currently operating. Satellite information sources include Landsat and NOAA. The primary photographic data base consists of large to medium scale photography of the type obtained by the RSRP group. Ground data is collected with the cooperation of both federal and state agencies such as U.S. Geological Survey, National Climatic Center, U.S. Forest Service, California Division of Forestry, and California Department of Water Resources.
 - 8.3.2.4 In the case of snow areal extent estimation, one of the advantages of the RSRP technique versus conventional methods is that it not only corrects the interpreter's snow areal extent classification to plot/ground values based on testing results, but also minimizes variation

in final classification results between interpreters. Thus, a consistent result can be expected even though areal extent of snow estimation is performed on different areas by different interpreters. Also, the double sampling method, which in effect calibrates the more coarsely resolved Landsat-based estimates, provides a good data bank for more accurate estimation of parameters of interest.

- 8.3.2.5 Based on the results obtained when using the remote sensing-based techniques described above, it can be concluded that there is a substantial advantage in terms of both cost-effectiveness and precision to be gained through their use, as compared to other, conventional methods. The complete version of a procedural manual for a remote sensing-aided system for snow areal extent estimation is described by RSRP personnel in Chapter 3, Appendix I, of the present progress report.
- 8.3.2.6 From the results obtained in the RSRP's snow water content studies, it can be shown that a potential cost and/or precision advantage is to be gained in this area, also, by use of remote sensing-aided methodology. Their method utilizes data obtained through conventional ground measurement of snow courses integrated into a double sampling framework with Landsat-derived data.
- 8.3.2.7 Level I and Level II evapotranspiration estimation models have been developed by RSRP personnel. Level I models are based on the first information level and utilize solar radiation, temperature, and humidity as the main input variables. Level II models are based on energy-balance. Level III models would offer further refinements based on energy-balance, and on aerodynamic and canopy resistance. Level I ET models have been applied to the Spanish Creek Watershed with satisfactory results. The results of ET models will be directly applied to the operational hydrologic model (known as the Federal-State River Forecast Center Model) that currently is being used by the California Department of Water Resources.
- 8.3.2.8 Since solar radiation is the major source of energy for hydrological processes, the quantity of net radiation constitutes the key parameter in hydrological modeling. A remote sensing-aided system developed by RSRP for solar radiation estimation is designed to give time- and location-specific estimates on a watershed or subwatershed basis. This system utilizes some constant physiographic data and some climatic variables. That methodology, as applied to Spanish Creek Watershed, has provided very satisfactory results. Solar radiation results, therefore, are being used as one of the major inputs in the RSRP evapotranspiration models.
- 8.3.2.9 In several specific instances RSRP has shown that the use of its methods can help water resources managers by making available to them better water resource inventories and more accurate water-yield predictions, thereby permitting them to devise and implement better management practices. Based on such experience, RSRP is preparing and refining various Procedural Manuals, as described in Appendices I, II, III, and IV to Chapter 3 of the present progress report.

- 8.4.0 In Chapter 4 of this progress report the following facts are emphasized:
- 8.4.1 During the current reporting period, personnel of the Geography Remote Sensing Unit (GRSU) on the Santa Barbara campus (authors of Chapter 4) have been concentrating their research efforts on the following water demand-related topics:
- 8.4.1.1 The development of manual and digital remote sensing techniques capable of producing cost-effectively most of the information that is needed in making water demand predictions for agricultural areas, whether in California or elsewhere.
- 8.4.1.2 More specifically, the development of remote sensing techniques for the generation of agricultural water demand information that will facilitate resource management by the Kern County Water Agency (KWCA) in the southern portion of California's San Joaquin Valley.
- 8.4.2 In the attempts that have been made to generate this agricultural water demand information, definitive experiments have been performed on the usefulness of remote sensing in quantifying each of the prediction variables, including estimates of acreage by crop type, physiographic variables, and meteorological variables.
- 8.4.3 In the above studies care has been exercised to ensure that efforts by the Santa Barbara group were complementary to, and not duplicative of, those engaged in by the Algazi group at Davis, personnel of the RSRP at Berkeley, or our remote sensing team at Riverside.
- 8.4.4 Sufficient success has been achieved in the above activities to permit the Santa Barbara group to prepare a preliminary version of its "Procedural Manual for the Use of Remote Sensing Techniques in Deriving Cropland Information for Water Demand Predictions". That procedure is given in Section 4.3 of the present progress reports.
- 8.4.5 Although the agricultural water demand prediction procedures described in Chapter 4 were developed by GRSU personnel of the U.C. Santa Barbara campus for a representative semi-arid region in central California, they may be applied to other water demanding regions if careful attention is given to the following procedural steps:
- 8.4.5.1 Empirically identify the regionally important nature of the water demand prediction variables, i.e., which parameters account for the most variance in the prediction procedure.
- 8.4.5.2 Evaluate information sources and identify those parameters which due to temporal or accuracy constraints should be inventoried using remote sensing techniques. Based on previous research, it is assumed that the agricultural landcover will be a major model driver.
- 8.4.5.3 Select one of the inventory techniques by evaluating the level of information detail required and the agency's hardware, software, and collateral information resources.

- 8.4.5.4 Conduct the agricultural landcover inventory.
- 8.4.5.5 Develop spatially accurate water demand predictions by interrogating the landcover dataset in conjunction with average irrigation rates.
- 8.4.6 The water demand estimates may then be used to make short- and long-term water resource management decisions regarding groundwater recharge, taxation schedules, and/or intra-regional water transfer.
- 8.4.7 The proposed research of the Santa Barbara group for the period beginning May 1, 1977 will be to perform a total resource complex inventory of the valley portion of Kern County, California. As the Geography Remote Sensing Unit has continually interfaced with public user agencies to identify information requirements and, in addition, has acquired a substantial amount of collateral information on this region in the past, it is felt that the only viable method of modeling the total resource complex is to develop an analytical geobase information system. The most significant driver of this information system will be the use of digital Landsat thematic products which will monitor dynamic topics. Such data will be merged with other collateral information such as soils, groundwater, census, etc., to yield higher order integrative data which is spatially accurate and useful for Kern County decision makers. By April, 1978, GRSU will document the procedural manner in which other regions can initiate and successfully operate a total resource complex information system such as that developed for the Kern County study area.
- 8.5.0 Chapter 5 of this progress report deals with studies conducted by remote sensing scientists on the Riverside campus, relative to water and other resource allocations in southern California.
- 8.5.1 These studies have led to the following accomplishments during the present reporting period:
 - 8.5.1.1 Production of a Procedural Manual for the use of remote sensing in Land Use Mapping. In its present form that manual will be evaluated by potential users after which a final, and well illustrated, version will be prepared.
 - 8.5.1.2 An analysis of the potential use of Landsat temporal data to monitor changes in irrigated land. The test area for this study is the Perris Valley region of the Upper Santa Ana River Drainage Basin.
 - 8.5.1.3 A study on the uses of remote sensing to provide inter-census estimates of the human population of specified areas in southern California.
- 8.5.2 In addition to the above, the Riverside group is in the process of documenting the kinds of software needed to maximize the usefulness of remote sensing for land use mapping by automated means.
- 8.5.3 Two attributes of the procedural manuals being prepared by the Riverside group are as follows:

- 8.5.3.1 All will go through successive reviews by the intended users before being produced in final form.
- 8.5.3.2 All will be integrated into the overall series of manuals being prepared under this multi-campus project.
- 8.6.0 Chapter 6 of this progress report, prepared by our Social Sciences group on the Berkeley campus, relates remote sensing to various socioeconomic impacts of the present drought on water management in California. Among the many cogent points made in that chapter are the following:
- 8.6.1 Whether an unprecedented drought offers the optimal context for developing water interest in a new technology like satellite-aided remote sensing techniques is still an open question. Certainly water managers in California at this time would prefer a technology that instantly produced large volumes of water rather than one that tells them how little water there is.
- 8.6.2 Nevertheless, the drought has stimulated the thirst of personnel in California's Department of Water Resources for any improved information source, such as remote sensing, by which to monitor the developing crisis.
- 8.6.3 We must recognize, however, that no space age breakthrough can be expected to overcome the myriad financial, legal, and political constraints on managerial action--action that is sorely needed in this time of crisis with respect to California's water resources.
- 8.6.4 Similarly we must realize that no "synoptic viewpoint" will unravel the resource depletion and environmental degradation difficulties exposed by the drought; and no multispectral marvel is going to eliminate the hardships posed by massive social and economic dislocation. All technologies, including those based upon remote sensing, have their limitations; the challenge is to discover the contexts in which they might prove useful for socioeconomic purposes.
- 8.6.5 Market pressures and the availability of water--irrigation water or groundwater--traditionally have been the primary forces affecting cropping patterns in California. If surface supplies dry up, subsurface supplies fall out of reach, and bankers grow increasingly impatient, the landscape of California agriculture will change dramatically. These prospects give California's Department of Water Resources incentive to develop methods for assessing statewide changes in agricultural patterns and water usage over a single growing season. Current research using Landsat remote sensing techniques for inventorying irrigated lands in California has shown promising results in this direction.
- 8.6.6 The process of technology transfer, however, is not automatic or mechanistic. It takes place only under certain conditions and circumstances, most of them organizational, institutional, political, social, and human. NASA's technology transfer program with respect to remote sensing is more concerned than ever with the technology/society

interface. It therefore can derive considerable benefit from study of the conditions impinging on and sometimes impeding, sometimes implementing successful transfer.

- 8.6.7 In the coming year the Social Sciences group will devote considerable effort to developing a User's Manual to accompany the technical manuals now under preparation by our various remote sensing groups. The Social Sciences Manual, as related to remote sensing, will be an educational document, designed to help the user understand the dynamics of utilizing technologically advanced data sources in making decisions related to the management of resources.
- 8.7.0 As in our previous progress report, Chapter 7 of this report deals with various special studies which were not funded by our NASA grant, but which are considered to be highly relevant to the grant's objectives and therefore worthy of inclusion. Two such special reports appear in Chapter 7. Specifically:
- 8.7.1 Special Study No. 1 is an analysis of reactions by various attendees to the "First Conference on the Economics of Remote Sensing Information Systems" which was held at San Jose State University, California, in January 1977. There seems to be general agreement that, (1) in any given specific instance, inadequate justification for using remote sensing techniques is worse than no attempt at justification at all; and (2) inadequate justification may result from (a) misdirected focus, (b) simplistic assumptions, and (c) partial analyses. Beyond that, a rather wide spectrum of opinions was expressed by the various California attendees as to what constitutes a valid appraisal of the economics of remote sensing information systems.
- 8.7.2 Special Study No. 2 seeks to document the great concern that currently exists relative to the adequacy of California's water resources, and therefore the concern that exists relative to the adequacy of information pertaining to the supply of and demand for water.
- 8.7.3 A reading of the two special studies cited above, as contained in Chapter 7 of this report, will provide the interested reader with an enlightened view of certain important aspects of the work which our integrated multi-campus study group has been doing for the past several years with funding other than that provided by our NASA-funded grant.
- 8.8.0 For additional details relative to any of the aspects discussed in this lengthy summary, the interested reader is referred to the correspondingly numbered chapter and section as contained in the main body of this progress report.