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

A report of work done by scientists of 6 campuses of the University of California. (Davis, Berkeley, Santa Barbara, Los Angeles, Irvine, and Riverside) under NASA Grant NGL 05-003-404

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198

FOREWORD

The organization of this progress report is designed to emphasize (1) the *integrated approach* which our group is using in the study of earth resources in the State of California by means of remote sensing, and (2) the *concentrated effort* that our group is initially making on one of the most significant components of California's earth resource complex, viz., the California Water Project.

It is recognized that most of the decisions required both in conceiving and in developing the California Water Project had already been made before our study was begun. This we regard as a major strength rather than a weakness in our Study. Our objective is *not* to criticize either the concept that resulted in the California Water Project or the steps being taken to implement it. Instead, we seek to use in our Study the valuable experiences gained and ground truth acquired by those who have worked for many years on the California Water Project. We would find it prohibitively costly and time consuming to acquire this same kind of "input" independently. Therefore, we are doubly grateful to those in the California Resources Agency and elsewhere who have so freely cooperated with us in this Study.

Viewing such information in the light of recent developments in the making of both *remote sensing inventories* and *socio-economic studies* our group seeks to develop a "model" approach to this type of resource development problem wherever it may occur in analogous areas throughout the globe.

Mindful of these considerations and after an introductory chapter, our progress report begins with a study (Chapter 2) of some of the complex socio-economic factors involved in the California Water Project. In this section we consider:

(1) the potential *users* of the various water resources that will be

provided by the California Water Project with special emphasis on their attitudes, prejudices and needs for information relative to that project. We are vitally interested in better understanding these segments of society, whether they are agriculturists or urbanites, recreationists or industrialists, conservationists or exploitationists.

(2) the potential managers of water resources that will be provided by the California Water Project, with special emphasis on their informational requirements in terms of format, frequency, rapidity and accuracy.

A second section of our progress report (Chapter 3) deals with a defining of the parameters that govern (1) the yield of water, especially in the source or headwaters area of the California Water Project, (2) the surface and subsurface flow of that water, and (3) the consumption of that water by plants and animals.

The third and largest section of our report (Chapters 4 through 9) deals with our efforts to determine the extent to which remote sensing can be used to measure hydrologic parameters in the "source", "central" and "sink" areas of the California Water Project.

A fourth and conclusive section of our report (Chapter 10) reflects our desire in this integrated project to begin remote sensing studies on a second major segment of the California resource complex, viz., the Coastal and River Delta resources. This interest is occasioned in part by the fact that approximately 75 percent of California's population lives in the Coastal zone. We consider it desirable to implement this new phase of the integrated study next year even while bringing to a conclusion our studies of the California Water Project.

TABLE OF CONTENTS

Chapter 10 ✓ COASTAL ZONE AND RIVER DELTA STUDIES

N 73-21348

Chapter 1

INTRODUCTION

Robert N. Colwell

The wise management of earth resources (timber, forage, soils, water, minerals, agricultural crops, etc.) is rapidly becoming one of man's most urgent responsibilities. Much of the urgency results because the supply or quality of certain of these resources is dwindling rapidly at the very time when the demand for them is increasing prodigiously. Only through wise management will earth resource managers be able to meet this every-increasing demand.

Human demands for earth resources are rising at an even greater rate than is suggested by the term "population explosion", because the per capita demand also is increasing, both in developed and developing countries. Several studies indicate that there will be a greater demand for earth resources in the next 30 years than in all prior periods combined.

This urgent need to manage earth resources wisely generates, in turn, a need to inventory them accurately. As a prerequisite to intelligent management, the earth resource manager must know, for each component of the earth resource "complex", how much of it is located in each portion of the area which he seeks to manage, i.e., he must have an "integrated" inventory. And since many components of the earth resource complex in a given area are dynamic rather than static, it is necessary for these resources to be inventoried frequently and rapidly -- frequently so that resource trends can be followed -- rapidly so that resource management decisions can be made and implemented while the inventory data are still current.

Up to the present time, the means for obtaining earth resource inventories that could satisfy such exacting requirements have been decidedly inadequate. However, during the past decade such important developments have taken place in three related fields of technology as to prompt many observers to believe that "remote sensing"* will soon provide that means. These three fields of development are:

(1) The development of improved remote sensing devices whether they be aerial cameras of higher spatial resolution than heretofore or thermal infrared sensors, gamma ray spectrometers, multispectral scanners and imaging radar devices, all of which can provide information heretofore unattainable about earth resources.

(2) The development of improved vehicles for the transport of these remote sensing devices. Not only has there been the development of remote sensing aircraft which can fly higher, faster and farther than ever before. Since the dawning of the space age little more than a decade ago, earth orbiting spacecraft equipped with suitable remote sensing equipment, also have been developed. Through the use of such earth orbiting vehicles one can obtain the overall synoptic view from which certain earth resource features can be discerned for the first time. The use of both types of vehicles (high altitude aircraft and spacecraft) in concert with conventional aircraft and helicopters, permits the earth resource analyst to use highly efficient "multistage sampling techniques" to a degree that was virtually unthinkable until very recently.

(3) The development of automatic data processing equipment and techniques to facilitate the rapid and accurate analysis of remote sensing data.

* The term "remote sensing" pertains to the acquiring of information about earth resources, or other features, through the use of aerial cameras or other sensing devices that are not in contact with the features of interest, but situated at a substantial distance from them.

Recent progress in this area has been so impressive as to prompt some scientists to make the following prediction: We soon will be able to make, and periodically update, earth resource inventories at a rate so rapid that it will be able to match even the phenomenal rate at which we will then be collecting the remote sensing data. They make this claim even though they fully realize that the data-collecting process of the future may employ multispectral scanners operating simultaneously in 20 or more wavelength bands, while covering swath widths of 100 miles or more, and while exhibiting a forward rate of travel of nearly 20,000 miles per hour.

Even with these remarkable advances, however, the wrong decisions could easily be made by the earth resources manager if certain socio-economic factors were ignored. It would not be the first time that technological advances had exceeded man's ability to cope with those advances, but it could easily be one of the most serious in this respect. Alternately stated, human needs and emotions cannot be overlooked (particularly in these days of the environment "crusaders") as we seek better to manipulate earth resources, whether on a local, regional, national or global basis.

The foregoing considerations were of primary importance in developing the rationale for our research project entitled "An Integrated Study of Earth Resources in the State of California Using Remote Sensing Techniques" as dealt with in the remainder of this report.

1.1 FRAMEWORK WITHIN WHICH TO VIEW THE MULTI-CAMPUS UNIVERSITY OF CALIFORNIA RESEARCH PROJECT ENTITLED "AN INTEGRATED STUDY OF EARTH RESOURCES IN THE STATE OF CALIFORNIA USING REMOTE SENSING TECHNIQUES"

A key word in the title of this project, which serves to differentiate it from other research projects funded under the NASA Earth Resources Survey and University Affairs Programs is the word "integrated". According to the dictionary, the term "integrate" means "to form into a whole; to unite with something else; or to incorporate into a larger unit". In order to appreciate how such a concept might best apply to the individual and collective efforts under this multi-campus project, let us consider the desires of two groups that are certain to be interested in this project and its findings.

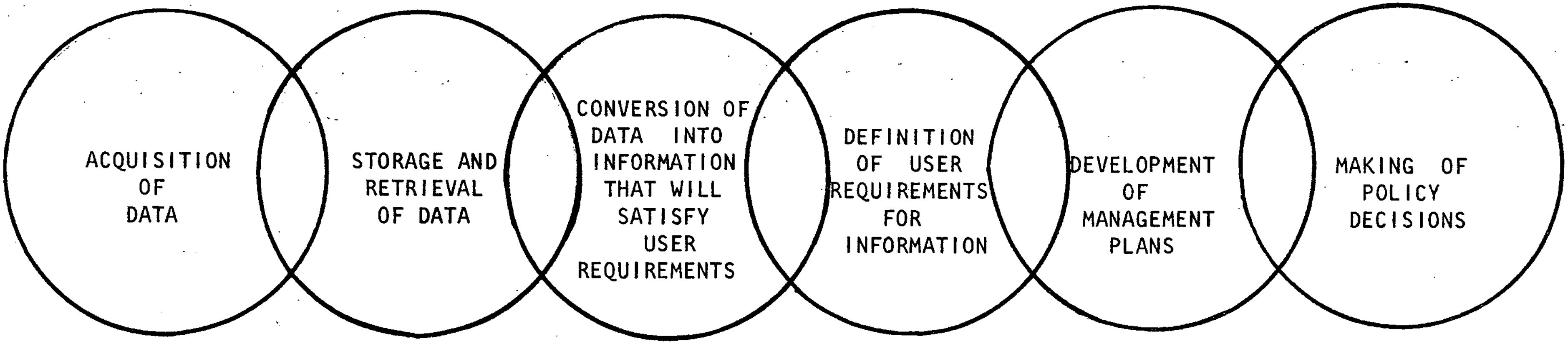
On the one hand, there are those who need to make major policy decisions with respect to the earth resources in a particular geographic area and then to develop management plans that will permit those decisions to be implemented in an efficient manner.

On the other hand, there are data acquisition and data processing specialists who are interested in knowing (a) what package of remote sensing devices (and the associated aircraft and spacecraft for transporting these devices) might best be used to collect meaningful earth resource data on a global basis, and (b) what techniques and equipment should be used in extracting useful information from the acquired data.

The interest of both groups in having research done in the State of California results primarily from the fact that the findings made there by a competent group of scientists might be applied, with only slight modification, to vast parts of the globe which are to varying degrees, analogous to the State of California in terms of the complex of earth resources exhibited and earth resource management decisions to be made.

The links of a chain which might serve to tie these two groups together are indicated in the diagram in Figure 1.1. Areas of research emphasis of the different campuses responsive to these different links are illustrated in Figure 1.2.

An additional way in which to view the links by means of which remote sensing techniques can be used to satisfy the informational requirements of various resource management groups appears in Figure 1.3. The "flow" suggested by that diagram has served to govern in large measure the sequence in



Specify spectral and spatial resolution characteristics of sensors, atmospheric constraints, target illumination and weight, power and volume requirements of the sensors. Specify performance characteristics of vehicles needed to transport sensors, including speed, attitude control, service ceiling, stay time and ability to satisfy weight, power and volume requirements of the sensor package.

Specify the "model" or "models" that will best facilitate the storage of data and its retrieval periodically by those who are to convert the data into information that will satisfy specific requirements of the various users.

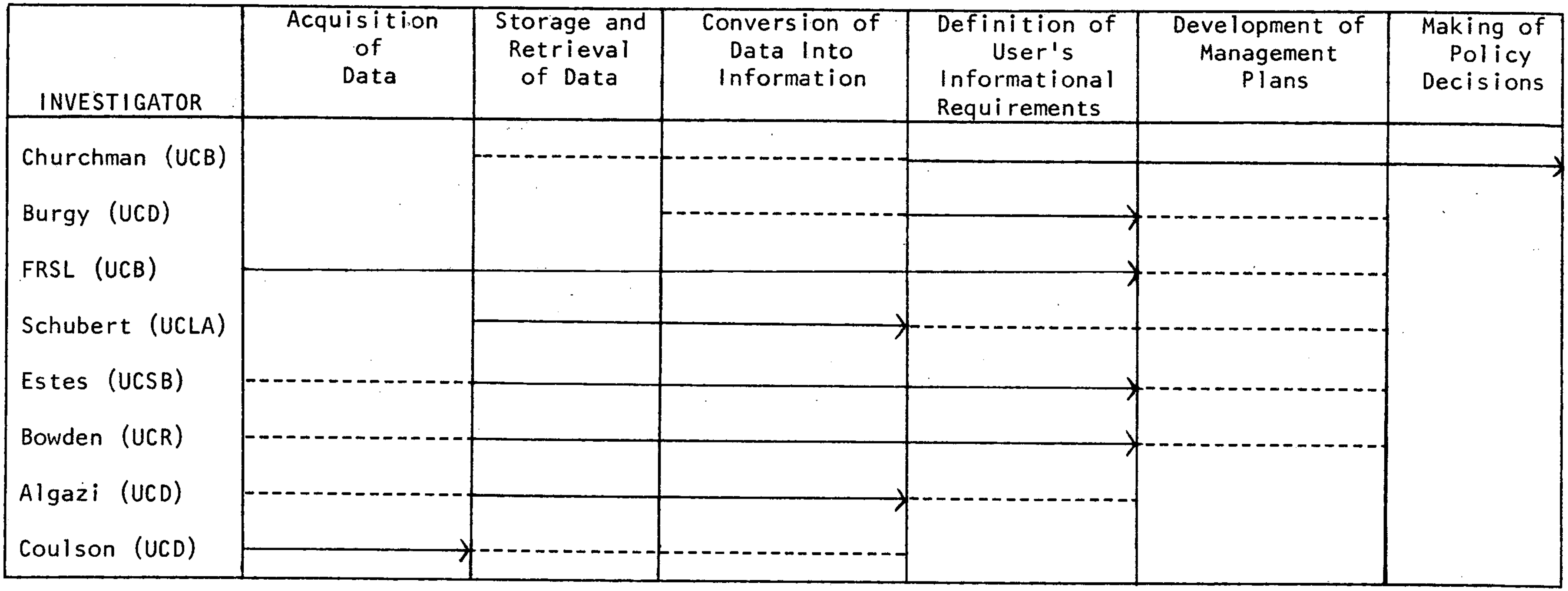
Establish the "signature" for each type of earth resource feature that is to be identified, as a function of its spectral, spatial, goniometric and temporal characteristics. By proper use of humans and ADP machines, provide an "in-place" delineation, area-by-area, of each type of earth resource, including vegetation type, soil type, water quantity and quality, topography, culture, and multi-resource interrelationships.

Precisely define the kinds of earth resource information needed by those who must develop and implement management plans and policy decisions; also define the speed with which these types of information must be provided following acquisition of remote sensing data, and the frequency with which these kinds of resource information are likely to be needed by the various users.

Determine, for example, how best to manage the watershed with a view to multiple use management; also how and where to store water and to develop and distribute hydroelectric power from it. Also, how best to transport water to farmlands, urban areas and other places of water consumption.

Determine, for example, whether to encourage or discourage (1) the growth of a megalopolis in a particular area, (2) the intensification of agriculture in a second area, etc.

Figure 1.1. LINKS BY MEANS OF WHICH REMOTE SENSING TECHNIQUES CAN BE USED TO SATISFY THE INFORMATION REQUIREMENTS OF VARIOUS RESOURCE MANAGEMENT GROUPS



——————————— = primary emphasis by the investigator

- - - - - - - - - - - - = secondary emphasis by the investigator

Figure 1.2. AREAS OF RESEARCH EMPHASIS OF THE VARIOUS PARTICIPANTS IN THIS INTEGRATED STUDY OF EARTH RESOURCES

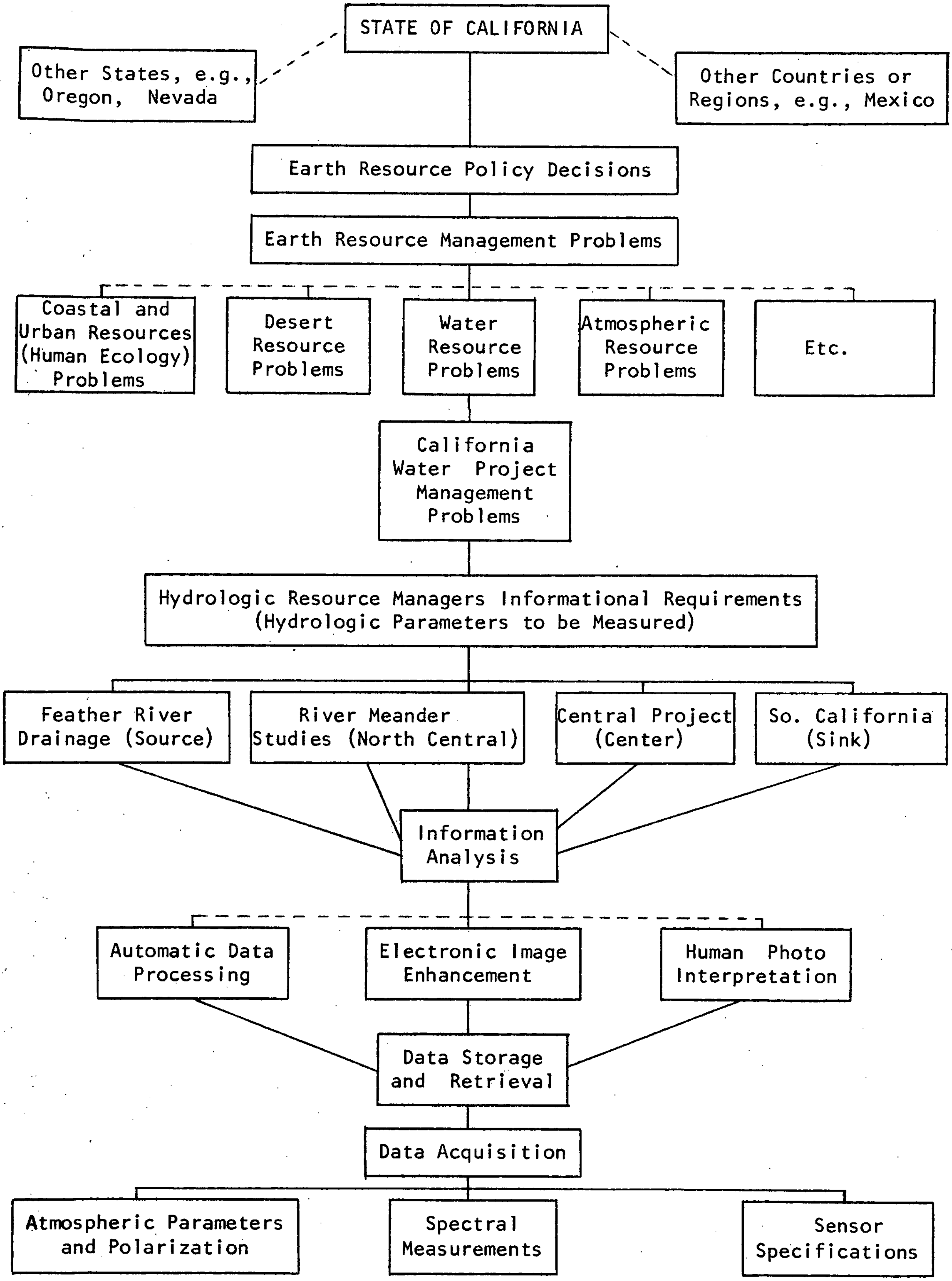


Figure 1.3. Diagram illustrating the structure of the integrated project and its relation to other critical resource problems in California.

which contributions to this progress report appear in the pages which follow. It is to be emphasized that our initial efforts, as suggested by the central portion of this diagram have dealt with only one resource -- the water resource -- and furthermore have been quite specific in dealing almost entirely with one example of that resource and the management problems associated with it, viz., the California Water Project.

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Chapter 2

DEFINITION OF EARTH RESOURCE POLICY AND MANAGEMENT PROBLEMS IN CALIFORNIA

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During the first year of our integrated study, as indicated earlier in this report, attention is being directed towards the California Water Project. This initial emphasis on water as the resource and on the California Water Project as the geographic area is helping to bring about a concentration of effort which would not have been possible had we tried at the outset to study multiple resources throughout the entire State of California.

Our concentration on the California Water Project has enabled us to design the integration in terms of that project's three geographic components: (1) the "source" (Feather River Headwaters Region); (2) "center" (San Joaquin Valley Area); and (3) "sink" (Los Angeles Basin). However, this terminology can be somewhat deceptive. Even the so-called source has some of the characteristics of a sink because some of the water in the source has ultimate use <u>locally</u> for recreation, hydroelectric power, etc. Similar remarks apply to the central or valley area, where agriculture uses of the water are obvious.

Furthermore, during this first year it has become clear that the California Water Project itself is closely interrelated with many other resource systems of the State of California. This point was well recognized at the outset by the Social Sciences Group which conceived of the California Water Project as a set of "decision nodes." At each stage alternative resource uses must be decided by some policy. The basic question is whether these

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policies are wise with respect to total state planning of resources. Figures 1.1 and 1.2 in Chapter 1 illustrate one way to look at our Integrated Study in which there is a flow of information (as derived from an analysis of remote sensing data and associated ground studies) to the managers and ultimate consumers of Feather River water resources.

During the coming year the Social Sciences Group's study will be extended more explicitly to other California resources. This will undoubtedly bring about a change in the implications of Figure 1.1 to emphasize the fact that the flow does not merely go from data collection to ultimate users. The ultimate users should have much to say about the kinds of data which will be collected, which means that information must flow from the users and policy decision makers to the acquisition of data. Hence Figure 1.1 is more appropriately represented as a circular chain. Actually much of the links of Figure 1.1 are connected by information flows to all the other links.

The remainder of this chapter is devoted to the discussion of the efforts of the Social Sciences Group with respect to the broader problem of California and its resources.

The objective of the Social Sciences Group is to examine the needs for ERTS and related data on earth resources with respect to the management of resources and the ultimate benefit to the public. A great deal of the first eight months' activity has been devoted to interviewing managers (administrators) in California's local and state governments, and in the federal government. This effort has also included the examination of an enormous number of documents relating to the utilization of satellite and aircraft information by managers.

The Social Sciences Group has defined two approaches to the problem of assessing the value of resource information. The first is to use the managers as experts and to ask them to explain how the new technologies of ERTS A and B and subsequent satellites might best serve their administrative functions. This effort culminated in a week-long seminar at Lake Arrowhead, California, in which a number of administrators and planners discussed their needs with members of the Integrated Study. The week-long session was divided into five sub-seminars. In the afternoon one or more of the members of the Integrated Study explained a particular application of satellite sensing. The evening and the following morning were then devoted to discussion on the part of the administrators as to the kinds of information that they would find most beneficial. The five topics were forestry, water, agricultural, urban and general land use. The theme of the seminar centered around the California Water Project, but the discussion of course was not restricted to the topic alone. For example, since one of the attendees was responsible for much of the resource development of Alaska, a small group of the seminar participants discussed the way in which remote sensing information could be used for integrated planning of Alaskan resources. Of special interest in this part of the seminar was the way in which one might assess the ultimate benefits for the public in the State of Alaska. Summaries of the proposed use of ERTS data which resulted from the Lake Arrowhead Symposium appear in Tables 2.1 - 2.4.

The second approach of the Social Sciences Group consists of trying to develop a model for the planning and managing of California resources, starting with the California Water Project as a core and spreading out to consider its ramifications with respect to other parts of the state and region. This effort has resulted in a collaboration between the Operations Research group of the Boise Cascade Company and some members of our Social Sciences Group. It is hoped that certain individuals from NASA Ames will also become part of this effort. The model provides a method of estimating the values of certain kinds of resource information. The model, if successful, should enable us to estimate the incremental gain in the economy and society of a class of information collected by the ERTS satellite and related information sources.

Hence the major contribution of the model is to enable us to estimate the social benefit of certain kinds of resource information, and specifically to identify the types of resource information which are of more importance to the public of the State of California.

Furthermore, it should also be possible to determine the frequency which the certain types of information need to be gathered. Very much to the point in this effort will be the possible conflicts between regions of the state. We believe that the model can show us how one region's optimal policy, if carried out, would affect another region. For example, if the Los Angeles Basin's utilization of resources were to follow a certain policy, then this might have a detrimental effect on the San Joaquin Valley and the San Francisco Bay area. For the first time it may be possible to estimate in economic and social terms the measurable conflict or cooperation between regions in the utilization of resources.

Several issues have been raised as a result of these two activities which will demand careful attention during the coming year. Specifically, it is clear that a great deal of satellite information will be used for regulatory purposes. The as yet unanswered question is the manner in

IMAGE TYPE \ USES	FIRE CONTROL	MULTIPLE USE	SOILS	TRANSPORTATION	ALASKA
Resolution 200' - 300' 18-day repetition	• Fuel condition • Measure of vegetation condition (dry, green)	• Gross land use • Stratification of resources • Change detection	• Soil patterns (associations) • Drainage conditions • Salinity	• Networks • Model inputs	• Fire - long-term • Unique features • Tundra recovery
	General: (<u>Use in Public Education Presentation</u>) & Damage Assessment				
Resolution 200' - 300' near real time	• Improved assessment of fuel condition • Fuel moisture conditions by secondary phenomena (i.e. veg. soil tone) • Prevention planning more effective in real time	• Damage assessment: Drought, Hurricanes, Earthquakes, Floods • Burned or damaged area rehabilitation (slides, disaster, blowdown)	• Soil temp (ERTS B) • Seeding - exp. cotton • Moisture change • Soil condition change	• Inland water and road conditions	• May serve as a change indicator; following logging operations • Sedimentation • Transporation routes for air cushion vehicles
	<u>Great Improvement in Damage Assessment</u>				
Higher resolution • 15' (manned) • 150' - 200' (unmanned) near real time	• Dynamic measurement of heat sources (& secondary effects)	• Develop dynamic land use planning on a national scale	• Small soil unit inventory	• Traffic analysis • Logging operations • Recreation	

TABLE 2.1. SUMMARY OF SEMINAR I - FOREST USES & MANAGEMENT, December 6 and 7, 1970.

IMAGE TYPE \ USES	SNOW	WATER	CLOUDS	ICE	VEGETATION	SOIL	SEDIMENT & POLLUTANTS
200' - 300' 18-day repetition rate	• Areal extent	• Areal extent: depth (possibly) surface areas	• Areal extent	• Areal extent: ratio of ice to open water	• Areal extent: by type and water requirement. Changes in coastal and marsh vegetation as an indicator of water quality	• Areal extent: surface soil ponding during floods	• Areal extent: oil & waste spills (synoptic reporting) parameters, dispersion, movement lifetime
200' - 300' near real time	• Spring thaw of ice • Flow movements	• Water quality • Water drainage • Thermal gradation can be used to check thermal discharge			• Sequential observation where salinity is a problem		• Possible detection of Eutrophication in large water bodies
Higher resolution •15' (manned) •150' - 200' (unmanned) near real time	• Snow cover depth & water content • Snow cover data by active & passive microwave	• Sedimentation plumes more accurately delineated • Regulatory use for thermal pollution				• Aquifer detection & definition by IR (4-6AM) Radar, & passive microwave	• Eutrophication monitoring

TABLE 2.2. SUMMARY OF SEMINAR II - WATER USES & MANAGEMENT, December 7 and 8, 1970.

IMAGE TYPE \ USES	LAND USE	CROP TIME	SOIL - LAND POTENTIAL	DAMAGING AGENTS	YIELD	LIVESTOCK	LAND TREATMENT
Resolution 200' - 300' 18-day repetition rate	• Irrigated vs. non-irrigated • Agricultural vs. non-agricultural	Major differences: • Agricultural crops • Grassland • Assessing of fertilization	• Salinity • Major soil associations • Gross topographical changes • Geomorphology • Shallow water table	Detection of: • Watershed damage • Drought • Logging • Water • Wind erosion • Insects • Disease	Stratification of low yield areas	• Indirect evidence of animal presence, i.e. which side of fence	• Cropping • Terracing • Water reservoir • Windbreaks • Stock water ponds • Reforestation
Resolution 200' - 300' near real time	• Irrigated vs. non-irrigated	• Increased effectiveness of crop identification	• Detection of surface water	• Detection of frost damage		• Detection of raindeer & caribou	• Brush conversion • Fertilizer effects
Higher resolution • 15' (manned) • 150' - 200' (unmanned) near real time	• Sprinkler vs. row irrigation	Crop inventories	• Sprinkler vs. flood irrigation • Topography (slope class) • Aquifers	Increased effectiveness for damage detection and monitoring		• Indirect detection & monitoring • Evaluation of effects of animal use	

TABLE 2.3. SUMMARY OF SEMINAR III - AGRICULTURE & RURAL USES, December 8 & 9, 1970

IMAGE TYPE \ USES	NATURAL FEATURES	MAN-MADE FEATURES	SOCIAL ENVIRONMENT	REGULATION USES	COASTAL & MARINE
Resolution 200' - 300' 18-day repetition rate	• Hydrology • Vegetation • Geology • Topography • Soil • Hazard	• Urban settlement • Land use • Transportation systems	• Scenic features • Air pollution • Water pollution • Thermal pollution		• Currents • Water color • Coastline thermal & pollution plumes
Resolution 200' - 300' near real time	• Location change detection	• Location change detection	• Check land use changes - boundaries, territories	• Zoning, interregional comparisons	
Higher resolution • 15' (manned) • 150' - 200' (unmanned) near real time		• Check land use changes - boundaries	• Possibility of blight detection		

TABLE 2.4. SUMMARY OF SEMINAR IV - URBAN, COMMUNITY & COASTAL USES, December 9 & 10, 1970

which satellite information would fit smoothly into the regulatory process, since there is a conceivable threat of overloading the process with the flow of additional information.

For example, the satellite may very well enable one to detect certain kinds of insect or disease infestations on California's crops at an early date. If so, the state or a local agency may wish to take certain actions to require the farmer to burn down a part of his crop or to use a certain kind of insecticide, in order to enforce state policies. Consequently, certain legal actions may be required. One can see that if satellite information is regarded as objective and authoritative, there may very well be an increase in the regulatory cases in the courts.

There is also the question of the relationship of the government (and NASA in particular) to the private sector. Assuming that the ERTS experiment will be reasonably successful, we should now begin thinking about how a satellite information system can become an institutionalized aspect of government service. Agencies like ESSA, the Geological Survey, and the Census Bureau serve as possible models of this trend in NASA's future.

Our porposal for the coming year therefore is as follows:

1. to continue our search for information on managerial needs for satellite information using the managers as experts;

2. to develop a model of the Feather River Project and its relationship to other state and regional planners;

3. to examine the issues relevant to regulatory agencies and government-private sector relationships; and

4. because the methods of operations research philosophy constitute a part of the social sciences, and may not be well understood, we are

considering holding a seminar of two days' duration in which we try to explain and discuss basic ideas underlying the modeling of California resources.

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Chapter 3

DEFINITION OF THE INFORMATIONAL REQUIREMENTS OF HYDROLOGIC RESOURCE MANAGERS

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The objectives of this portion of the integrated study are (1) to delineate the parameters involved in hydrologic systems (2) to outline the conventional means used in acquiring information relative to those parameters, and (3) to consider the potential usefulness of modern remote sensing techniques for acquiring certain parts of this information.

In the past five to ten years, many assessments have been made of the potential for use of remote sensing data, both supplementary to current methods of data acquisition or as alternative sources. Most hydrologists have recognized that, for certain specific tasks, there are significant advantages inherent in the concepts of remote sensing. Many have indicated possible applications in a wide variety of hydrologically important functions. In this developing "state of the art" framework, some have noted the trend toward over-optimism in predicting the feasibility and usefulness of remote sensing in hydrology, suggesting in-depth research to explore the potential applications.

Recent experience of project members engaged in evaluating, for the National Academy of Sciences, proposed programs for applying satellite-based sensors to the measurement of hydrologic parameters has led to the analytical approach used in this study. The investigation is designed to provide a comprehensive review of current methodology, with the ultimate objective of determining where inputs which can be acquired via remote sensors might best be applied. The approach has been programmed as outlined in Figure 3.1, "A Logic Network...," to guide the study tasks and define the paths and investigative stages. Inherent in the research sequence are interface points where other groups working on various aspects of this integrated study are briefed and where feedback information is generated to insure compatibility of analyses and consistency of the interpretations.

Several contacts between our group and others have occurred to this date and others are planned for the immediate future. Our participation in the "Users' Seminars" which were held at Lake Arrowhead in December, 1970, as part of the "Integrated study" served to give our group some valuable insights.

An intensive literature search is in progress and is almost completed. Our review of this literature is proving to be very valuable by yielding information on current remote sensor hardware, techniques, R&D prospects and specifications as related to the measurement of specific hydrologic parameters.

The present status of our work may be summarized as reflecting progress through Junction 8 (Figure 3.1) of the logic network, in terms of research accomplishment. Selected hydrologic functions have been detailed in both preliminary classification and in refined form. The major effort has been directed to delineation of the primary hydrologic systems and components.

A conceptual model of the total hydrologic system and its various subsystems is depicted in Figure 3.2. Included are all of the quantifiable processes and parameters that may be rationally judged adaptable to remote sensor input. Each of the "cells" of the model represents subsystems that are identified by parametric groupings. Measurement methods are being specified, including those based on remote sensing techniques. Logic tests are being applied to each parameter of the subsystem in an effort to determine

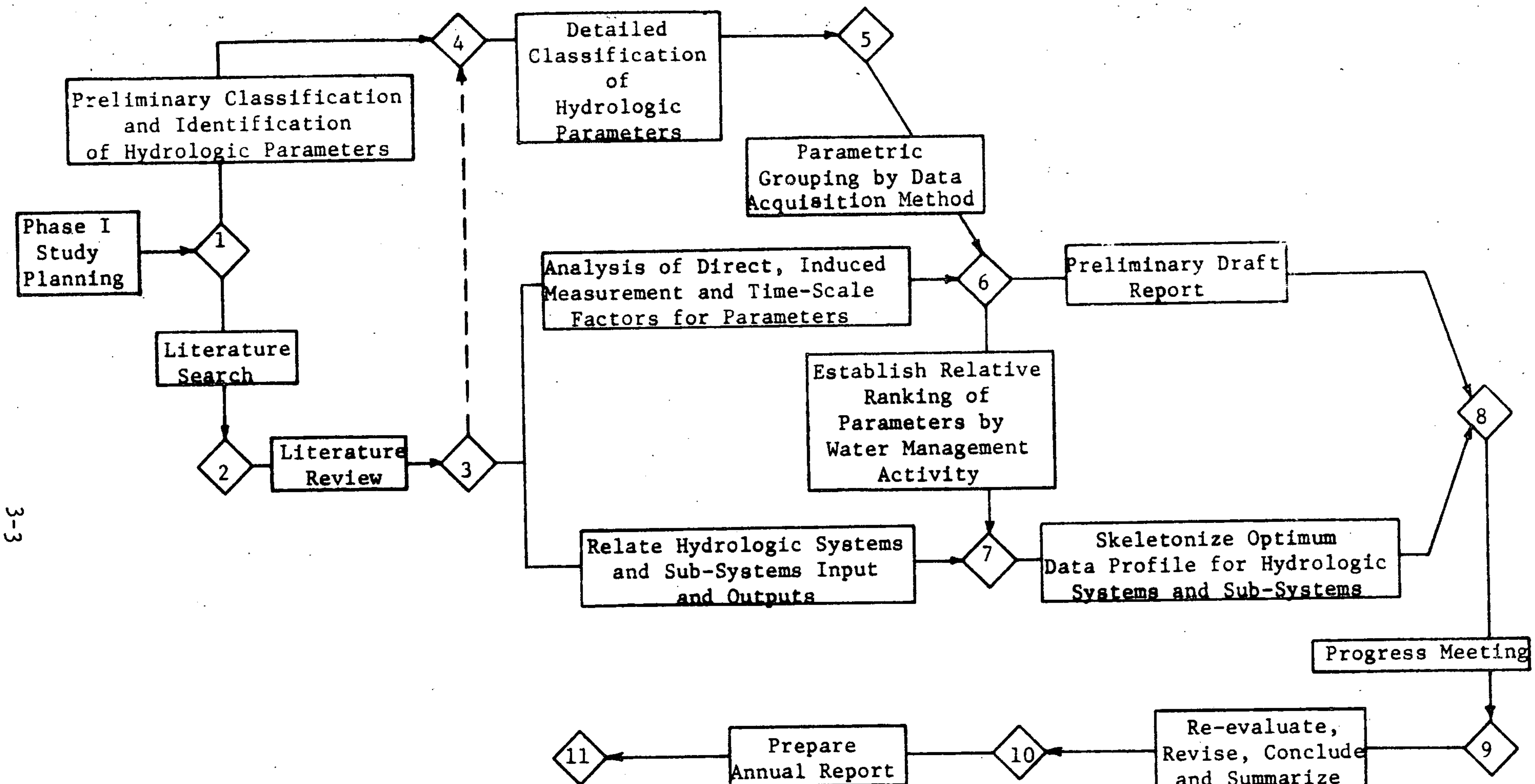
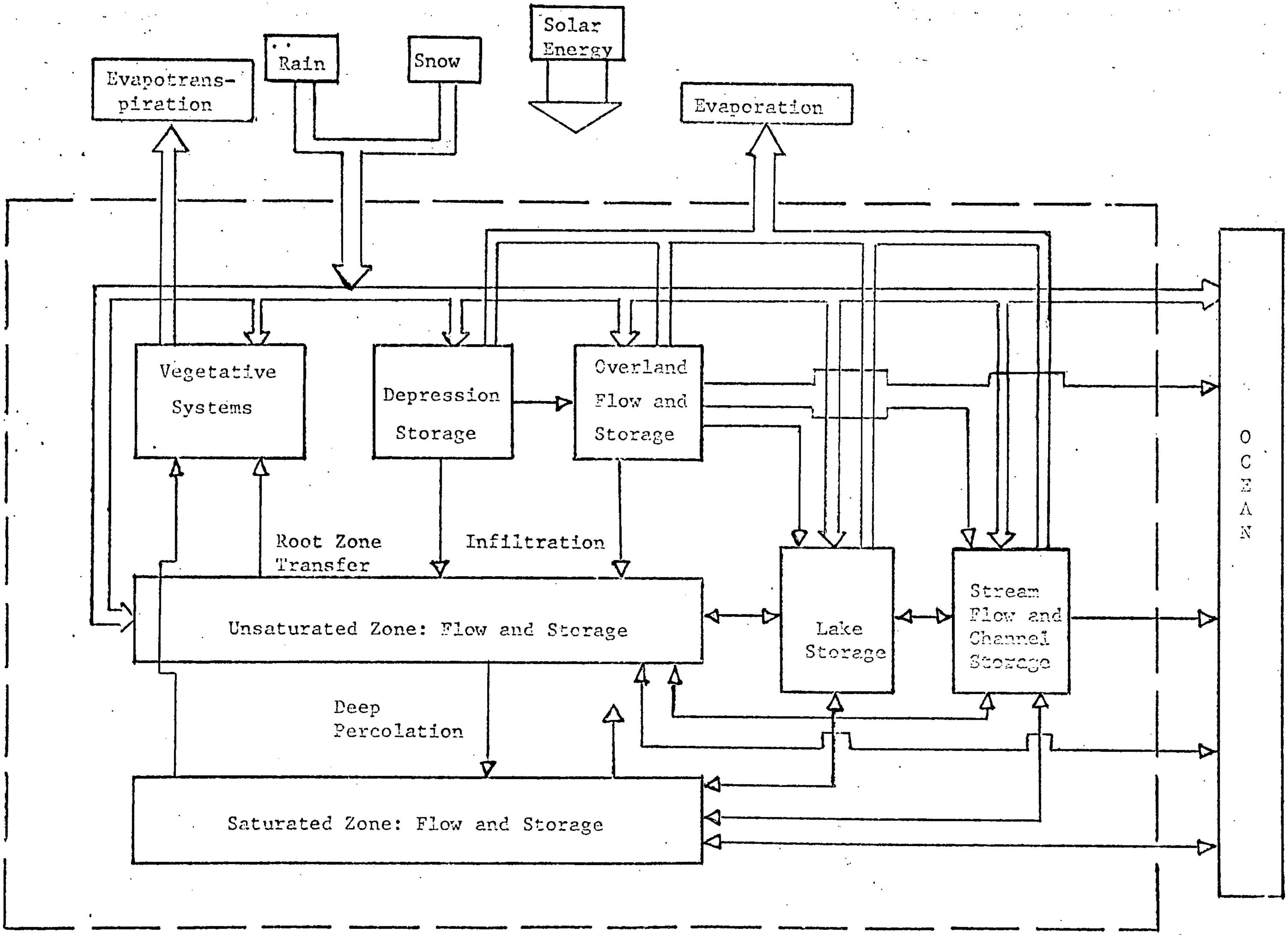


Figure 3.1. Logic Network of Investigative Tasks for Remote Sensing Applications to Hydrologic Systems



Runoff Cycle Boundary

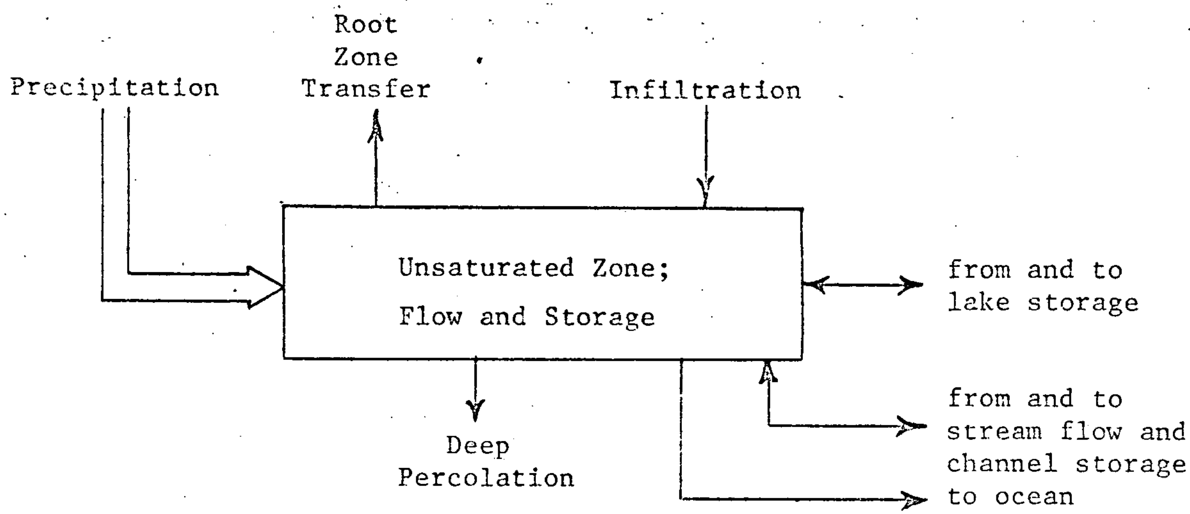
Figure 3.2. Conceptual Model of the Total Hydrologic System.

the extent to which user (i.e. earth resource manager) requirements for hydrologic information can be satisfied. Where a parameter cannot be adapted to alternative measurement, the analytical procedure that we are using redirects the search in an effort to deduce an acceptable substitute from parametric combinations or recombinations.

Specification of the parameter measurement requirements will include "desired" and "minimum acceptable" ranges or tolerances. Tests are being incorporated to evaluate the relative accuracy of each type of measurement and its effect on the ultimate output. At present it is anticipated that a combination of data acquisition methods will be needed, using a variety of platforms and sensors.

To illustrate the analysis, a sample is presented in Table 3.1, selecting the storage subsystem represented by the unsaturated zone (soil moisture), as depicted in Figure 3.2. The parameters listed are generally used in one or more common hydrologic user operations. The deduction of a nonavailable parameter is illustrated, based on known physical relationships. Where measurement of a parameter may not be possible, some acceptable substitute may be developed or, in some cases, the parameter may be eliminated from consideration if the output response will permit. Many user applications of the data for prediction and estimating purposes, as well as in planning, may not require detailed understanding of the subsystems. The mere measurement of gross phenomena may prove to be satisfactory for many purposes.

Another example of a complete subsystem used in the prediction of water yield involves quantification of snowpack water content. Some of the elements usually expressed in snow runoff and other subsystem definitions are listed in Table 3.2. Obviously, many of these are readily sensed with available hardware; hence with even nominal advances in technology, the capability of



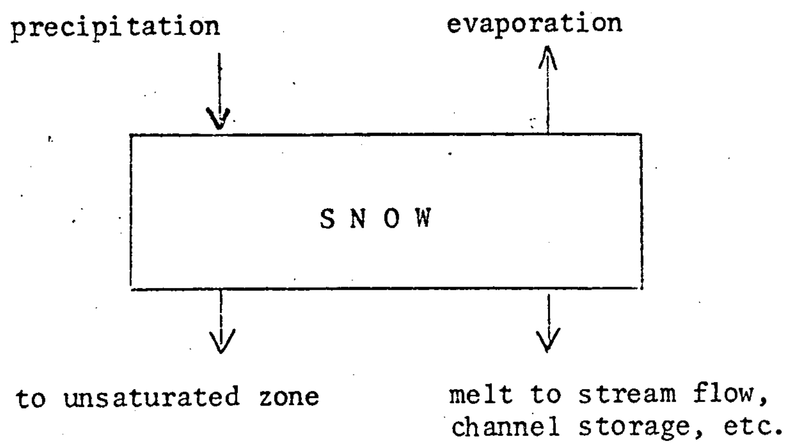
Definition of Subsystem

1. direction of flow
2. soil-moisture flux
3. soil-moisture content and/or soil-moisture tension
4. salt movement (miscible displacement)

	Units	Classic Acquisition	R.S. Possibilities
1. Porosity*	percent voids	undisturbed soil sample, lab	
2. Thickness of zone	inches	auger; well log	
3. Soil-moisture tension	inches of H_2O	tensiometer or "r" blocks	
4. Capillary conductivity*	inches/hr	soil sample, lab	
5. Water content	percent H_2O	field analysis neutron meter etc.	
6. Infiltration capacity	inches/hr	soil sample, lab	
7. Soil characteristics*	----	soil sample, lab	
8. Electrical conductivity of soil water	mmhos/cm^2 @ 50°C	soil-water sample, lab	

*1 and 4 derived or estimated from 7 as an alternative

Table 3.1. Storage System for Unsaturated Zone.



Definition of Sybsystem:

1) Water yield potential of snowpack

2) Weather modification precipitation increment

3) Snowpack status

Snow	Units	Classic Acquisition	R. S. Possibilities
areal extent	acres	snow survey	
depth	inches	" "	
density	lb/ft^3	" "	
water content	percentage	" "	
temperature	°C. or °F.	" "	
albedo	per cent	-------	
precipitation			
duration	hours	precipitation gage	
rate	inches/hr	" "	
form	------	field observations	

Table 3.2. System for Water Storage in Snow.

quantifying the water content of snow by means of remote sensing soon may exist. Other "breakthrough" developments are to be anticipated which will permit alternative parameter selections.

The conceptual development of a complete framework of hydrologic and atmospheric parameters, showing their inter-relationships, is planned for completion in the spring of 1971. The assessment of several combinations of tasks and parameters in subsystems for all sizes of systems will also be completed this funding period. Efforts to make systematized groupings of hydrologic parameters and to discern more clearly the user requirements for hydrologic information will continue into next year, as will the definition of the role of remote sensing for measuring these important hydrologic informational needs.

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ORIGINAL CONTAINS
COLOR ILLUSTRATIONS

Chapter 4

MEASUREMENT OF HYDROLOGIC RESOURCE PARAMETERS THROUGH REMOTE SENSING IN THE FEATHER RIVER HEADWATERS AREA

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During the period covered by this report, the program of our Forestry Remote Sensing Laboratory has attempted to assess the usefulness of remote sensing techniques for acquiring information of importance to resource managers, especially those responsible for the water resource. Our experience to date has convinced us of the necessity to use a systems concept and team approach to define the role of remote sensing. With a view to using this approach, four units of our Laboratory are working on studies in the Feather River Headwaters area. These units address themselves to the most important problems which must be solved if a remote sensing system is to be employed successfully for earth resources inventory purposes. The four problem areas being investigated under this team concept are as follows:

(1) determination of the feasibility of providing the resource manager with operationally useful information through the use of remote sensing techniques;

(2) definition of the spectral characteristics of earth resources and the optimum procedures for calibrating the tone and color characteristics of multispectral imagery of those resources;

(3) determination of the extent to which humans can extract useful earth resource information through a study of remote sensing imagery in either original form or when enhanced by various means;

(4) determination of the extent to which automatic classification and

data processing equipment can extract useful earth resources information from remote sensing data.

The units of our Forestry Remote Sensing Laboratory which are engaged in these four problem areas are respectively, (1) the Operational Feasibility Unit, (2) the Spectral Characteristics Unit, (3) the Image Enhancement and Interpretation Unit, and (4) the Automatic Image Classification and Data Processing Unit. The following sections of this chapter are devoted, respectively, to the activities of these four units.

4.1 REPORT OF THE OPERATIONAL FEASIBILITY UNIT

4.1.1 Work Performed During the Period Covered by This Report

The primary areas of responsibility of the Operational Feasibility Unit during the initial phase of this research project consisted of: (1) definition of specific problem areas upon which efforts of the Forestry Remote Sensing Laboratory (FRSL) might best be focused in light of operational needs of the prospective data user, (2) interfacing with other investigators to ensure that efforts of the FRSL were complimentary to those of other investigators in the overall project, and (3) determination of optimum methods for evaluating remote sensing techniques as employed in this integrated study.

Problem Definition

Initial efforts at defining those primary areas of investigation in which the Laboratory should focus its work consisted of an extensive literature review and discussions with persons in the fields of hydrology and watershed management. Our goal was to ascertain (through efforts complimentary to those of Professor Burgy at the Davis Campus) those physical parameters of the watershed environment of interest to management planners, and to compile a list of previous remote sensing research aimed at supplying their needs. In addition, questions were posed in those discussions to determine uses to which various types of remote sensing data relative to hydrologic resources might be put in an operational context.

As a result of these discussions, it appeared that a definite immediate need for data of the type that remote sensing might provide did not exist. When asked, for example, if a vegetation map would be put to immediate use, the potential user would say, "no, we aren't currently using that kind of information, but we should". In many cases research has shown that various environmental parameters could be used for more effective management planning, but for a number of reasons (including politics, lack of money and time, shortage of personnel and bureaucratic snarls) operational practices often lag far behind research findings.

Thus, while it was found that it would be difficult to tie our studies directly to actual current practice, it seemed feasible, and quite useful, to attempt to help fill the gap between research and practice. We felt that this could be accomplished by concentrating our efforts on certain physical parameters which are obviously important in terms of hydrologic phenomena and which might be used more frequently in the future if one could demonstrate that the data could be quickly and cheaply gathered. Further utility could be expected if the data were stored in a "data bank" which was flexible and efficient enough to permit "withdrawals" by a variety of users in a format with which they were familiar and could easily work.

A list of suggested categories to be mapped in the Feather River Headwaters area was prepared and presented to the technical units in the Laboratory. The categories and the suggested breakdown for mapping were as follows:

A. General Management Zones

   1. Valley Front

   2. West-side Intermediate

3. Crest

4. East-side Intermediate

5. Basin Front

B. Vegetation Terrain Types

1. Water

   a. Standing Water

   b. Flowing Water

2. Marshes

3. Grassland

   a. Dry Grassland

   b. Meadow

   c. Subalpine Grassland

4. Chaparral

   a. Foothill Chaparral

   b. Mountain Chaparral

5. Forest

   a. Pine-Oak Forest

   b. Mountain Coniferous Forest

   c. Subalpine Forest

6. Sagebrush

7. Juniper Woodland

8. Bare and Rocky Areas

9. Urban

10. Agricultural

C. Vegetation Cover (applied only to 3, 4, 5, 6 and 7 above)

1. 80-100%

2. 50-80%

3. 20-50%

4. 5-20%

5. Less Than 5%

D. Watershed Boundary Delineation and Stream Channel Delineation

E. Steepness of Slope

1. 0-10%

2. 10-20%

3. 20-30%

4. 30-40%

5. 40-50%

6. 50-60%

7. 60-70%

F. Aspect

1. Level

2. North

3. East

4. South

5. West

G. Geology-Soils

1. Instrusive Igneous

   a. Acid

   b. Basic

2. Volcanic

   a. Acid

   b. Intermediate

   c. Basic

3. Metamorphics

   a. Serpentine

   b. Other

4. Sedimentary

    a. Consolidated

    b. Loosely Consolidated

    c. Poorly Consolidated

5. Alluvial

6. Glacial

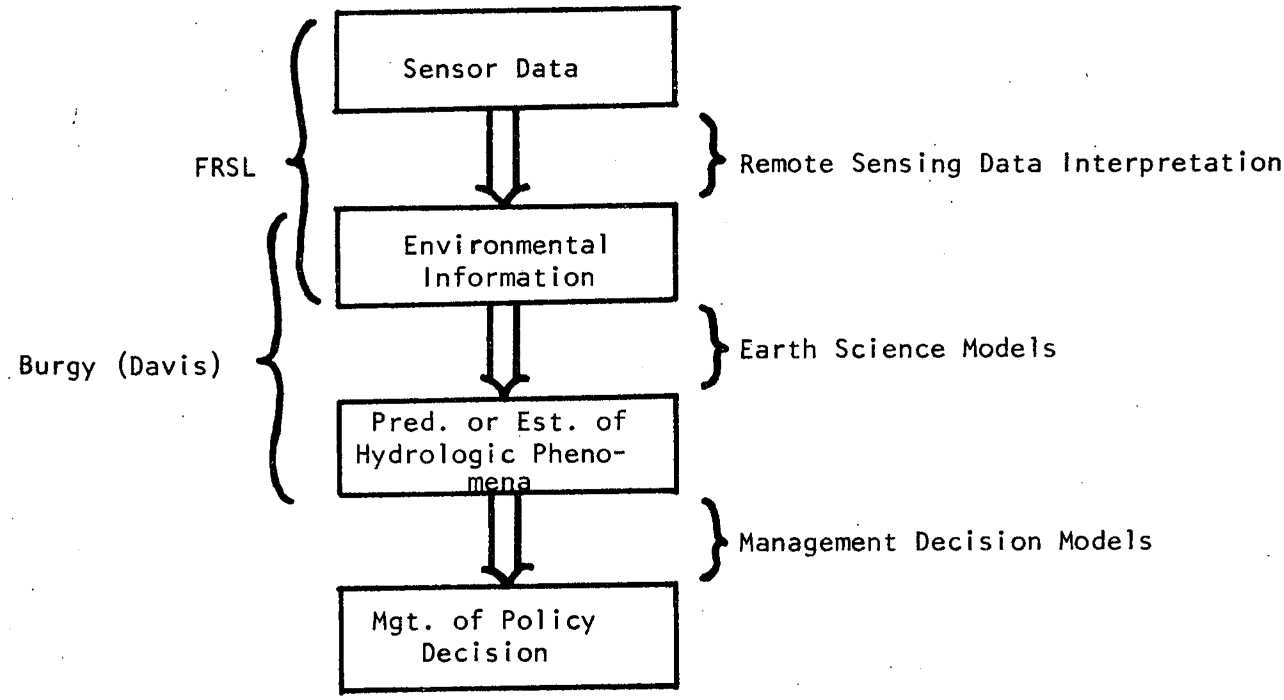
H. Sequential Snow Area Delineation

In terms of priorities for work, it was felt that tests to ascertain the relative interpretability of various types of imagery for mapping the general management zones, vegetation-terrain types and vegetation density, geology-soils, and sequential snow area delineations were of highest priorities. In addition to suggesting categories for mapping studies, we developed, in cooperation with the Image Interpretation and Enhancement Unit, methods for evaluating the mapping results quantitatively and presenting the results in an understandable format. These testing procedures must be established with the ultimate user of the mapping information in mind.

Integration with Other Investigators

A. The categories and procedures discussed above were determined using the best information available. However, it is hoped that as Professor Burgy and his colleagues at the Davis campus complete their first year's studies relating to physical parameters of the watershed and the importance of these parameters in the determination of hydrologic phenomena, their findings can be incorporated into our plans.

The responsibilities of the FRSL in relation to those of the Davis campus groups can perhaps best be described by means of the diagram seen on the following page.



In this diagram, each box represents a "hard information site", while each arrow represents an "interpretive process" which transforms information of one kind to information of a different kind further along the path that leads to a resource management or policy decision.

In this study the primary responsibility of the FRSL is to ascertain the degree to which sensor data can be interpreted to supply basic environmental information to the hydrologist, while the Davis group is primarily concerned with determining the kinds of environmental information needed to predict or estimate hydrologic phenomena by means of earth science models.

B. The User Seminars on Remote Sensing which were held at Lake Arrowhead, California, sought to ascertain the uses to which data acquired by earth resource satellites (such as ERTS-A) might be put by land managers in the State of California, and to define the benefits which might be expected from such satellite systems. The seminars presented an excellent opportunity for representatives of our Operational Feasibility Unit to speak with various representatives of land management and planning agencies within the state, and to gather additional information relative to the planned testing of remote sensing systems in the Feather River area. In addition, the discussions suggested further coordination meetings with data users which will be discussed in a later section of this report.

4.1.2 Work Currently in Progress

Problem Definition

It is expected that during the balance of the funding year considerable effort will be focused on cooperative work with the Image Interpretation and Enhancement Unit as actual tests of the ability of interpreters to extract resource information from simulated space photography are performed.

Integration with Other Investigators

One result of the Lake Arrowhead meeting was a concensus by the participants that further meetings with representatives of those state and federal agencies charged with monitoring and management of the natural resources of California would be useful. The problems which will be involved and the formats which should be used in disseminating ERTS and subsequent resource satellite data to users were discussed at Lake Arrowhead. Certain of the problems appear to be formidable indeed. However, it seems that a logical starting point for developing practical uses of ERTS-type data could be the formulation of a list of common requirements and the initiation of a cooperative program involving researchers and users. It is toward this end that the Forestry Remote Sensing Laboratory intends to conduct a one or two day meeting of the Lake Arrowhead participants at a convenient location somewhere in the San Francisco Bay Area. Hopefully, one result of this meeting will be the formulation of a definite plan which will lead to the use of ERTS data by most of the major resource-management agencies of the State of California.

4.1.3 Future Proposed Work

During the second funding year of the study, the efforts of the Operational Feasibility Unit will be directed toward an evaluation of the resource mapping and evaluation procedures using remote sensing techniques. Also closer cooperation with users of resource data will be attempted in an effort to more accurately ascertain the operational value of remote sensing techniques. Specifically, contact has been made with several individuals or organizations which will be active in the Feather River Headwaters area during the coming year in the fields of hydrology or watershed management.

A private engineering consulting firm with experience in the field of hydrology has proposed an operational watershed modeling project to an agency of the federal government, for purposes of flood forecasting. Their modeling techniques have been proven to be effective on major watersheds in the Southern Sierra Nevada, but have yet to be applied to an area as diverse as the Feather River Basin. The firm has expressed the desire to cooperate with the FRSL in evaluating remote sensing techniques in providing input data to the watershed model.

The California Cooperative Snow Survey regularly monitors the snowpack of the Feather River Watershed by means of fixed-point snow course measurements. The accuracy of predictions of runoff derived from these measurements is limited due to the necessity of extrapolating from a few points the entire watersheds. However, it seems possible that the use of aerial photography in conjunction with these point measurements could greatly increase their value. Thus an attempt will be made to work with the Snow Survey to investigate these possibilities.

Finally, the U. S. Forest Service, which administers the bulk of the wildlands comprising the Feather River Watershed is engaged in a project designed to ascertain the effects of land use-soil interactions on water quality and quantity. Again, contacts have been made and an agreement reached that cooperative studies between the FRSL and the Forest Service are desirable. Thus, an excellent opportunity is afforded to draw upon the expertise of Forest Service personnel in the fields of soil science, hydrology and land management, in combination with the remote sensing capabilities of the FRSL.

In summary, each of these opportunities for cooperation with other organizations will enable the FRSL to evaluate remote sensing procedures in an operational context. Each case represents a situation in which the desired resource data will continue to be acquired by conventional means unless it can be demonstrated that an innovative technique can provide the kind of information required, at an accuracy necessary for satisfactory performance of the job.

4.2 REPORT OF THE IMAGE INTERPRETATION AND ENHANCEMENT UNIT

4.2.1 Work Performed During the Period Covered by this Report

Research being performed by personnel of the Image Interpretation and Enhancement Unit (II&E) is oriented towards developing image interpretation techniques that can be applied to the entire Feather River watershed above Oroville Dam and that will provide resource inventory information of use to the hydrologist or watershed manager. To accomplish this objective, we are building on our experiences and knowledge previously gained while working within the Bucks Lake-Meadow Valley Test Site. This smaller, intensively studied area, is being used as a calibration site from which we can extend to the adjacent and analogous areas comprising the entire Feather River Watershed. This concept of expanding the scope of our work from the Bucks Lake-Meadow Valley area to a surrounding larger area certainly conforms with the "extended test site principal" currently being voiced by NASA personnel.

In no way are we duplicating, for this much larger area, work that has already been completed and reported upon by our group. Instead, we are concentrating our efforts on deriving image analysis techniques applicable to extremely large areas using mainly synoptic view, small scale imagery. We have found that in many cases we are able to directly apply what we have already learned from our studies within the smaller, centrally located calibration site.

Three types of imagery constitute the raw data which our Unit is analyzing: (1) a degraded semi-controlled photo mosaic made from RB-57 Infrared Ektachrome copy transparencies, (2) RB-57 Infrared Ektachrome copy transparencies -- viewed in non-stereo, and (3) RB-57 Infrared Ektachrome copy transparencies -- viewed in stereo. The degraded photo mosaic has been prepared in an attempt to simulate (in terms of scale and level of image resolution) a single, reconstituted false-color image that might be obtained early next year by the ERTS-A vehicle. The non-stereo RB-57 high flight photo mosaic is a close approximation of the very best hard copy photography that might be obtainable from space sometime in the near future (similar to what might be procured during the proposed Skylab experiment, tentatively scheduled for launch in late 1972 or early 1973). The stereo RB-57 high flight coverage is a true representation of the quality of imagery obtainable from state-of-the-art high flying aircraft; in the future, aircraft such as the RB-57 will be used to support spacecraft overflights for the purpose of obtaining high resolution imagery of sample and subsample geographic locations, i.e., calibration sites such as the Bucks Lake-Meadow Valley Test Site.

All three types of raw data are currently being analyzed for the purpose of determining their information content. Specifically, three kinds of resource survey information are being sought with the aid of these types of imagery:

(1) vegetation-terrain surveys, (2) snow surveys, and (3) environmental change surveys. In an effort to thoroughly define these inventory objectives, our group is working very closely with Professor Burgy and his associates on the Davis campus and personnel of the Operational Feasibility Unit at the FRSL. A major portion of each of their contributions to this report, found in preceding sections, dwells on defining informational requirements of the hydrologist and environmental parameters relating to vegetation/terrain, snow, and environmental changes that might be measured and evaluated by means of remote sensing. Our integrated efforts have successfully led to a series of well defined project objectives for our Unit. For example, for each environmental parameter the following mapping criteria have been defined: (1) the type of imagery to be used, (2) the extent of the area to be mapped, (3) the minimum mapping size of the unit, (4) the proposed method of evaluation, and (5) the source of ground truth information.

Furthermore, during this first reporting period for the project, we have evaluated all existing remote sensing and ground truth data available for the Feather River Watershed area. The Bucks Lake-Meadow Valley Test Site, selected as one of the very first NASA Earth Resources Program test sites, has been periodically flown with a variety of aircraft capable of procuring conventional aerial photographs and exotic remote sensing data (e.g., thermal infrared and active microwave - SLAR - imagery). Before, during and for some time following each overflight, FRSL field crews were actively collecting supporting image calibration data and resource condition information. In addition, a flight by the NASA RB-57 aircraft covering the entire Feather River Watershed area was carried out on July 25, 1970. As in the past, field crews supported the mission by collecting ground truth information; in this case, terrestrial photographs were taken of representative terrain features and conditions found throughout the entire study areas.

Figures 4.1, 4.2 and 4.3 illustrate the three types of imagery (degraded high-flight photo mosaic, non-stereo high-flight photo mosaic and stereo high-flight photos) constituting the raw data which is undergoing analysis. These images have been prepared using the July 1970 RB-57 photography. With the aid of these high-flight photos we have been preparing and will continue for several weeks to prepare reference and image interpretation key materials which will be used by the image analysts during the mapping phase of the project. For each parameter to be mapped, we are developing a working key which includes (1) a general description of the resource feature, (2) a description of its image characteristics, (3) terrestrial photographs showing representative examples of the feature, and (4) high-flight imagery showing representative examples of the feature.

4.2.2 Work Currently in Progress

Once we have prepared interpretation key materials for each of the environmental parameters to be mapped, we will begin the actual mapping phase of this study. In each mapping exercise, we are attempting to determine the kinds of information that can be extracted from, first, low resolution simulated spaceborne imagery, then, high resolution simulated spaceborne hard copy film, and, lastly, high resolution high-flight photography. Furthermore, in each case, we are emphasizing the optimum sampling procedures needed to accomplish a particular survey task -- which often include the employment of limited amounts of small scale photo coverage, large scale photo coverage and on-the-ground observations and measurements.

4.2.3 Future Proposed Work

During the second year of this study, which leads off, fortunately, with

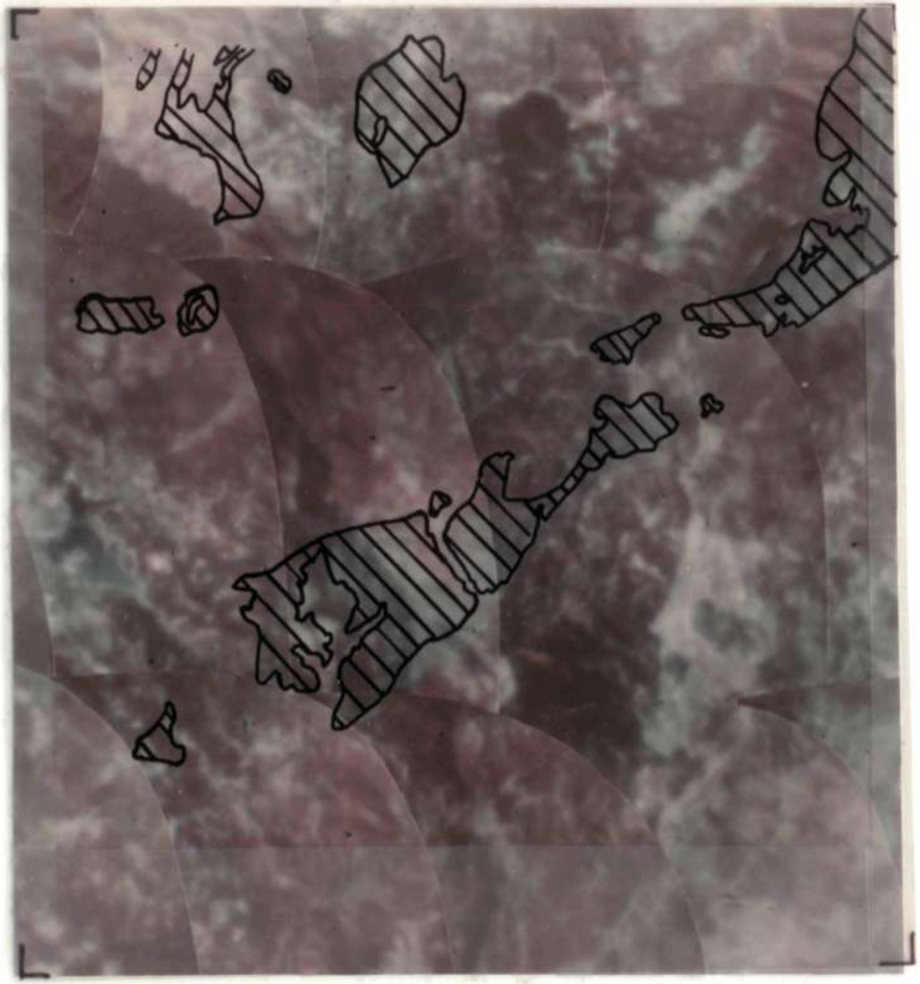


Figure 4.1. A portion of the degraded semi-controlled photo mosaic for the Feather River Watershed area made from RB-57 Infrared Ektachrome copy transparencies is shown here at a reduced scale equal to 1:250,000. The ground resolvable distance for this imagery is between 500 and 1000 feet -- certainly no worse than what can be expected with proposed ERTS imagery. Note, however, that an important geologic-soil condition, viz., serpentine soils derived from an ultrabasic metamorphosed parent material, can be accurately mapped even on poor quality imagery such as this.

Figure 4.2. Non-stereo prints (in mosaic form) made from RB-57 Infrared Ektachrome copy transparencies are shown here at a reduced scale equal to 1:250,000. The ground resolvable distance for this imagery is between 50 and 100 feet; earth orbiting spacecraft returning hard-copy film might sometime in the future obtain imagery approaching the quality displayed here. Note that the soil-vegetation boundaries seen in Figure 4.1 are more clearly defined on this imagery.

Figure 4.3. A central portion of the Feather River Watershed area, including much of the Bucks Lake-Meadow Valley Test Site, is shown here in the form of a stereo triplet and at a reduced scale equal to 1:250,000. The ground resolvable distance for this imagery is equal to that on the imagery shown in Figure 4.2, 50-100 feet; however, with the addition of stereo parallax, the amount of extractable information from the high-flight imagery is greatly increased. The soil-vegetation boundaries, shown in Figures 4.1 and 4.2, are quite easily mapped when given the added advantage of seeing the terrain in the third dimension. Terrestrial photos taken at points X and Y are shown in Figure 4.5.

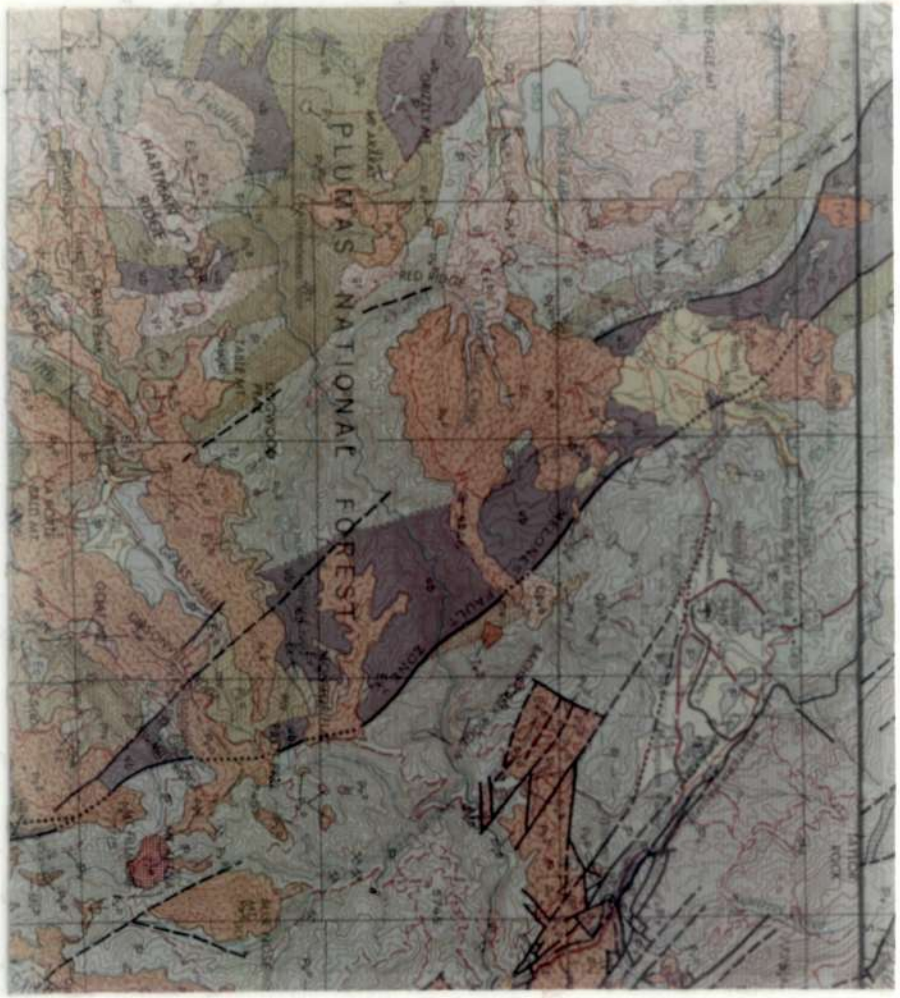


Figure 4.4. A portion of a geologic map (Chico Sheet, State of California, Division of Mines and Geology) covering the areas presented in Figures 4.1, 4.2 and 4.3 is shown here. Ultrabasic intrusive rock materials are colored purple on this map sheet, and this information was used to prepare the ground truth overlays on the preceding photo illustrations.

Figure 4.5. These ground photos were taken on September 29, 1970, when nearly all participants in this project, including several NASA representatives, toured the Bucks Lake-Meadow Valley Test Site. The photo on the left was taken at point X (see Figure 4.3) and shows the "tension zone" found to occur on a sharp soil-vegetation boundary; within this zone there can be found species of plants and trees not found on either site adjoining the boundary. The photo on the right was taken at point Y (see Figure 4.3) and shows a large area of exposed granite rock. Knowledge concerning the areal extent of such a terrain feature would be extremely important to a hydrologist as he attempts to evaluate a factor such as runoff rate for sections of land under his management.

four months considered to be the prime field season in the Feather River Watershed area, our field crews will collect detailed ground truth data on field plots systematically located throughout the entire study area. New methods for collecting ground data will have to be devised and perfected. In the past, working in limited areas with adequate road networks, we have relied on the use of field vehicles which have provided us with speed and mobility while collecting field data. However, it is unrealistic to consider the use of automobiles when working in vast areas, especially newly developing areas lacking an efficient road system. Consequently, a helicopter will be employed to transport a field crew throughout the entire study area and an attempt will be made to determine the optimum use of such a vehicle for these purposes. Once this ground truth is procured next summer, we will be a position to thoroughly evaluate, with the aid of quantitative statistical methods, the interpretation results obtained during the previous year. Delineations on each survey map made during the previous year will be analyzed and definitive statements will be made concerning their accuracy and, therefore, usefulness. In essence, a major part of our Unit's activities during the second year will center on the evaluation of the survey data collected during the previous year.

In addition, there will be increased coordination between our Unit and the Spectral Characteristics and Automatic Image Classification and Data Processing Units of the Forestry Remote Sensing Laboratory. Spectral data collected from those resource features deemed most important to the hydrologist will be available and useful for defining the optimum specifications for acquiring imagery (i.e., proper spectral bands) and for developing reliable image interpretation keys in which image characteristics can be presented as, or supported with, spectral data. Furthermore, the interpretation results, presented in map form, can be prepared in such a format that the ADP Unit can incorporate them into a flexible computer operated "data bank", from which key environmental parameters can be not only efficiently extracted but withdrawn in a format useful to the land manager.

Hopefully, the work being performed by the personnel of our Unit, along with the findings of other staff members at the FRSL, will result in the development of sound resource inventory techniques applicable to enormous land areas. We feel that the key to a successful input to this project from our group lies in being able to demonstrate that meaningful regional resource surveys can be rapidly performed with the aid of synoptic view remote sensing imagery.

4.3 REPORT OF THE AUTOMATIC IMAGE CLASSIFICATION AND DATA PROCESSING UNIT

4.3.1 Work Performed During the Period Covered by this Report

The studies performed to date by our Unit on this integrated project have been confined primarily to the NASA Forestry Test Site, which is a portion of the Feather River Headwaters area. Our contribution has been aimed at integrating a variety of automatic image classification techniques with conventional manual interpretation methods in an effort to better define the overall resource analysis task in light of large-scale planning decision requirements. In order to effectively accomplish our intended role in the overall project effort, we centered our preliminary activity upon the upgrading of our existing FRSL (Forestry Remote Sensing Laboratory) data handling facilities. Careful consideration was given to (a) the greatest utilization of existing campus computing facilities where possible, and (b) the development of a local data handling system which would provide both ease of access and analytical flexibility for possible use by all project participants -- especially where man/machine interactions might best be successfully studied.

Coincident with our effort to develop a local data handling system, we have made significant progress in several additional areas of activity that are pertinent to our overall project objectives. We have successfully converted the LARS (Laboratory for Applications in Remote Sensing, Purdue University) pattern recognition routines to run on the Berkeley Campus CDC 6400 computer, thus providing a proven "automated" recognition system for remote sensing data here on the west coast. Preliminary input tape format processing is necessary for CDC compatibility, but this step is readily accomplished in a minimum amount of time. We also expect to complete in the near future certain program user revisions as well as additions to the basic core of statistical algorithms which will provide greater data dimensionality for decision-rule classification.

In addition, several of our staff members were able to visit other remote sensing centers specializing in remote sensor data collection, processing and analysis in order to familiarize us with each center's areas of interest and expertise. For example, the partial results of a recently completed joint study between the FRSL and University of Michigan of vegetation and related resources in the Feather River region are included herein as representative of certain data collection systems of interest to the project. We intend to continue ties with these centers in the belief that mutual "cross-talk" of ideas and techniques for automated image analysis is beneficial to all parties involved. We intend to work closely with several groups which exhibit unique hardware facilities that are too costly to duplicate within the project structure but which show promise in the analysis of earth resources from an automated approach. These centers have already expressed a desire to trade data of mutual interest for algorithm testing, technique evaluation, etc.

Our efforts and successes to date regarding development and study of a "data bank" using a portion of the Feather River Watershed area for testing purposes have been such that an even greater portion of time will be devoted to this area of endeavor in the near future. Our preliminary results indicate our approach, or some modification if it, will be of great assistance to the resource manager in making certain decisions requiring rapid access to information about a region of interest. Several examples are presented in subsequent parts of this section. As we continue to work more and more closely with the users and planning decision-making interfacing at other junctures within the total project, we will learn additional features about optimizing update procedures and streamlining the system for maximim utilization. Each of the above mentioned areas of activity by our Unit is discussed in greater detail in the succeeding sub-sections.

4.3.1.1 FRSL Data Handling Facilities. A preliminary requirement for the successive stages of study in our long-range project objectives was the upgrading of our existing data processing facilities. Certain hardware components were already available to us (in particular configurations) as a result of prior studies. What was required, in view of the stated integrated project effort, was the design and specification of a more flexible "system" using our existing components to the fullest extent in conjunction with those additional components necessary to properly conduct our tasks.

With respect to our data processing tasks and the specification of an effective system to handle them, we considered there to be two primary design requirements: (1) the system was to be highly suited for rapid operator interactive data display and decision-making employing digital techniques; and (2) the system was to be readily accessible and usable by any of the project participants having need for particular types of data reduction and processing.

Considering the following list of existing hardware components in light of our design requirements, it is fairly evident that effective, interactive display components were necessary:

- programmable "process control" unit having 4096 sixteen-bit words of addressable memory.

- magnetic cassette recorder unit for special purpose programs and data storage (up to 3.6 million bits/cassette).

- customized scanning microdensitometer for digitizing film transparencies as a source of input to feature classification techniques.

- low-speed teletypewriter for input/output of alphanumeric information either by direct keyboard entry or paper tape read and punch.

With the above list as the base structure of our system, we have successfully interfaced to date the following components which are principally oriented towards satisfying the first of our two design requirements:

- 9-track industry compatible magnetic tape transport for added data storage and data manipulation, especially where it is required to transport reels between remote sensing centers.

- additional 4096 sixteen-bit words of programmable memory for increased program requirements and to facilitate data transmission to and from the campus computing center facilities.

- data communications link to the computing center facilities for "near real-time" digital transmission and display work.

- 10-inch storage tube display unit for alphanumeric, vector, and/or point-plot display capabilities.

While our "local" remote computer terminal system is by itself a fairly modest unit in terms of in-house process control and data recording, it becomes a very powerful research tool when it is linked up with the campus large-scale computers for statistical analyses and man/machine interactive processes. Additional components, aimed primarily at improving the second of our two design requirements are listed and discussed in the subsequent section entitled "Future Proposed Work".

With the FRSL Terminal/Display System in its present first year configuration, we have progressed to the following data handling and analysis capabilities. We presently have the capability to digitize black-and-white film transparencies (either negatives or positives) and perform certain preprocessing of the data prior to transmission to the larger high-speed computer for subsequent analyses. At this stage, many options are available to the investigator as to his choice of analysis. Our Unit personnel are primarily interested in classification of the digitized data while others in the FRSL, or co-investigators within the total project, may have need for different forms of processing and analysis prior to display and decision-making. One important aspect of our digitizing efforts is determining, for various resource features and conditions, optimum scanning parameters for successful automatic classification of them using various classifying algorithms. Our scanning microdensitometer will digitize at the approximate rate of 300 samples per second (because of the scanner's software routine for controlling the two stepping motor operations; much higher rates are possible by changing this controller routine, but a significant loss in geometric fidelity results between adjacent lines for certain applications). The stepping motors have specifications for 0.0005" incremental steps, but we believe our tolerance levels for the staging mechanisms to be such that 0.001" is our minimum sampling interval. We do not at the present time feel it is necessary to upgrade the staging mechanism to further reduce the sampling interval.

We have proceeded along two paths of development in making total use of the system's data handling "software" capabilities:

(1) development of routines which control the operations of the various peripheral devices that are currently interfaced to the central processor unit; and

(2) development of routines which enable user controlled data preprocessing and analyses, either locally at the system terminal or remotely to the campus computer center.

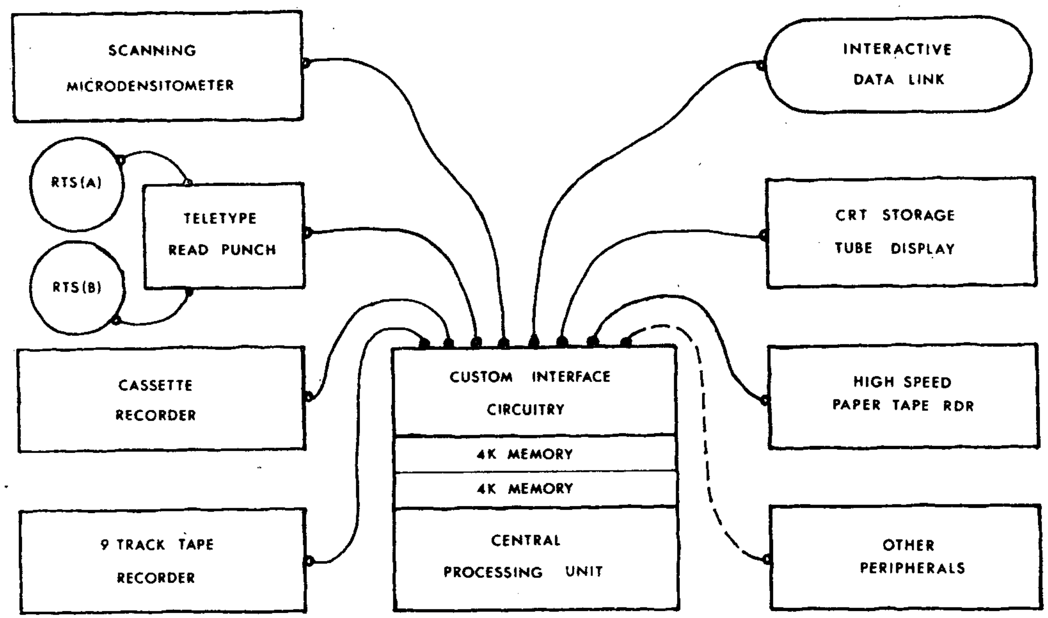
A well designed, comprehensive package of routines of the first type is essential for the fullest exploitation of capabilities afforded by the second type. Routines exist which enable random access of either programs or data strings from the magnetic cassette recorder. For example, it is possible to digitize high altitude aerial photography of important agricultural crops on a field-by-field basis and, depending on scale of photography and sampling intensity, store up to several thousand fields on a cassette. Then, various combintaions of fields can be accessed and stored in computer memory in just a few seconds from the cassette for the purpose of determining tone signature variability, plotting frequency histograms of digitized optical densities, displaying selected density "slices" for comparison with ground truth information, or a number of other alternatives which can be made available to the investigator. Figure 4.6 summarizes the current status and capabilities of the FRSL Terminal/ Display System.

4.3.1.2 Ties with Other Remote Sensing Centers. One important aspect of our research effort is the need to stay abreast of related research being conducted at other remote sensing centers across the nation. Mutual cooperation can be realized at a small cost to the project wherein ideas and techniques are shared and discussed with other experts in the field. Too, in many instances, particularly unique capabilities are exhibited by each of these centers to the point where both parties can participate in exchanges of data, sensor systems, or interpretation systems. Thus we have formulated plans to exchange freely, techniques and results of various classifier algorithms with those centers wishing to do so. Several examples of exchanges and mutual studies have already transpired which complement our specifically funded objectives. Four centers are involved as primary contacts expressing interest in our endeavors as they relate to their own particular studies.

Laboratory for Applications in Remote Sensing (LARS), Purdue University

This group has long been active in developing "pattern recognition" techniques through computer applications of remote sensing data. We were able to acquire from them the source program listing for their LARSYSAA routines. We

E



Current Capabilities

- density slicing and display (L)
- frequency histogram plotting (L)
- LARSYSAA analysis (L, T)
- density isolation and display (L, T)
- multiband classification (T)
- density variation analysis (L)
- edge enhancement (L, T)
- fourier transforms (T)
- hadamard transforms (L, T)
- color display of classification results (L)
- statistical analyses (L, T)
- training sample selection and testing (L)

Figure 4.6. Current system status and software capabilities of the FRSL Terminal/Display. Shown at the left is a schematic of our FRSL system components. The 8k mini-computer's capabilities were previously described in the text. Our scanning microdensitometer can digitize optical densities to 12-bit resolution on an X, Y scale as small as 0.001". Both scales can be independently computer controlled for recording either on the cassette recorder or 9-track tape transport for subsequent analyses. The storage tube display unit has a sophisticated controller for character, point and vector generation which was student-designed as a Master's project. It is an extremely fast device which interacts well with the CPU's ability to handle bits of information rapidly. Shown next to the schematic of present hardware components is a partial list of software capabilities, which is presented to indicate the diversity of analytical techniques which is possible from the Terminal/Display System. Following each itemized entry, either the letter "L" appears signifying this technique can be performed "locally", without need for the large computer; or the letter "T", signifying that this technique requires transmission to and from the CDC 6400 computer for completion.

have been familiar with the activities of LARS for many years, enjoying several opportunities to "squeeze" into their own heavy schedule of activities. This has permitted us to work directly with their computer programs, modifying these programs as necessary for studies aimed at classifying wildland features and rangeland vegetation communities (this latter study performed for Dr. Poulton at Oregon State University). With the source listings in hand, together with duplicate magnetic tape copies of known terrain sites and conditions which had been previously scanned with a multi-channel scanner, it was a fairly straightforward task to adapt the routines to our own campus computer center facilities. The major problem which had to be overcome was that of modifying the tape formats to be compatible with the CDC equipment. With this set of routines now more readily available to our Unit interests as well as others in the project, we anticipate increased use and study of computer-oriented recognition techniques in the handling of high-altitude and satellite-altitude remote sensing data. The ability to rapidly inventory resources for planning requirements, of course, suggests the use of high-speed devices for data handling and interpretation. We will first make some modifications to the LARSYSAA routines in order to make full use of our system's capabilities in terms of input and output. For example, it is desirable to have the interactive segments of the program displayed on the CRT storage tube device for operator decision of various options. Also, it is highly desirable to include additional analytical dimensionality routines for utilizing the total information contained within the scanned remote sensing data. It is felt that "textural" data (i.e., the relationship of neighboring points or samples with each other) will provide increased ability to classify some of the difficult features and conditions which it is presently desirable to attempt to delineate.

Willow Run Laboratories, University of Michigan

We have recently concluded a NASA funded joint study of computer-oriented feature classifications using a variety of digital and analog techniques for display of results. An important rationale for maintaining close association with the Willow Run Labs is their proven experience in optical-mechanical scanner technology. Part of the ERTS satellite program involves the design and use of a four-channel optical-mechanical scanner device for terrain data recording and subsequent analysis. The Willow Run Labs presently have an eighteen-channel scanner which spans the four ERTS bands and should prove of interest in assessing the usefulness of scanner data for resource delineation. The digital approach to feature identification used by the Willow Run Labs closely parallels the LARS programs mentioned previously. Because the raw scanner data are collected and digitized by the same group, some additional tape preprocessing is used to correct any drift in signal due to changing aspects or slopes. Figure 4.7 shows the comparative spectral recording capabilities of the ERTS four-channel device and the Willow Run eighteen-channel scanner.

Center for Research, Inc., Engineering Sciences Div. (CRES) University of Kansas

The thoughts of this group of experts very closely parallel our own thoughts with respect to texture analysis of digitized remote sensor data. CRES has developed a unique hybrid computer display system based upon multiple flying-spot scanners linked to a color video monitor. CRES personnel have recently added a computer/disc interface which permits storage of images and subsequent "overlay" displays. We have worked with them in the past on studies of wildland feature and agricultural crop discriminations using their interpretation system with a wide variety of remote sensing imagery. Figure 4.8 illustrates an example of video display from the CRES system showing the

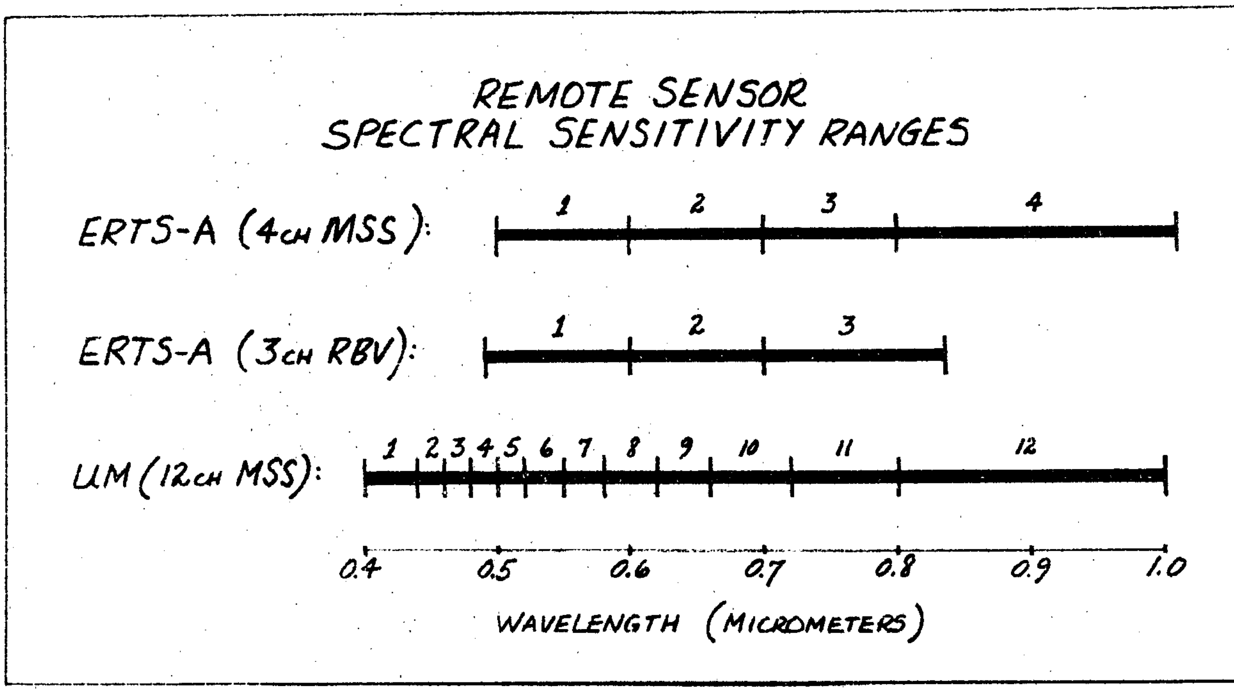


Figure 4.7. Comparison of spectral sensitivities of the ERTS-A sensor package vs. the University of Michigan multispectral scanner. Shown in this chart are the respective spectral sensitivities, by channel numbers, of the ERTS-A sensors and University of Michigan multispectral scanner. In the above chart, only the 12-channel spectrometer device from the Michigan sensor package is noted for reference. An additional six channels comprise the total 18 channel sensor capability (1 UV channel and 5 near infrared and thermal infrared channels). Without special filtering, little comparison of signatures appears possible between these systems. Notice also that the ERTS-A sensors are not sensitive below 0.5 micrometers. Several studies of resource recognition systems conducted by this author using multiband input data have shown that information between 0.4 and 0.5 micrometers improves the overall classification accuracy.

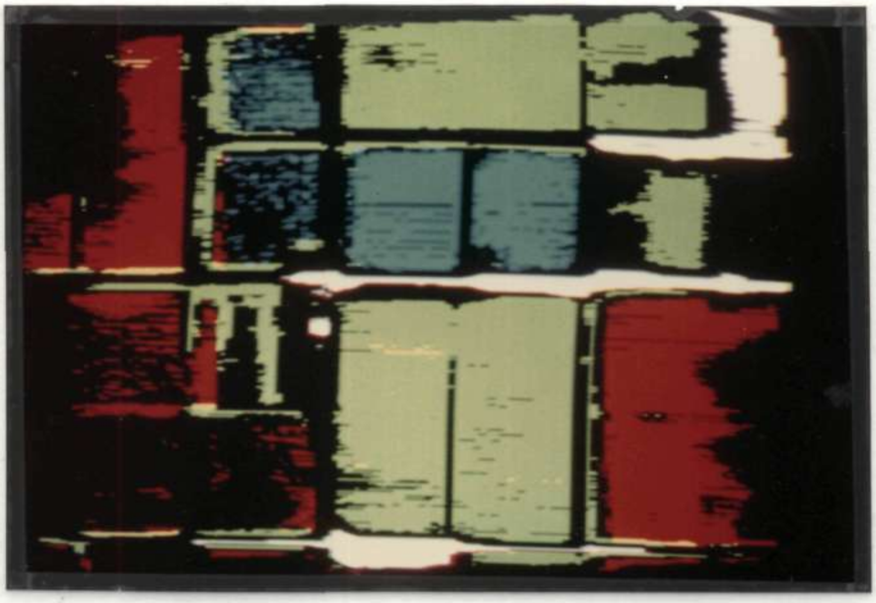


Figure 4.8. Example of color video display using multiple inputs as performed on the University of Kansas (CRES) IDECS system. As many as four flying spot scanners can be simultaneously employed to color enhance multiband images of interest. In the above example, agricultural crops are displayed using multiband black-and-white photo transparencies as input. Cotton fields are displayed as light blue; alfalfa as red; and sorghum as green. A great variety of colors can be selected for highlighting a particular feature of interest, or, to merely assign various colors to separate tone signature "slices". Note that a more readily interpretable image is presented to the viewer when color is used as the encoding medium rather than greyscales, or alphanumeric symbols (which suffer additionally from the annoyance of raster distortion). However, the video related color display technique places greater demands on data volumes and rates of transmission between computer/disc and monitor. The modified color system shown in Figure 4.12 will enable single frame manipulation and classification display without video disc requirements.

added advantage of color for interpretative analysis. We have noted upon numerous occasions the value of displaying electronic discriminations in contrasting color hues in preference to greyscale display. Our Unit is proposing a simplified digital color display unit to complement the real-time video display device being developed for the project by Dr. Algazi's group. Further discussion of this device appears in a later section of this chapter.

Remote Sensing of Nature (RESEÑA), Colorado State University

One final group is mentioned because of recent correspondence which suggests that our two laboratories have much to gain by exchange of ideas and various kinds of remote sensor data. The RESEÑA group is entering into some studies of automatic pattern recognition and has developed a modest system for data handling and analysis. We have agreed to exchange data (magnetic tapes, etc.) of various kinds of digitized data for analysis purposes. Of particular interest to our Laboratory is their field van ground data collection facility which, of course, must accompany most image interpretation systems closely in order to determine accuracies of discriminations.

There are numerous other centers which might be mentioned here, but we feel that those mentioned above provide a complementary set of objectives with respect to automated interpretation techniques of interest to this project, and also possess some unique capabilities in terms of systems development that are impossible to duplicate within our project. With our Unit seeking to develop a comprehensive digital system for resource analysis and with the Davis campus effort by Algazi, et al., seeking to provide the analog (video) counterpart, it will be possible for our two groups to respond knowledgeably to inquiries from the user/planner members of the project about optimum interpretation systems and information displays for the efficient utilization of ERTS type resource information.

4.3.1.3 Meadow Valley Working Circle "Data Bank". Coincident with our hardware development for the FRSL Terminal/Display system, we have devoted considerable time to the task of implementing a "data bank" for use by other project participants. The concept of a data bank as it relates to our Laboratory needs requires explanation. First, we desired to establish a file of information about a test site of interest (in this case, the Meadow Valley region of the Feather River Headwaters area was chosen as a suitable starting place for study) that was fairly refined as to spatial resolution. Consequently, quite large amounts of data were to be stored and manipulated within the data bank system. We have presently settled on a mapping and display scale which accesses a point on the ground which is slightly less than one acre in size. To date, this has not been an unreasonable scale with which to work.

A second requirement for the data bank was that it be fairly unlimited as to the type of information which it would be required to handle for display. The system we have been working with enables an essentially unlimited amount of data to be entered as storage files using magnetic tapes. Conceptually, each storage file represents a "profile" which can be added on at the end of the list when it is found useful to include it in the total system. Profiles can thus be added and/or purged depending on their usefulness in the display or analysis. Figure 4.9 depicts our data bank design, with some of the profiles we presently have stored in it noted as examples of the type of data of interest to the resource manager. We expect to have enough data stored in our data bank by late summer 1971 to submit it for investigation and criticism. Figures 4.10 and 4.11 represent the results of combining the total information retrieval capability of the system for displaying various

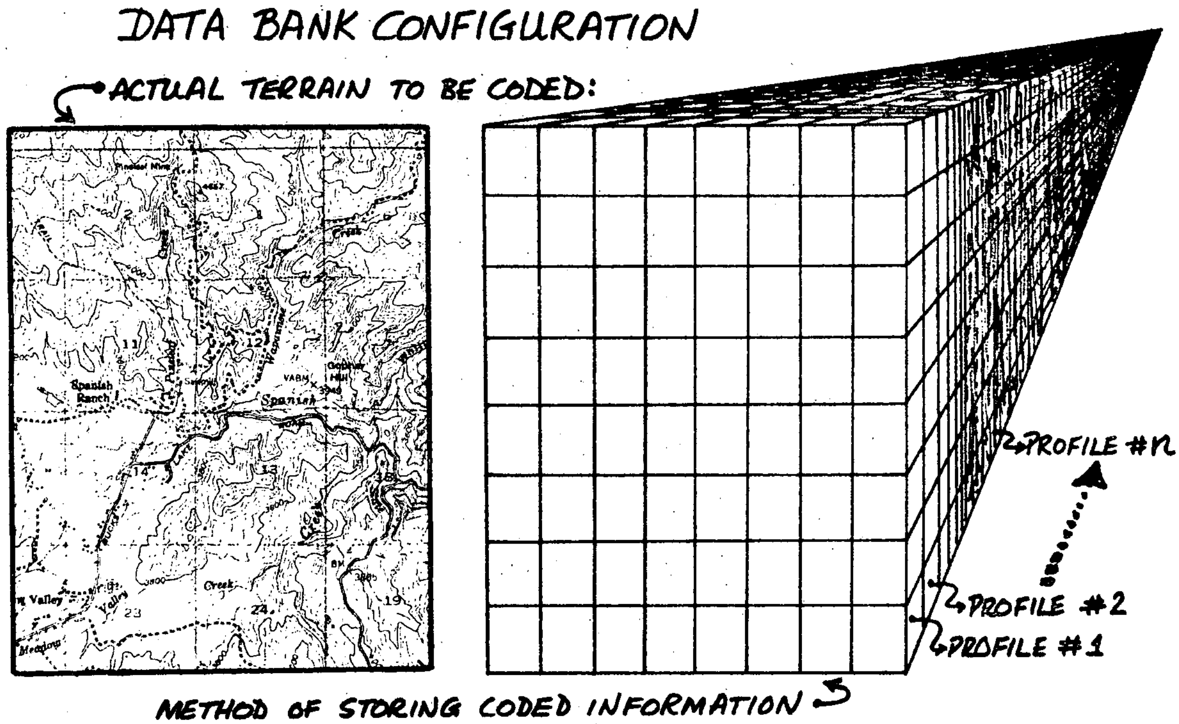


Figure 4.9. FRSL "data bank" configuration. Shown above, in a highly simplified schematic, is our conceptual approach to storing and retrieving information about an area of interest. In this case, a portion of the NASA Bucks Lake Forestry Test Site in Northern California is shown for illustrative purposes. The data bank is a three dimensional array of data points with X and Y coordinates representing ground location points. The Z coordinate consists of "profiles" of discrete types of information being stored for subsequent retrieval. The types of information which currently reside in our FRSL data bank are data about vegetation types, forest fire history, cutting history, land-use activity, zoning classifications, geologic types, etc. The amount of profile information which can be stocked on the X and Y scales is virtually unlimited; however, in terms of computer processing time for data extraction, it behooves the user to maintain useful profiles, culling out data which has become outdated or which might be better replaced by alternative data. Access to the data bank is by reference to the particular profile addresses. It is a fairly simple matter to extract information from the data bank which has been compiled from several discrete profiles. This is illustrated in the following two figures.

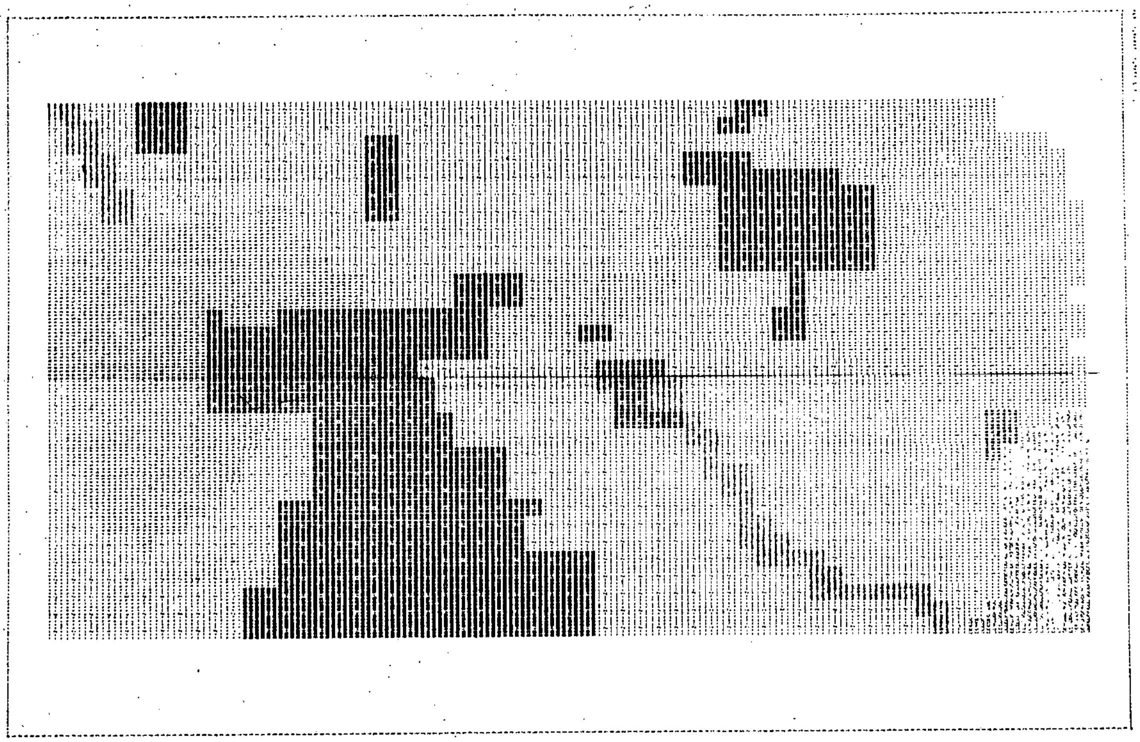


Figure 4.10. Example of data bank information retrieval. Shown above is a computer printed display of one of the profiles resident within the FRSL data bank. The map shows the various classifications of land use categories employed by the U. S. Forest Service. Data were encoded from maps originally obtained through their cooperation. Each cell (which is designated by a 3 x 5 symbol matrix with label code in its center) represents slightly less than a one acre parcel of terrain.

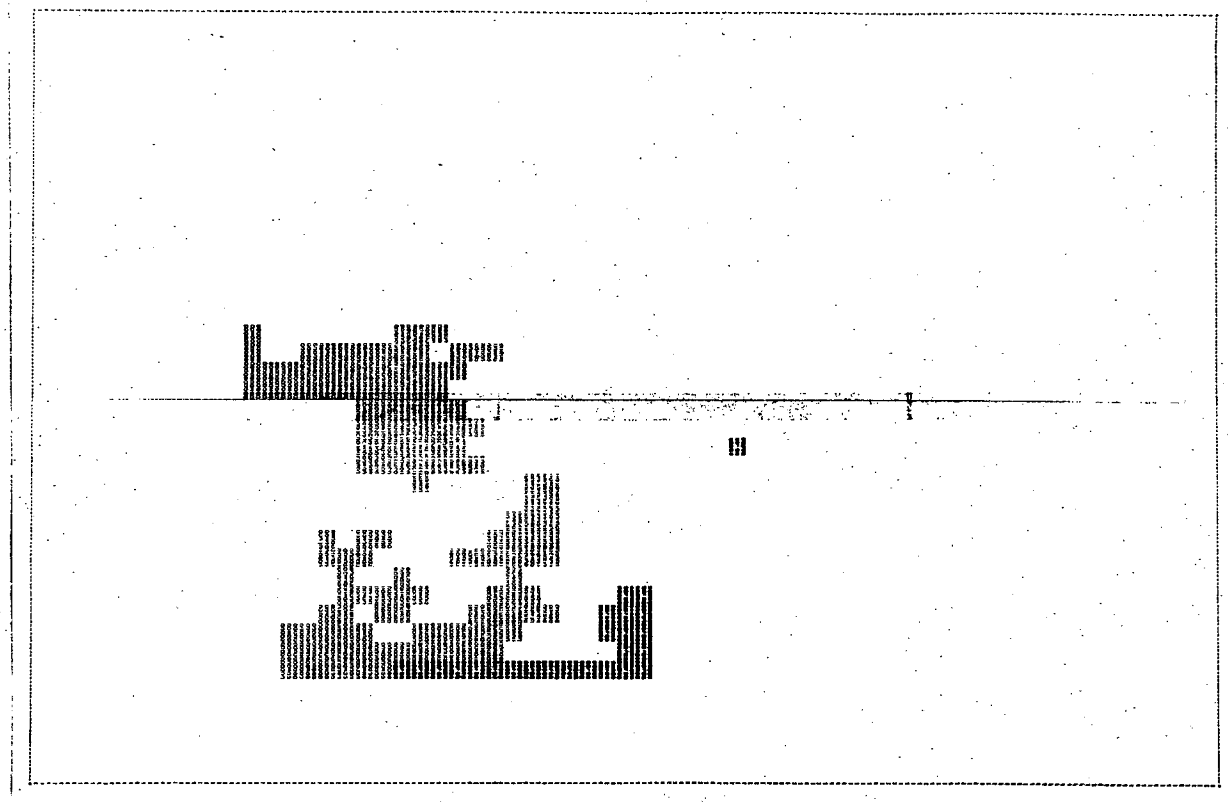


Figure 4.11. Example of combined profile information retrieval. The above map depicts a hypothetical situation described in the test legend below to illustrate the possibilities for examining multiple profiles of data;

LEGEND

THE MEADOW VALLEY DEVELOPMENT COMPANY WISHES TO PURCHASE PRIVATE HOLDINGS AND CONSTRUCT PART-TIME RESIDENCES IN THE MEADOW VALLEY AREA. A WELL-STOCKED FOREST, WHICH HAS NOT BEEN CUT SINCE 1951, IS PREFERRED AS A SETTING, BUT A MOUNTAIN MEADOW IS ALSO ACCEPTABLE.

THOSE SITES WHICH MEET THESE REQUIREMENTS ARE DESIGNATED 'F' FOR FOREST SITES, AND 'M' FOR MEADOW SITES.

We are working on software routines which will enable interactive retrieval such as this example illustrates directly through our FRSL Terminal/Display system.

kinds of information which might be desired for a hypothetical problem. As these examples illustrate, we are presently utilizing the campus computer center facilities for output and display purposes. The intent is to modify the routines to be compatible with the FRSL Terminal system for "in-house" display.

4.3.2 Work Currently in Progress. Between the time when this progress report is submitted and completion of the first year's annual report on 1 May 1971, our Unit will (1) bring the Terminal/Display system to a complete state of readiness in order that all project participants can avail themselves of its total analytical capabilities, and (2) complete the design and specification work for the closed circuit color digital display device. This device complements our existing black-and-white display for the digitally recorded information storage and retrieval system we have defined during our first year's effort. As our original proposal documentation indicates, the completion of our Terminal/Display system rests on both color and black-and-white display techniques. It is well known from our own research efforts, as well as those of the other remote sensing centers, that the ability to analyze multiband data for interpretation of results (whether manually or "automatically") is greatly enhanced by the added dimension of color. Our preliminary examination of the technical requirements to implement an inexpensive, closed circuit CRT for color digital display reveals we could have an operating device interfaced to our present Terminal/Display system within one month of receipt of the various components for the system.

Software programming of additional routines to handle our analytical objectives will also be given considerable effort during these three months. We expect to complete display routines which plot density frequencies as a preprocessing to multiband analysis. Most statistical routines which we anticipate using are already on file at the computer center facility and they can be "called" for use with our digitized data through the remote computer terminal link. With respect to the use of the LARS routines for pattern recognition, we plan to make several tests of them using data collected by the University of Michigan C-47 aircraft multichannel scanner over our NASA Bucks Lake Forestry test site. We will want to determine the increase in analysis time using the faster CDC computer equipment in conjunction with our remote terminal transmission capabilities. We will then spend some time in modifying the routines to accept other digitally recorded remote sensing data, separating the routines into two types:

(1) those that can be run "locally" at the FRSL using the process controller and peripherals; and

(2) those that require large core memory and high-speed data manipulation not available within our FRSL configuration of hardware components. The high-speed transmission link will be used to send and transmit intermediate stages of the classification requiring operator interaction.

We will do some work on digitized vegetation resources, attempting to separate important species and conditions. Our investigations will include identifying certain routines which can be added to the LARSYSAA package of routines that will enable texture analysis to be made. In this regard, we are working with staff members and graduate students from the Electrical Engineering/Computer Sciences Department (Berkeley Campus) to try and define promising textural analysis techniques to complement manual photo-interpretation methods. It will be important to relate whatever findings are made to ERTS-type data recording systems as well as SKYLAB satellite programs. Low altitude interpretation systems are fairly common but the problem of identification of classification becomes increasingly acute as the distance between the target and sensor is increased. We anticipate that we will be exchanging some of these data with a few of the remote sensing centers mentioned previously where an interest in "texture" analysis has been indicated.

Finally, we will continue work on the data bank, expanding it in depth with additional profiles of information as they are defined by other members of the Laboratory. Examples of output will be compiled for the annual report.

4.3.3 Future Proposed Research. Several areas are obvious for follow-on second year effort by our Unit in this integrated study of earth resources. By order of importance, we feel the following items need attention for a smooth conclusion of total project effort in the successive final phase of research to be performed.

A. Our Unit needs to complete the FRSL Terminal/Display system with an interface of our proposed closed circuit CRT color digital display device. Figure 4.12 shows a schematic diagram of the proposed addition. With the existing system development which has already been completed, it is a fairly simple task to design and interface a digital color display system to the central processing unit we presently have. So simple is it, in fact, that we conservatively estimate that our design can be operational within one month of receipt of the hardware components required to implement its construction and testing. This is of importance because we would be able to commence our second year's effort with a complete data handling and display system, taking advantage of almost the full term for activities described below.

B. We feel that the success we have had to date with our data bank concept warrants two major extensions: First, to increase its dimensionality to data adjacent to the Meadow Valley region to determine scale limitations; and, second, to test the concept using an area quite different from our Forestry

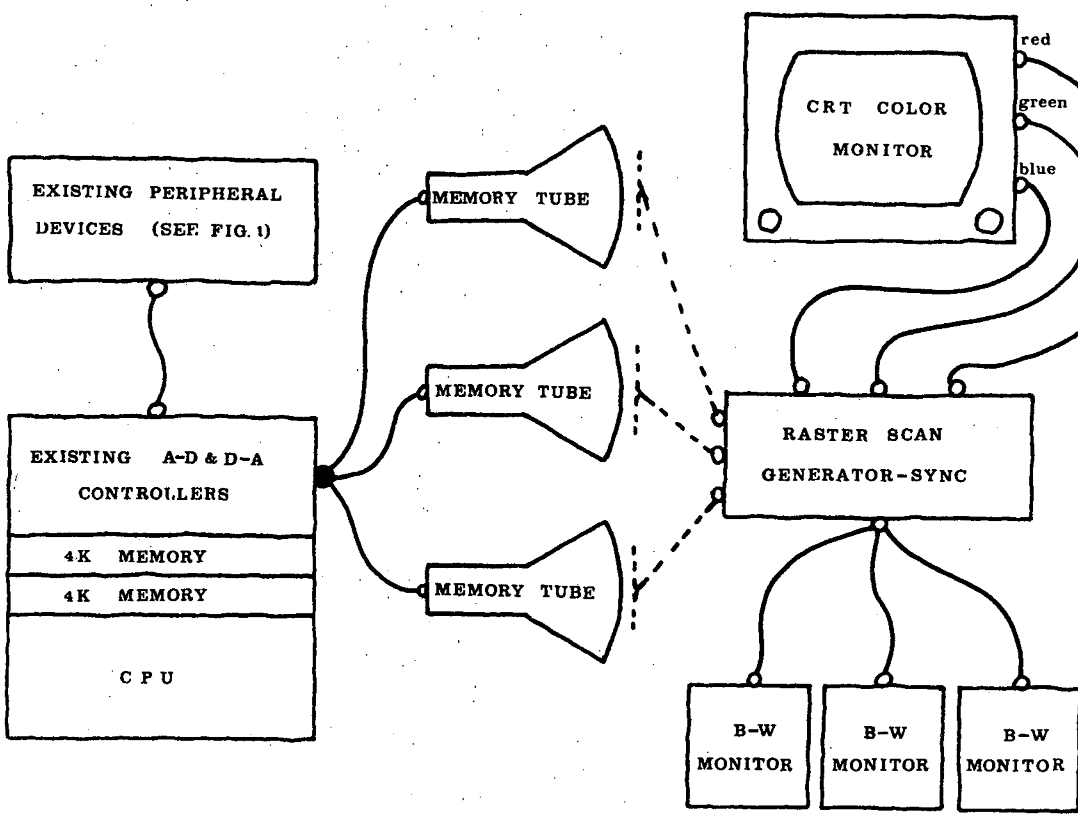


Figure 4.12. Schematic of proposed digital color display unit. The above Schematic shows the additional components required to complete our FRSL Terminal/Display System as originally proposed. The heart of this subsystem is the memory tube which permits write and read capability. When three tubes are properly synchronized and programmed to control each of the CRT color "guns", multi-colored displays are feasible to improve classification displays. Over 200 color values are available as a function of color mixing possibilities.

F

Test Site to determine what restrictions, if any, might occur in a different environmental situation. There are, within the total project a number of possible areas for testing purposes. We are working closely with Dr. Estes at the Santa Barbara campus for his ideas and suggestions as to the usefulness of such an information system oriented around his own activities and interests in inland valley geographical analysis as well as coastal environmental problems.

C. We will want to organize and conduct a wide number of experiments designed to compare the relative merits of manual photo-interpretation versus automatic classification techniques. Very rudimentary tests have revealed that the inconsistent nature of human activity with respect to image analysis will require the definition of certain tasks which are best performed by automatic techniques, releasing the manual interpretation tasks to those that are best performed by human endeavor. The experiments will seek to determine the optimum mix of man/machine relationships for the assessment of various resource types and conditions using state of the art remote sensing systems data for interpretation. Emphasis will be placed upon the use of high-altitude and satellite imagery. Maximum effort will be spent to develop experiments which are of significance to investigators at the other campuses, in addition to our interests here at the FRSL.

D. An additional area of activity which we will want to commence is the study of model building and simulation techniques in cooperation with Dr. Churchman's staff.

4.4. REPORT OF THE SPECTRAL CHARACTERISTICS UNIT

4.4.1 Work Performed During the Period Covered by This Report

In order to maximize the effectiveness of multispectral aerial photography, the reflectance characteristics for features of interest and their background should be known. With this information in hand one can make more effective interpretation of multispectral imagery. In addition, if this information is known at the time when missions to acquire such imagery are being planned, it can be used to help determine the spectral bandpasses which should provide the greatest likelihood of discrimination among features of interest.

Several approaches to gathering data on spectral reflection have been used. The most common involve the use of some type of laboratory spectrophotometer to obtain measurements from prepared samples. However, laboratory measurements have major limitations when used to estimate the spectral characteristics of natural surfaces. For example, two major objections frequently are raised with respect to the taking of laboratory measurements of severed leaves mounted as flat samples:

(1) The spectral reflectance from a canopy of foliage may not be the same as the reflectance from individual leaf samples. Plant reflectance is a composite of the reflectances from variously oriented and variously illuminated leaves, stems and underlying soil and litter. The density of a plant's foliage and the orientation of its leaves with respect to both the sun and the sensor may greatly influence the spectral reflectance of the plant as recorded by the sensor. Furthermore, on small scale aerial photography the smallest resolvable detail consists of an <u>aggregation</u> of plants, rather than the individual plants, themselves. This fact makes it even more difficult to infer the multispectral photographic tone signature of vegetation merely from spectral reflectance measurements of foliage samples made in the laboratory. (2) Laboratory measurements are obtained with artificial illumination. The resulting data are plotted for a constant spectral intensity source, whereas in a natural scene as recorded by an airborne sensor the intensity of the illuminant, (consisting of direct sunlight, diffuse skylight and reflectances from nearby objects) varies greatly as a function

of wavelength. Because of these and other limitations of laboratory measurements, the Forestry Remote Sensing Laboratory has undertaken to study the spectral characteristics of features by making measurements in situ.

Field measurements of spectral reflectance overcome many of the limitations inherent in the laboratory. Measurements are made with the feature illuminated by sunlight, skylight and light reflected from nearby objects, as it is when recorded by a remote sensing device. In addition, it usually is possible for the field of view of the instrument to encompass an area large enough to integrate the reflectance from heterogeneous surfaces as occurs on aerial photographs.

Fabrication of Instruments and Development of Software

The major effort of the Spectral Characteristics Unit during this reporting period has been directed toward development of a data acquisition and data handling system for spectral signature measurement. The system utilizes our existing spectroradiometer equipment and includes modifications to this equipment and the addition of other data storage and transfer equipment. The entire system is designed to be completely field portable and can be operated from a battery power supply. The system can be used in its entirety, yet retains the flexibility to be used as individual units to perform other laboratory or field functions if necessary [1/].

The system is shown as a functional block diagram in Figure 4.13. One of its components consists of a spectroradiometer which measures irradiance at a cosine corrected diffuser plate illuminated by incident sunlight and skylight. The instrument measures over the range 380 nm - 1350 nm and can be automatically scanned through this range by a drive motor. The analog voltage

[1/] Matching funds to assist in the development of this system have been provided by NASA Contract No. R-09-038-002.

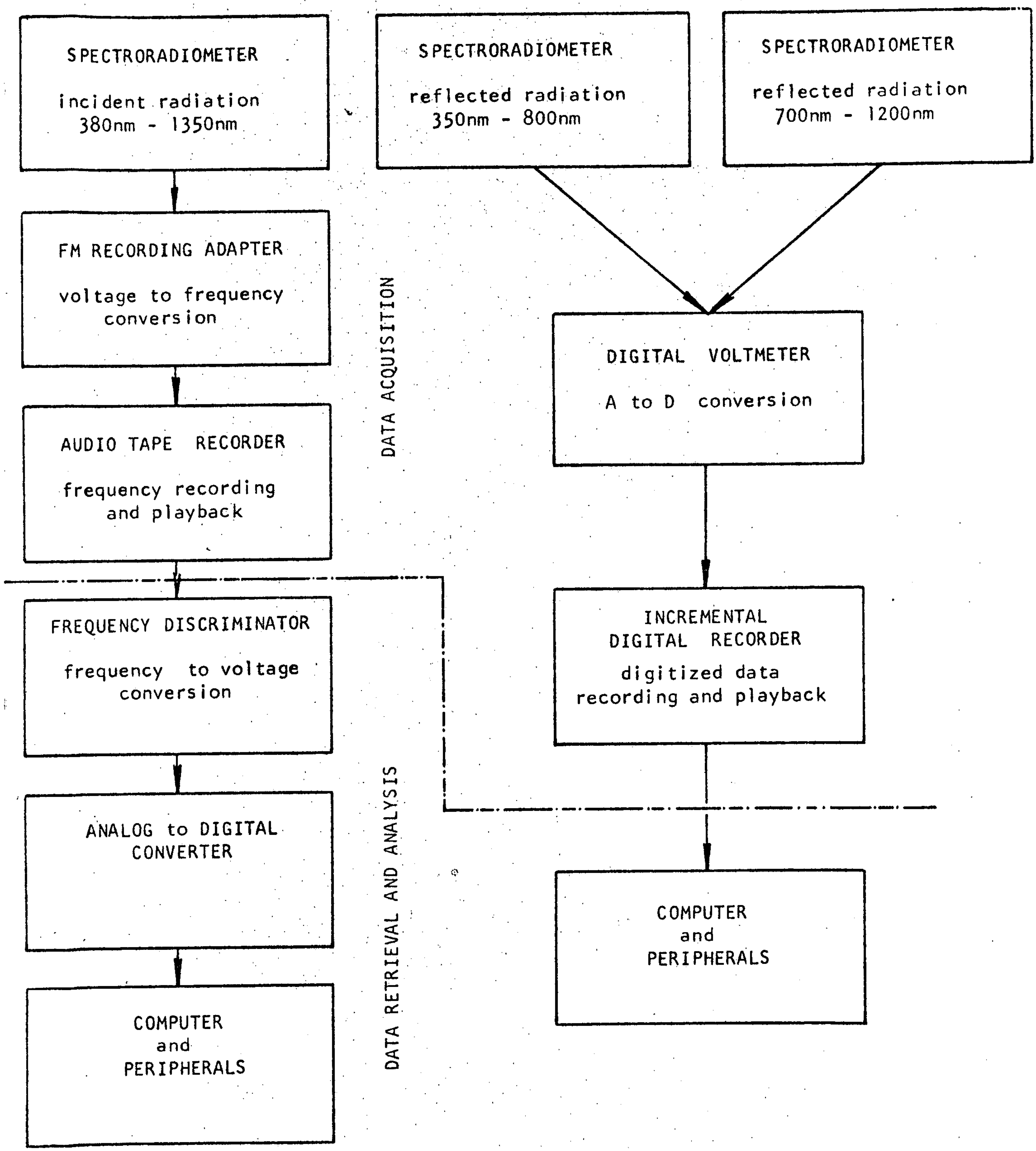


Figure 4.13. Functional block diagram of the FRSL computer compatible, field portable system for acquiring and recording incident and reflected spectral radiation in the range 350 nm - 1350 nm.

from this spectroradiometer is passed through an FM adapter which converts the voltage input to a frequency output. The frequency output is recorded by an audio tape recorder. The stored data are played back through a frequency discriminator which converts frequency to voltage. The voltage output is entered into a computer through an analog to digital converter.

A second set of spectroradiometers operating over the range 350 nm - 1200 nm is used to measure the spectral reflectance of surfaces. The analog voltage from the spectroradiometers is passed through a digital voltmeter with binary coded digital output, thence into an incremental digital tape recorder. The recorded data can be input directly into a computer for processing and output in tabular or graphical form. It should be emphasized that reliability is not sacrificed. In the event of failure of any of the components, other than the basic radiometer systems, the analog data are still available for hand recording from meter display as was the case originally.

Hardware fabrication for the spectroradiometer system is ninety-five percent complete. Preliminary software has been developed to the point that some calibration and debugging of the system is beginning and simple listings of computer output from the radiometer are possible.

The spectroradiometer system for measuring reflected radiation has about seventy percent of the hardware fabrication completed. Software for this system will be more easily developed than for the incident radiation system; its first iteration will be ready for testing in February.

Standardization of Spectral Data

Preliminary testing of a method to standardize spectral data has yielded good results. The method is being developed for the standardization of measurements of spectral irradiance reflected from ground features, such that measurements taken at various times and places and under various illumination conditions can be directly compared. Incident spectral radiation is measured at the same time as reflected spectral radiation. At each wavelength for which data are obtained, the actual measured incident radiation is compared with a "standard incident radiation". The standard, although arbitrary, is representative of midday incident radiation in the area of study. For that wavelength, a ratio of standard radiation versus measured radiation is established. The measured reflected radiation at each wavelength is multiplied by the appropriate ratio to arrive at a standardized value. By standardizing in this manner one can present all the spectral signatures acquired by the system as if illuminated by "standard incident radiation".

In addition, standardizing in this way, rather than as reflectance (which is a ratio of incoming to reflected radiation), has the advantage of eliminating the need for a ratio between measurements made by different types of radiometers. For remote sensing studies, the data are in terms of the radiation actually reflected toward an airborne sensor under normal conditions of natural illumination.

4.4.2 Work Currently in Progress

By the end of the first year of the project, all the hardware fabrication for the radiometer systems will be complete. Software for handling the recorded data will also be developed. Development of data reduction and analysis procedures will be an ongoing task. Local field testing and calibration of the operational system will be possible by early in the spring. Gathering of spectral data within the test area on a regular basis and the choice of targets for repetitive measurement as described in the next section may be possible during the month of May.

4.4.3 Future Proposed Research

During the spring and summer of 1971, repetitive measurements of reflected spectral radiation in the wavelength range of 400-1200 nm will be made of specific vegetation types. These measurements will enable us to characterise the spectral properties as they change with the phenological development of the vegetation. The data derived from analysis of these measurements will aid in determining the optimum time of year (state of development) and spectral bands where the greatest differences can be expected to occur in the reflected radiation from features of interest. In addition to studies of vegetation the spectral characteristics of soils will be studied in the test area.

With the development of the previously described spectroradiometer and data handling system it will be possible to acquire and analyze sufficient data to begin work on separating the effects of changes in the reflectance characteristics of features themselves from the effects of changes in external parameters such as look angle and illumination angle.

In collaboration with the Image Interpretation and Enhancement Unit our Unit will compile a list of important features which are difficult to distinguish on multiband imagery. From the data on characteristics of spectral reflection from these features, a recommended spectral bandpass and time of year will be specified for obtaining maximum discrimination between the features. Film-filter combinations which have maximum sensitivities in the recommended bandpasses will then be computed. Small test areas will be flown and photographed with these film-filter combinations. The resulting photographs will be interpreted by the Image Interpretation and Enhancement Unit and compared with photography obtained from previous NASA overflights.

N73-21352

Chapter 5

RIVER MEANDER STUDIES

Co-investigator: Gerald Schubert
Contributor: Richard Lingenfelter
Institute of Geophysics and Planetary Physics, Los Angeles Campus

We are undertaking a basic study of river meander patterns, the results of which, we believe, would be of benefit to hydrologic development in two specific areas. First, the study which we have outlined should result in new criteria by which the stability of a meander pattern at arbitrary discharge may be examined. Such an examination would then be used as part of the evidence in the decision as to whether existing river control systems--levees, check dams, and diversion areas--are adequate at some assumed flood stage, or whether additional control facilities must be built. It is already clear that at some flood stage, rivers produce rapid, often disastrous, alterations in their meander patterns, and it is an objective of our study to see if such alterations can be anticipated. The Feather and Colorado Rivers are appropriate for attempted application of this technique, although the initial basic study which we are undertaking may require data from an undeveloped river to avoid the additional complication which river development will add to the problem. A second anticipated benefit of our study will be in the area of preliminary regional planning.

One of the now apparent shortcomings of many previous development programs is the limited regional scale to which the preliminary studies have been applied. The trend in recent years has been toward more extensive alterations in natural river flow patterns over large areas, which may involve more than one important drainage basin. As important and expensive as the Feather River Water Project in California has become, it is dwarfed by proposals already being advanced to divert large volumes of water from the Columbia River basin to the Southwest.

It is the intent of our research to develop a relatively simple and inexpensive technique to assess the water resources of large, relatively undeveloped geographical areas in order that comprehensive water development plans may be prepared with less expenditure of money and time for the collection of data on the earth surface. We are seeking to determine whether it will be possible to extract data on the total discharge of a river, both past and present, from satellite television photography of river meander patterns. We expect also that this technique will yield indirect information on the average rainfall over large drainage basins, calculated by relating the flow measurements to the geographical areas involved.

Since most river drainage basins in the U.S. have already undergone substantial development, and since river discharge and rainfall data are reasonably reliable in this region, we expect the proposed technique to be of value largely in underdeveloped and poorly surveyed areas of the world. Data available in such areas as the United States will serve for the validation of the technique, which is our principal research task.

If the technique can be validated by our research, hydrologic data can be acquired for large regions at low cost, and a data base established to support a water management program for large, presently underdeveloped geographical areas.

5.1. SCIENTIFIC BACKGROUND

The geomorphological investigation of a possible correlation between the stream meander power spectrum and the stream discharge frequency distribution requires the accomplishment of the following tasks:

(1) Selection of appropriate rivers.

(2) Collection of suitable photographic coverage.

(3) Collection of historical streamflow data.

(4) Digitization of streamflow data.

(5) Digitization of stream meander patterns.

(6) Matching of individually digitized portions of meander patterns to obtain a continuous record.

(7) Construction of stream discharge frequency distribution from discharge data.

(8) Construction of power spectra of local river meander directions and radii of curvature.

(9) Determination of relationship of meander power spectra to discharge frequency distribution.

To date we have completed the first five of these items. The rivers were selected according to several criteria:

(1) Uniformity of geology.

(2) Length of reach with minimum spatial variation in discharge along the course.

(3) Length of reach with minimum seasonal variation in discharge.

(4) Availability of historical photographic coverage.

(5) Availability of continuous historical hydrologic data.

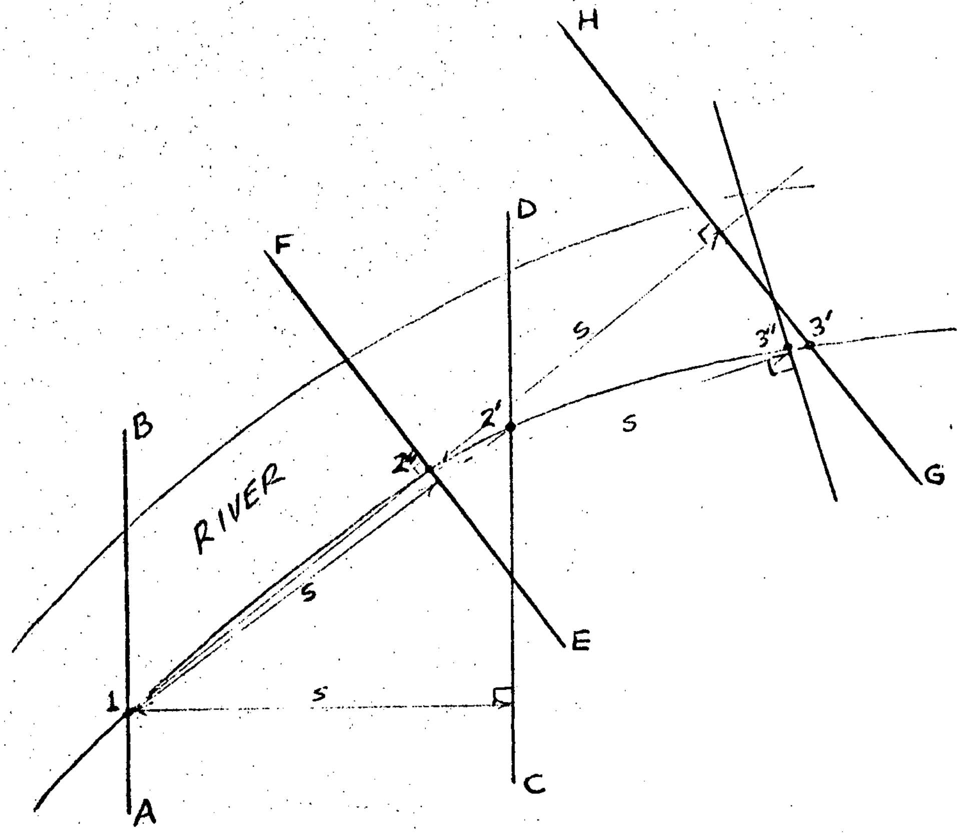
The statistical reliability of any correlation between the meander spectrum and the discharge frequency distribution depends upon the study of a large number of rivers whose discharges cover as great a range as possible. On the basis of the above criteria we have selected for study a number of rivers both inside and outside the state of California. For the initial phase of this study we are considering two rivers: a 25-mile reach of the Feather

River below the dredge tailings at Oroville to the junction of the Yuba River and a 10-mile reach of the Chippewa River below Bruce. The discharge data for the Feather River near Oroville covers the period from 1901 to the present, showing a mean annual discharge of about 6,000 cubic feet/second with flood peaks as high as 200,000 cubic feet/second. The data for the Chippewa River at Bruce covers the period from 1913 to the present, showing a mean annual discharge of about 1000 cubic feet/second with minima as low as 150 cubic feet/second. These two rivers span the range of pertinent discharges.

We have obtained aerial photographs (both infrared and panchromatic) of these and other rivers from the Agricultural Stabilization and Conservation Service of the U.S. Department of Agriculture, and Department of Water Resources of the California State Resources Agency, the Topographical Division of the U.S. Geological Survey, and the Cartographic and Audiovisual Records Dividion of the National Archives and Records Service. Historical streamflow data in machine readable format have been obtained from the Water Resources Division of the U.S. Department of the Interior.

Various digitization techniques for photographic data reduction have been investigated. We have concluded that the most accurage and economical technique is photoelectric optical scanning. The Programmable Film Reader/Recorder (PFR-3) developed by Information International Inc., Los Angeles, employes this technique and we have constructed a program for digitizing river meanders on this machine. An important condition on the digitization procedure is that we locate points at equal increments of distance along the meander curve. This condition follows from the fact that local meander direction and radius of curvature are functions of distance along the meander and the algorithms used for constructing their power spectra require that we know these quantities at equal increments of distance.

The essence of the digitization procedure is as follows(it will be helpful to refer to the sketch below during this discussion):



The initial point on the meander pattern is found by scanning along a horizontal or vertical line and measuring the density profile along the scan (line AB in the sketch). The river bank, i.e. the point digitized, is defined as the location of the point of maximum gradient in the density provile (point 1). The second point is determined by an iterative process starting with a scan (line CD) parallel to the initial scan but displaced by a distance, s, from point 1. The first estimate of this point (2') is determined in the same manner as above. The distance between points 1 and 2' is then calculated and if it is not equal to the required spacing, s, plus or minus some small Δ, another scan (line EF) is made along a line perpendicular to that line connecting points 1 and 2' at a distance s from point 1. Point 2'' is then determined along this scan. If the distance between it and point 1 is still not within s $\pm\Delta$, the iterative process is repeated until convergence is obtained. Once point 2 is located, the search for point 3 begins along scan line (GH) perpendicular to the line connecting points 1 and 2 at a distance s from point 2.

In this manner the machine proceeds along the meander curve digitizing points at equal distance increments along the curve. The whole process is then repeated for the other bank of the river.

We have prepared a short film which illustrates the digitization of an actual river meander. We propose to continue our river meander study by proceeding with items (6) - (9) as given earlier in our progress report.

N73-21353

Chapter 6

ASSESSMENT OF THE IMPACT OF THE CALIFORNIA WATER PROJECT IN THE WEST SIDE OF THE SAN JOAQUIN VALLEY

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A primary objective of the Santa Barbara portion of the project is to assess the ability of remote sensing techniques to effectively monitor, on a continuing basis, the impact of a change in the water supply of an arid area. Research of this nature involves the collection of a substantial body of information relative to both physical and biological phenomena or systems operative within the study area (see Figure 6.1). This information must be organized and correlated with remote sensing imagery so that an evaluation can be made of the capability of remote sensing systems and techniques to provide useful data.

To date, no current imagery has been received for this project and the investigators have concentrated on the accumulation of library materials, field data, and on making contacts with individuals within the study area. The work to date has generated an excellent data base and an area familiarity which will prove extremely useful in the interpretation of the remote sensing data.

As imagery becomes available, for the first annual report and in the coming year's study, we hope to extrapolate from field data to the entire study area and begin to assess the potential of the remote sensing data for general land-use mapping, as well as for special studies (e.g., the ability to detect the ef-

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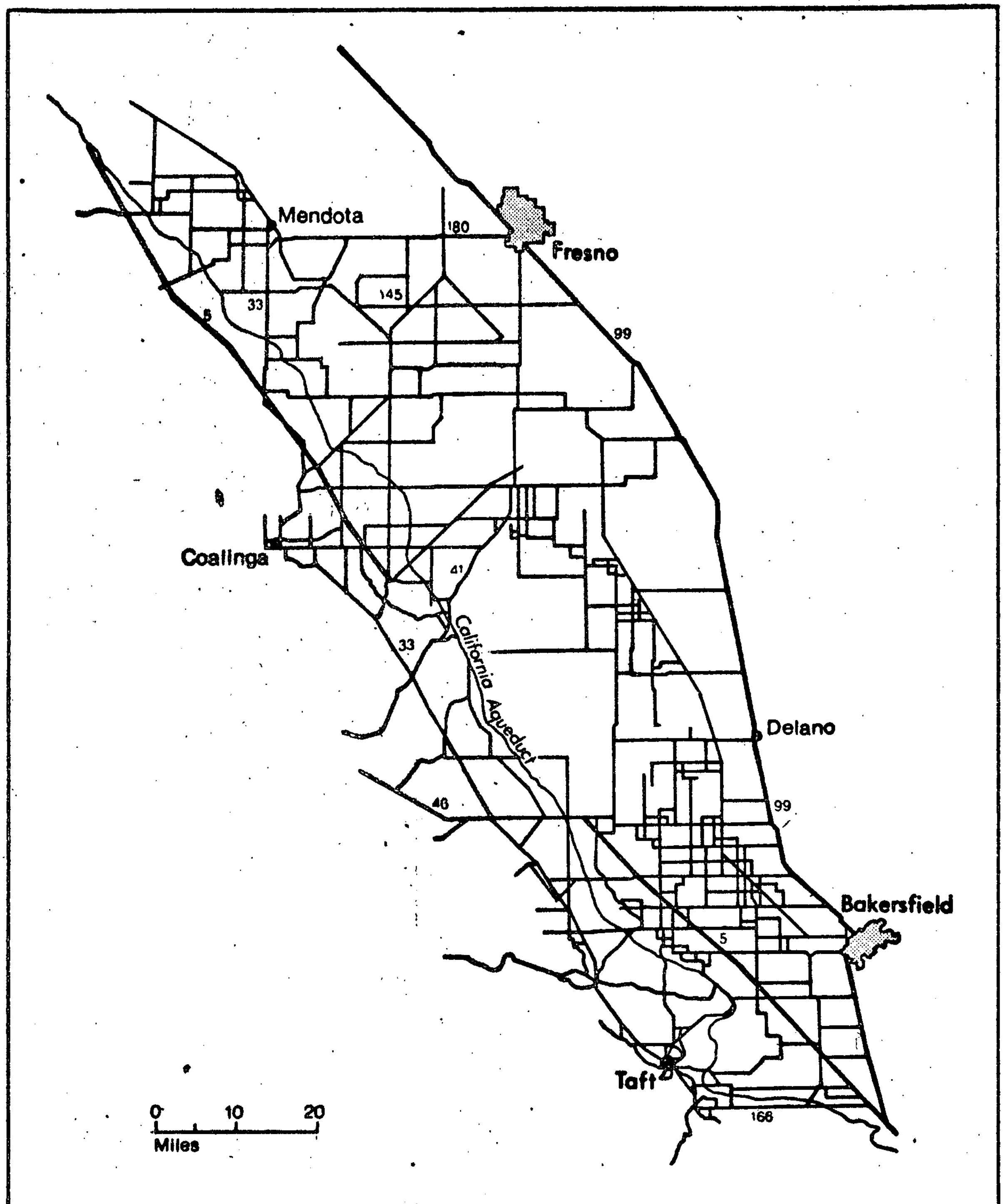

Figure 6.1. Map depicting the areal extent of the "westside" of the San Joaquin Valley.

fects of excessive boron and/or other salt concentrations on various crops). We will also conduct an agricultural inventory of the area and hope to begin to put our land-use data into a computer format with the assistance of personnel at the Forestry Remote Sensing Laboratory and at the University of California at Riverside. An assessment is also being made of the effects of new water on land tenure and urbanization and the services which the cities provide to the area.

We will also continue to interface with personnel studying socio-economic modeling from the University of California campuses at Berkeley, Los Angeles and Irvine in an attempt to determine the potential utility of remote sensing data as an input to decision-making structures. Personnel from the Santa Barbara campus will also aid and complement personnel from the University of California at Davis in their studies concerning hydrologic phenomena and image enhancement techniques and methodologies.

The following material presents the status of our investigations to date in terms of the inventory and assessment of printed materials and information gleaned as a result of field contacts and mapping. Topics which are discussed include regional transformation, agricultural practices, studies of natural vegetations, and the results of some of our field contacts. Further research in these and other areas will be discussed further in our annual progress report.

6.1. THE TEST SITE

The physical environment has historically played an influential role in the land-use development of the West Side. This section of the report includes a brief review of some of the important physical-environmental parameters in the area and temporal land-use patterns up to the time of the California Aqueduct.

Probably the single most important environmental factor influencing the development of the West Side is climate. The eastern boundary of the area lies approximately along the 300-foot contour line; the western boundary is the southern extension of the Diablo Coast Range and the eastern slopes of the Temblor Range; the southern boundary is demarcated by the northern slopes of the Tehachapi Range; the northern boundary is the approximate northwest-southeast bisector of the San Joaquin Valley. The area is dominated by air masses of oceanic origin. These air masses are modified, losing most of their maritime characteristics, by the physiography of the land extending 60-80 miles between the area and the Pacific Ocean. The West Side is on the leeward side of the California Coast Ranges and in their rain shadow. Because of this rain shadow location the area receives little of the summer rain that falls over the more eastern areas of the San Joaquin Valley in the form of occasional thunder showers. During the winter, the entire land mass receives frontal type rainfall. The annual rainfall within our West Side study area generally averages between 3 and 6 inches.

Topography of the West Side can generally be characterized as consisting of dissected uplands and low plains. The dissected uplands tend to be hilly with anticlinal ridges that are important sources of petroleum. The low plains are the result of coalescing alluvial fans and essentially form a piedmont alluvial plain which exhibits relatively gentle slopes. The majority of the area might be described as gently to moderately sloping (maximum of 20% gradient). The streams that cross the area are intermittent and only occasionally carry a substantial flow to the basins of interior drainage Buena Vista, Tulare, and Kern Lakes. Water tables have been consistently lowered since settlement of the area through use and the lack of an adequate natural capability to recharge them. The alluvial soils in the area are deep and apparently fertile, with some problems arising in specific areas due to salinity and concentrations of boron. "Natural" vegetation associations, consisting of various combinations of grasses, xerophytic shrubs, and perennials, are found in conjunction with this particular environmental complex.

This area is fairly typical of arid environments where the lack of water has placed severe constraints on human occupance patterns. The earliest known inhabitants of the West Side were Indians with a relatively low level of technology. They were able to exploit the area's environmental potential in a limited fashion through hunting and gathering activities. Population densities were low and stress on the environment was probably minimal. The Spanish arrived in the late 1700's. Despite their limited technological capacities, they turned the area into an extensive rangeland and, as is done today, grazed sheep and cattle (see Figures 6.2 and 6.3). A limited amount of irrigation agriculture was practiced, but primarily for subsistence purposes. Population densities, although still low, increased with greater stress placed on limited environmental resources.

The changeover to American dominance of the West Side, after California became a state, led to further intensification of land-uses. Grazing continued to be the principal land-use, but more acreage was put into crops (particularly wheat). The wheat was used for cattle feed and food production. Pump water irrigation systems were employed to provide water for the wheat crop.

By 1900, oil acquired value in a changing technological climate. The mineral had been known to exist in the area, but there had been no use for it in quantity. Now the picture changed, and the anticlinal hills of the West Side were drilled for their valuable product. Oil wells dotted the landscape (see Figures 6.4 and 6.5) and became the dominant economic land-use. Grazing continued as an important extensive land-use, while crop acreages stabilized or declined owing to lowering water tables and increased costs of pumping for irrigation.

This was essentially the situation up to the 1960's. The pattern of

Figure 6.2. Sheep grazing on melon stubble west of Mendota, California, September, 1970.

Figure 6.3. Cattle grazing on wheat stubble west of Mendota, California, September, 1970.

Figure 6.4. Wooden oil derricks (ca. 1920), presently unused, near McKittrick, California, taken October, 1970.

Figure 6.5. Contemporary oil mining operation south of Bakersfield. Note the California Water Project pipelines from the Tehachapi Pumping station. Taken October, 1970.

land-use continued to intensify, while population densities increased at a slower rate. Pressure on limited environmental resources increased with concurrent changes in the composition of natural vegetation associations and marked lowering of water tables. Conditions had reached the stage where further growth of the area was inhibited by the lack of a sufficient water resource.

In 1960, the California State Water Project was financially authorized to direct excess waters from the northern third of the state to southern portions. This introduced a new factor into West Side development, a substantial, although limited, new source of water supplies. An additional factor which could enhance expansion was provided by the proposed, and now actual, construction of a segment of Interstate Highway 5, connecting San Francisco and Los Angeles. The new freeway passes along the eastern portion of the West Side, providing access for the area to major urban centers on a scale never before seen there.

By 1968, water was being delivered in limited quantities to the area and considerable sections of Interstate 5 were in the process of being constructed. New lands were being brought under cultivation and formerly abandoned acreage was once more being cropped. At present an intensification of land-use, related to the new input of water from the California Aqueduct, is transforming the West Side into an irrigated agriculture landscape with far-reaching consequences affecting the lifestyle within the area. Various local and supra-local agencies, such as the West Side Coordinating Council, are attempting to supervise this new growth so that the changes will make a positive contribution to the continued development of the West Side. One of the major objectives of our efforts and those of the Berkeley Social Sciences group is to interface with these agencies, determine their information requirements, and assess the ability of remote sensing imagery to provide these data. These investigations are being conducted and will be reported on more fully in the final report and as imagery becomes available.

6.2. NATURAL VEGETATION

Based on our background research we have found that few botanical studies pertaining to natural vegetation have been made in the San Joaquin Valley. A long history of human disturbance has strongly modified natural vegetation. Two vegetation maps have been published which cover this area, the first by Piemeisel and Lawson[1] in 1937 and another by Jensen[2] in 1947. Both maps hypothesize communities as they existed before European contact. Other researchers who have used Jensen's map have shown the extent of changes owing to expansion of agricultural land-use in recent years.

In the section of the San Joaquin Valley presently under consideration, Jensen delineated only three units. The "marsh grass" form corresponds roughly to the "lowland types" mapped by Piemeisel and Lawson. Other than this the two maps show little relation. The earlier work was constructed in more detail but any one or a combination of the categories do not correspond to the broad areas used by Jensen. Neither study has provided much detail on the plant species present in their respective groupings, defined either by structural types or by a single dominant species.

A reconnaissance survey of our study area was conducted in early September, 1970. Land-use transects along major roads were made in order to obtain some concept of the extent of agricultural land-use, and of the various more natural communities. The quadrat method was used to sample those "natural"

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1. Piemeisel, R.L. and F. R. Lawson (1937), "Types of Vegetation in the San Joaquin Valley of California and Their Relation to the Beet Leafhopper," U.S. Dept. of Agric., Tech. Bull., No. 557, Washington, D.C.

2. Jensen, H.A. (1947), "A System of Classifying Vegetation in California," Calif. Fish and Game, 33:199-266.

communities which did not show signs of having been disturbed by ploughing in the last few years. It was clear that no land had escaped human modification either by grazing of domestic animals, clearing for agricultural crops or the more complex disturbance caused by oil extraction. Subsequent detailed studies of the "natural" vegetation associations of the study area will attempt to establish a classification for the nature and degree of disturbance of the plant communities. It might be necessary to distinguish between the fallow state of commercially cropped land, areas once cleared but which have had some time to become reestablished, and plant communities which have been only subjected to light grazing and are approaching natural conditions.

It was found that summer was a poor time to attempt vegetation analysis. Few species were in flower or fruit, most annuals were dead so as to defy identification and no doubt some of the more fragile forms had been destroyed altogether. More specifically, the several species of Atriplex which form the dominant shrub over much of the area were especially difficult to identify under these conditions.

In our quadrat mapping at each sample area, all species within the quadrat were noted, the percentage cover estimated, and general observations made about the structure of the vegetation and the characteristics of the soil (see Table 6.1).

Plant Communities

From the matrix indicating species found in each quadrat, it is clear that three introduced species are almost ubiquitous--two grasses, both belonging to the genus Bromus, and a weed common in disturbed places, Eremocarpus seligerus. It was observed that these species dominated the ground layer. A perennial shrub, Atriplex polycarpa, was common and frequently the only plant growing more than a few inches above the ground. A considerable number of

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Bromus 1	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Typha		X																				
Distichlis		X																				
Amaranthus		X																				
Atriplex 1		X			X																	
Frankenia		X			X				X												X	
Scirpus		X																				
Heliotropium		X																				
Rumex		X																				
Brassica 1		X																				
Compositae 1		X							X													
Compositae 2		X																				
Eremocarpus			X	X	X	X	X				X		X	X			X					X
Brassica 2			X	X					X													
Bromus 2			X	X	X		X	X	X	X	X	X		X	X	X	X	X	X	X	X	X
Poa 1				X																		
Lepidium				X		X	X					X		X					X	X	X	
Atriplex 2	X		X	X			X	X	X	X	X		X	X	X	X	X	X	X			X
Salsola					X		X	X					X	X								
Euphorbia					X	X							X									
Boraginaceae 1						X																
Astragalus						X										X						X
Brassica 3							X															
Graminae 1										X										X		
Suaeda										X		X			X					X	X	
Haplopappus										X												X
Salicornia												X			X						X	
Chrysothamnus														X								
Graminae 2															X							
Boraginaceae 2															X							
Compositae 3																X						
Erodium																		X	X			
Crypthantha																		X				
Poa 2																		X				
?																			X			X
Plantago																			X			X
Hordeum																				X	X	
Compositae 4																				X		X
Boraginaceae 3																					X	
?																					X	
Barassica 4																					X	
?																						X
Avena																						
% ground cover	95	90	95	90	85	95	95	95	75	15	95	80	65	65	40	85	75	95	65	70	80	80
% dead plants	60	0	29	70	0	0	20	13	7	20	100	80	25	17	8	24	15	17	22	0	0	57

Note: Numerals after genus names indicate number of different species observed in the field.

Table 6.1. Matrix of quadrats sampled, indicating vegetation present, percent ground cover and percent dead plants.

species encountered were only found once or twice, due in part to the small number of quadrats taken. These species could not be used to correlate with environmental parameters but may be shown to be useful indicators if a larger number of samples can be taken. This reconnaissance was able to suggest that certain plant associations are restricted to definable environments.

(1) Communities of Rolling Well Drained Sites

Atriplex polycarpa is the dominant shrub and often the only perennial species. Plants may range from only a few inches high, in areas which have presumably been cleared and regeneration limited by grazing animals (see Figure 6.6), to situations where the shrubs reach waist height and cover a large percentage of the ground area (see Figure 6.7). There is clearly great variety in the structure of this community which will most likely appear very different on aerial photographs. The ground cover for the community is high, generally greater than 80%, a fact which may aid its identification on imagery. The annual plants in this association include the species of *Bromus* which are common everywhere and *Eremocarpus seligerus* which is restricted to this community. *Salsola kali* and *Astragalus* sp. are commonly found in this community and not elsewhere. These species are typically plants of disturbed habitats suggesting perhaps the degree of human interference is greater here than in other associations. A *Brassica* sp. and an annual Composite (*Compositae* 1.) were restricted to this region and may prove useful indicators if they can be collected at a more suitable time and propertly identified.

(2) Communities of Low Lying, Saline Sites

These areas may be defined by the presence of high salinity. This may be in the form of an actual salt crust, or by the presence of large areas of bare soil which appear to be the result of salt burn. These communities have lower ground cover, often less than 60%, a fact which may be useful in defining their limits, from aerial photographs. The same *Atriplex polycarpa*

Figure 6.6. Low Atriplex polycarpa and introduced grasses on well drained soils in an area which has most likely been cleared in the past. Ground cover is almost 100%.

Figure 6.7. Tall Atriplex polycarpa in the Elk Hills oil reserve, where the natural vegetation has been largely protected from human distrubance. Here a considerable number of dead plants may be seen and the community does not appear to have been heavily grazed.

(see Figure 6.8) may be found in this association also but Salicornia subterminalis and other species (see Figure 6.9) give the community a distinctive aspect. Although structurally similar the brighter green of Salicornia is easily distinguished from the grey-white of Atriplex. It is likely that the areas of internal drainage may be distinct on air photographs if they are taken as the soil of better drained regions begins to dry out.

Although there appears to be no distinctive annual species restricted to this association, the number of samples is too low to draw any definitive conclusions. It is, however, interesting to note the absence of Salsola kali, Eremocarpus seligerus and the Astragalus sp., which are often indicators of disturbance. It may be that these saline areas (because of their unsuitable soil) have suffered less human disturbance and conditions more closely approximate the natural state in this community. Quadrat 2 may be an exception to this. Located in the bed of Tulare Lake, water was clearly more available here than elsewhere. Here there was evidence of recent disturbance related to channel and embankment construction. This may account for the large proportion of species not found in other areas. The small number of samples taken in this community prevents any conclusions being made concerning the diversity. Transects from well-drained areas running towards the center of the region of internal drainage may well reveal species associated with various salt concentrations in the soil.

Soil

Only the most preliminary observations were made concerning the characteristics of the soil. The texture of the A horizon varied from gravel and coarse sand to fine clays and was characteristically grey in color. Variations did not seem to have much effect on the vegetation association. Salt was occasionally evident but clearly some more precise method is necessary to

Figure 6.8. Medium height Atriplex polycarpa on well drained soils.

Figure 6.9. Atriplex polycarpa, Salicornia subterminalis and Suaeda sp. growing in an area of internal drainage. Plants are growing on higher areas raised above the bare salt-burned patches.

Figure 6.10. Atriplex polycarpa and Salicornia subterminalis community of low lying areas where soil has soft, spongy mounds bare of plants.

determine the nature and concentration of soluble salts. Low-lying regions were occasionally observed to have areas of fine spongey sections raised above the general level of the ground (see Figure 6.10). This unusual phenomenon merits further investigation.

Health and Regeneration of Perennial Species

In certain sites it was found that a large percentage of the perennial species were dead. These dried woody branches were presumably the same species of Atriplex and were scattered through the community and not concentrated in patches. The matrix shows that not all sample areas contained dead plants and the proportion of dead to live plants was variable. Seedlings were found in areas recently disturbed so the species seems to be capable of regeneration after the land has been cleared. Grazing pressure from cattle may keep the shrubs low, as in Figure 6.10, but they alone are not responsible for the dying plants, as the condition was found where cattle were not grazed and where there was no sign of animal browsing on healthy plants.

The dead plants may be the result of severe drought in the past and in these dry conditions it takes a long time for plant material to decay. Further investigation will be conducted to determine whether the dead shrubs are the result of forces no longer acting or whether the process is continuing and even threatening the perennial vegetation. Once imagery of the area has been obtained, a selective vegetation map will be prepared and attempts made to correlate specialized vegetative communities with particular soil conditions.

6.3. REGIONAL TRANSFORMATION

From our investigations to date it is evident that the transportation of large quantities of good quality water to the arid West Side is resulting in a significant transformation of the region. The detection and identification of

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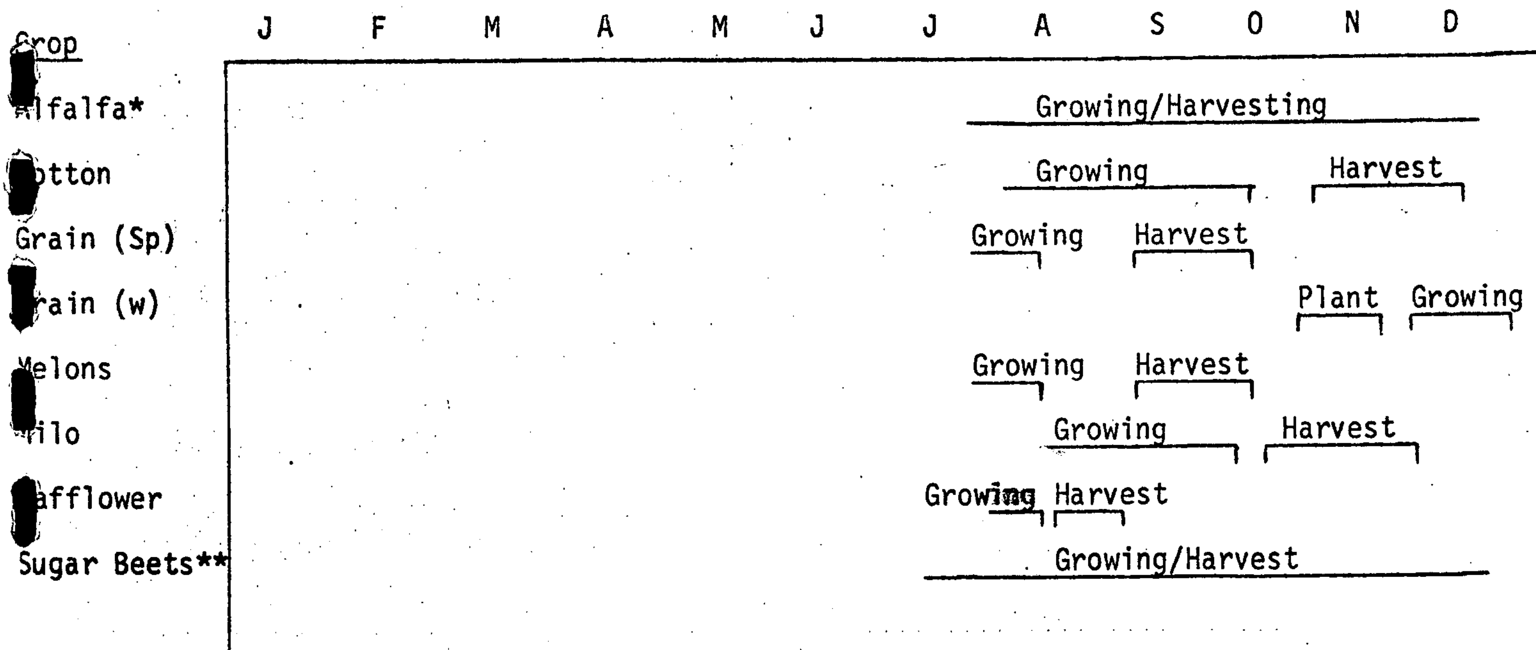
such changes may be accomplished by the compilation of sequential land-use maps. The pattern of land-use of a region tells a great deal about the characteristics of the area. The potentials of remote sensing data, specifically simulated space photography, for detecting land-use patterns on the West Side are being investigated. At present, since no imagery has been received, maps depicting past land-use patterns are being compiled using United States Geological Survey photo indices for 1957 and 1967. In addition, we are developing a current reconnaissance land-use map from transect observations. In time, as imagery is received, this map of a portion of the study area will play an important role in the overall mapping of the West Side. Comparison will also be made of the methods of constructing land-use maps from imagery alone, from field observation alone, and from a combination of field and image interpretation.

The most apparent of the recent changes which have occurred in the study area relate to agricultural land-use. Therefore, our land-use studies have mainly been oriented toward the variations and changes in agricultural production within the study area. Forthcoming remote sensing imagery, as well as data collected on the ground during field investigations will be used to assess our capability to detect and quantify changes in agricultural practices and cropping patterns. The determination of which crops are cultivated and what agricultural practices are being employed forms the basis for the ground truth investigation currently being conducted. A crop calendar has been initiated and four months of data have been gathered. These data are presented in the following graph (see Figure 6.11).

It is our intention to produce a calendar which follows the cropping patterns in the study area for two to three years. Because a great deal of experimentation is being conducted in this area, a crop calendar which includes more than a single year will aid in the detection and documentation of the

CROP CALENDAR

West Side San Joaquin Valley August - December 1970



*Alfalfa may be grown for two purposes. If for hay, it is grown for about 2 months and mown, then allowed to grow up again. If for seed, it is planted in rows and grown for about 4 months, harvested and replanted. Both continue throughout the year.

**Sugar Beets may be planted at any time, yielding 2 crops per year, thus there is no strict seasonal limit.

Figure 6.11. The initial field investigation occurred in August 1970. The segments represent spans of time in which certain activity occurred, and were observed by the investigators.

developmental evolution of the cropping pattern of the area. Such a calendar will not only reflect crop progress, but would also indicate any systems of crop rotation coming into existence. As previously stated, cropping patterns on the West Side are, on the whole, experimental at present. This experimentation constitutes an attempt to determine what crops and cropping patterns are the most cost effective from the marketing standpoint for this area. Valuable information about the potential for further development of this region and other analogous areas may be gained by monitoring these "experiments."

In cooperation with the Belridge Land Company, a subsidiary of the Belridge Oil Company, a crop calendar for a portion of the agricultural lands operated by them has been compiled (see Appendix I). This calendar covers a three-year period. While this information is useful, it represents the pattern of crop rotation for only a limited portion of the total acreage of the study area. Only after comparisons with similar data from other land holdings on the West Side under different kinds of management may some general conclusions be drawn for the entire study area. Nevertheless, these Belridge data constitute an important beginning and one which may prove valuable in the long run.

Based on our field research to date for the rest of the West Side, our data indicates that after the fall harvests, nearly all land remains fallow until at least the middle of January.

6.4. IRRIGATION PRACTICES

In our field research we have observed a variety of irrigation practices throughout the West Side. In the Mendota area, the northern section of the West Side with a long history of irrigated agriculture, row flooding (see Figure 6.12) and stationary line sprinklers (see Figure 6.13) are the most widely used systems. In the southern West Side from Taft northward to Lost Hills, more complex sprinkler systems seem to be in much greater use. Many field and

Figure 6.12. Row flooding irrigation of young Broccoli west of Mendota, California, September, 1970.

Figure 6.13. Stationary line sprinklers irrigating young winter Barley, south of Mendota, California, November, 1970.

Figure 6.14. Circular field rotating irrigation system on Belridge Farms, near Lost Hills, California, October, 1970.

truck crops are irrigated by center pivot (circular) sprinkler systems (see Figure 6.14) and linear moving sprinkler systems (Figures 6.15 and 6.16), while one relatively new peach orchard was being irrigated utilizing a garden hose sprinkler-type system (see Figure 6.17).

Through the cooperation of the Belridge Land Company, it was learned that the more complex irrigation systems are in the experimental stages with investigative emphasis on the correlation of water volume use and drainage with specific crop types. Our investigation will continue to monitor any changes that may occur in the irrigation practices used for a specific crop type. Attention will be paid to the correlation between crop type and particular irrigation systems utilized. An understanding of the various irrigation systems and their relation to landscape characteristics and seasonal utilization may prove useful in identifying crop types and crop patterns from high altitude photography.

6.5. INVESTIGATION OF LAND TENURE AND URBAN CHANGE

An important factor in determining the specific land-use of a given area is the patterns of land tenure. Large and small farms, owned and leased farms, may exhibit dissimilar practices and have a varied impact on landscape. Large land holdings are being investigated as well as individual farms and small holdings. The land which receives water from the Federal Central Valley Project (north of Kettleman City) will fall within acreage limitations. This may result in changes in land tenure in the future. Leasing of relatively small parcels of land may have a significant effect upon the developing agricultural pattern.

With the large increase in crop acreage, the question of processing and marketing arises. The possibility of new or significantly expanding urban areas on the West Side to solve this problem seems remote. Most discussions

Figure 6.15. Linear moving sprinkler system on sugar beets on Belridge Farms near Lost Hills, California, October, 1970.

Figure 6.16. Linear moving sprinkler in field preparation for winter Barley, Belridge Farms, near Lost Hills, California, October, 1970.

Figure 6.17. Garden hose irrigation of young peaches on Belridge Farms near Lost Hills, California, October, 1970.

(e.g., with Belridge Land Company and University of California Agricultural Experiment Station Supervisors) have revealed that farmers who expand to the West Side will probably continue to utilize already existing market facilities on the East Side. However, the centers which are expected to be influenced the greatest are Huron, Five Points and Mendota. Changes in these centers will be monitored and the relationship of these changes to the development of the study area will be considered throughout the remainder of the study.

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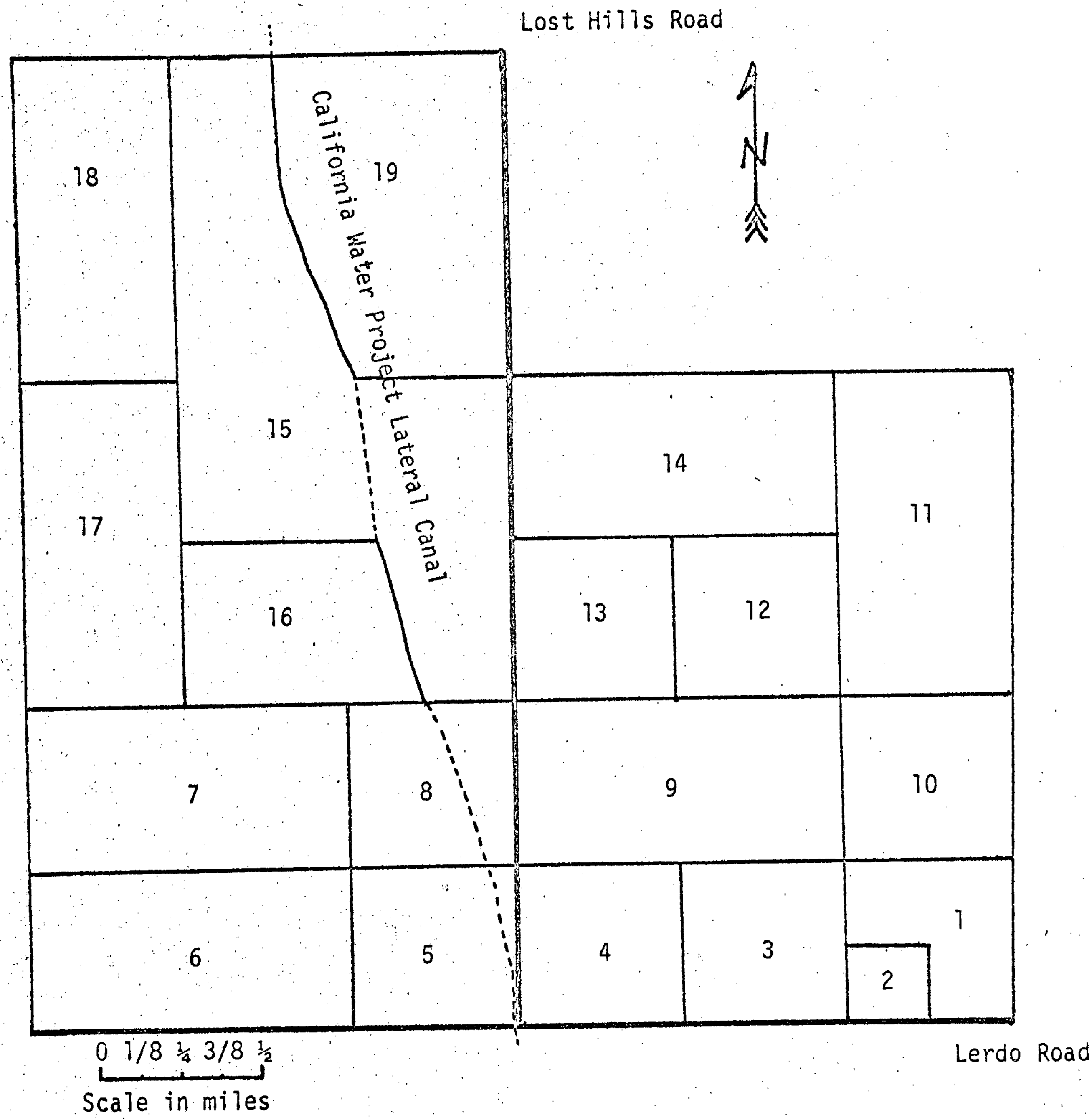
6.7. APPENDIX

This appendix contains a crop calendar and crop rotation patterns obtained through the cooperation of Belridge Land Company. The investigators would especially like to thank Mr. Jim Ryan, Superintendent of the Belridge Ranch. As noted previously, the data represents only a portion of the land under Belridge management.

Milo is used as a beginning crop because it is highly tolerant of excess salt and boron in the soil, and it is easy and inexpensive to cultivate and may be plowed back under to refurbish the soil. It is followed by various combinations of truck crops, grains and alfalfa.



Holdings of Belridge Land Company, near Lost Hills, California. Information concerning the cropping patterns over a three year period for those fields was supplied by Belridge farms.

SYMBOLS USED IN RECORDING THE PROGRESSION AND FIELD CHANGES WITHIN THE WEST SIDE SAN JOAQUIN VALLEY TEST SITES

<u>Crop Types</u>

A	Alfalfa
B	Barley
BP	Bell Peppers
C	Cotton
Ca	Cantaloupes
Ct	Carrots
Hy	Honeydew Melons
L	Lettuce
M	Mustard
N	Natural Vegetation (Uncultivated)
O	Onions
P	Pasture
Po	Potatoes
R	Rye
RP	Red Peppers
S	Sorghum
SB	Sugar Beets
Sf	Safflower
SFt	Salt Flat
T	Tomatoes
Wh	Wheat
WM	Watermelon
N.C.	No change in crop types or field condition

BS	Bare Soil (plowed or minimum plant cover)
C	Cut
D	Dry
F	Flowering
H	Harvested
M	Mature
R	Redivided
S	Sparce
VY	Very Young (seedling)
Y	Young (immature)
W	Weeds

 Photography taken, view angle and #

B

Field	Spring 68	Summer 68	Fall 68	Winter 68	Spring 69	Summer 69	Fall 69	Winter 69	Spring 70	Summer 70	Fall 70	Winter 70
1	F	F	F	F	Milo	Milo	Milo/F	F	Lettuce	L	F	
2	F	F	F	F	Milo	Milo	Milo/F	F	BP	BP	F	
3	Milo	Milo	Pot	Pot	Pot/F	F	F	F	SB	SB	SB	F
4	F	F	F	F	Milo	Milo	Milo/F	F	SB	SB	SB	F
5	F	F	F	F	Milo	Milo	Milo/F	F	Ca	Ca	Ca/F	F
6	F	F	F	F	Milo	Milo	Milo/F	WH	WH	F	Po	Po
7	F	F	F	F	Milo	Milo	Milo/F	F	A(Hay)	A	A	A
8	F	F	F	F	Milo	Milo	Milo/F	F	F	0	0	F
9	Milo	Milo	Milo/F	WH	WH	B.B.	B.B.	Ba.	Ba	Ba/F	F	
10	F	F	Pot	Pot	Pot/F	Ct	Ct	F	F	F	Pot	Pot
11	F	F	F	F	Milo	Milo	Milo/F	F	SB	SB	SB	
12	Milo	Milo	Milo/F	F	0	0	F	WH	WH	WH/A	A	A
13	Milo	Milo	Milo/F	F	Milo	Milo	Milo/F	F	A/Seed	A/S	A/S	A/S *
14	Milo	Milo	Milo/F	F	A/Seed	A/S	A/S	A/S	A/S	A/S	A/S	A/S **
15	N	N	N	N	N	N	N	N	N	N	N	N ***
16	F	F	F	F	Milo	Milo	Milo/F	F	Wm	Wm	Wm/F	F
17	F	F	F	F	Milo	Milo	Milo/F	F	Ca	Ca	Ca/F	F
18	Milo	Milo	Milo/F	WH	WH	WH/F	F	WH	WH	WH/Ct	Ct	Ct/F
19	F	F	F		F	F	F	F	SB	SB	SB/F	F

* To continue to 3 years.

** Total to be 3 years in A/S.

*** Not cultivated.

Crop Calendar of portion of land under Belridge Land Company
by numbered field (see map) during period Spring 1968 to Winter 1970

CROP ROTATION PATTERNS
BELRIDGE LAND COMPANY
SPRING 1968 - WINTER 1970

Break-in Crop - Milo

Milo----- Fallow----- Sugar Beets--- Fallow

Milo----- Fallow----- Lettuce------- Fallow

Milo----- Potatoes--- Fallow-------- Sugar Beets

Milo----- Fallow----- Bell Peppers-- Fallow

Milo----- Fallow----- Cantaloupe---- Fallow

Milo----- Fallow----- Wheat (w)----- Fallow----- Potatoes

Milo----- Fallow----- Alfalfa (hay)

Milo----- Fallow----- Onions-------- Fallow

Milo----- Fallow----- Wheat (w)----- Blackeyed-- Barley------- Fallow
Peas

Milo----- Fallow----- Onions-------- Fallow----- Wheat-------- Alfalfa (s)

Milo----- Alfalfa (s) (3 yrs)

Milo----- Fallow----- Watermelons--- Fallow

Milo------Fallow----- Wheat (w)----- Fallow----- Wheat (w)---- Carrots----- Fallow

---

Break-in Crop - Potatoes

Potatoes- Fallow----- Carrots------- Fallow----- Potatoes

Break-in Crop - Sugar Beets

Sugar---- Fallow
Beets

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Chapter 7

ASSESSMENT OF THE IMPACT OF THE CALIFORNIA WATER PROJECT IN SOUTHERN CALIFORNIA

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7.1 THE NATURE OF RESEARCH STUDIES PERFORMED ON THIS PROJECT AT RIVERSIDE

Research efforts at the University of California, Riverside are directed toward the inventory, monitoring, and analysis of the landscape in selected areas to be serviced, and affected, by the impending California State Water Project. Further objectives of this research effort is the application of aircraft and satellite remotely sensed imagery to these studies. While all of Southern California may be subject to analysis as a California State Water Project service area, the first year's study has been confined to investigations in two specific regions: (1) the Perris Valley surrounding the future Lake Perris; and (2) the Sheep Creek Fan-Mirage Basin area of the Mojave Desert. As the California State Water Project progresses and enters operation, it is suggested that changes in land use which may be monitored and analyzed by remote sensing techniques will follow suit. Progress in each of these areas of research and automated mapping techniques to monitor these changes is presented in the following sections.

7.2 BRIEF REVIEW AND SYNOPSIS OF THE CALIFORNIA STATE WATER PROJECT

The California Water Project is the first major water resource development under the California Water Plan. The masterplan was published by the Department of Water Resources (Bulletin 3) and approved by the State Legislature in 1959. It is the outgrowth of studies in the 1950's of the ultimate potential land use and the water resources of the state as per Bulletins 1 and 2 of the DWR.

The state Water Project will deliver 4,320,000 acre feet of water annually to Central and Southern California. The major supply of water comes from the Feather River and is impounded by the Oroville Dam for subsequent release through the Sacramento River and the Delta pool to pumps on the south side of the Delta. Water is pump lifted to the South Bay Aqueduct and the California Aqueduct (244 feet).

The California Aqueduct, which will deliver the water to Southern California, carries the flow to the joint federal-state utility, San Luis Reservoir, the second major storage reservoir of the Project. Deliveries are made from the San Luis Reservoir to the federal Central Valley Project in the California Aqueduct for delivery to the southern San Joaquin Valley and Southern California. At the south end of the Central Valley, Project water is pump lifted nearly two thousand feet through the Tehachapi Mountains. South of the Tehachapi's the system divides into a West Branch for delivery to the MWD and a number of smaller contractors and an East Branch for delivery to Antelope Valley-Mojave Desert water agencies and the balance of the MWD committments. The terminal reservoirs for the project are Castaic in the West and Lake Perris in the southeast. The Project is the largest single water resource development undertaken in the United States. In addition to the transfer of 4,230,000 acre feet annually through 684 miles of aqueducts it provides a storage capacity of nearly 7 million acre feet. The project facilities will generate 5.3 million kilo-watt hours of electricity annually and consume 13.4 million kilo-watt hours annually at full development.

A number of essential features of the California Water Project are still in various stages of study and litigation. Future water supplies to augment the California Aqueduct and the Delta Pool may be needed before the project can operate at full capacity. A Peripheral Canal around the Delta has been proposed protect the ecology of the San Francisco Bay and Delta areas as well as to provide for an adequate flow of fresh water. The Central Valley Master Drain to prevent soil salts from accumulating is still in abeyance until agreement is reached on repayment of its cost.

In total, the State Water Project is over 95% completed or under construction. As of late 1969 it was operational to northern Kern County. The tunnels through the Tehachapi Mountains are completed and construction on the pumping plants is nearly completed. The aqueducts of both the West and East Branches of the system are under construction as well as the four major reservoirs, Pyramid Lake, Castaic Lake, Silverwood Lake and Lake Perris.

The DWR expects to begin dead storage of water in Castaic Lake in June next year, looking toward water delivery in December 1971. This anticipated delivery of water to Los Angeles County will be followed by delivery of water to both San Bernardino and Riverside Counties in the first months of 1972.

Water deliveries from Castaic Lake will be made to three water contractors. The principal user, Metropolitan Water District of Southern California, will receive more than 1.4 million acre feet per year from that facility after 1990.

Water delivery at the Devil Canyon Powerplant near San Bernardino will include service to all the San Bernardino-Riverside area. When the terminus reservoir, Lake Perris, is completed, it will serve this area as well as the extensive water market which includes San Diego and Orange Counties. Water delivery from the Perris Reservoir is expected in the early months of 1973.

Financing for the State Water Project has been a problem area almost from its inception. At the time of its authorization in 1960 the cost was estimated at 1.75 billion dollars. Today the conservative costs estimates of the DWR amount to 2.8 billion dollars, while more liberal estimates project a cost of 4.0 billion dollars. Project customers will repay those amounts allocated to water supply, hydroelectric power and agricultural waste water disposal amounting to 90%. The remaining 10% will be repaid by federal flood control funds and state tideland oil and gas revenues.

The California Water Project is only one of a number of large inputs into the Southern Coastal Hydrographic Unit. The local safe yield supplies and the imported water from Owens Valley and the Colorado River exceed the projected import of Project waters. The problems associated with water resources and water importation are numerous. The Project will alleviate such situations as sporadic water runoff, maldistribution of water supply, ground water overdraft and the intrusion of sea water. On the other hand, it raises and contributes to still other problems such as inadequate drainage, disputed water rights, water pricing policies of agencies such as the MWD and the general efficacy of water redistribution and the efficiency of water use.

7.3 LAKE PERRIS STUDY AREA

7.3.1 Introduction

Personnel at the University of California, Riverside are studying the present and future land use of the terminal area of the California Water Project. This area includes Lake Perris, which is presently under construction, and the surrounding Perris Valley, shown on Map 7.1. Of primary concern in this study are the effects of the California State Water Project -- the importation of Feather River water and the creation of a terminal reservoir and recreation facility -- in terms of future land use and development of the surrounding Perris Valley.

To date the study has taken three approaches. (1) A land use survey has begun in a sample study area using both ground observations and interpretation of high altitude color infrared photography; the sample area is nearing completion (scheduled for February 1, 1971), and the completion of the present

Map 7.1. The future location of Lake Perris is shown on this map of the Perris Valley and surrounding areas. (Source: USGS)

land use survey in the Perris Valley is scheduled for May 1, 1971, pending availability of suitable aerial photography. (2) A cursory survey of residential attitudes towards Lake Perris and personally postulated land use changes resulting therefore has been conducted. Reported and preliminary results are contained herein and suggest the need for expanded investigation in the coming months. Finally, (3) estimates of potential population, development and expansion, and/or land value increases resulting from the creation of Lake Perris have been carried out using conductive sheet analog models and preliminary results are reported herein. Future simulations will add greater realism to the models and similar experiments and should provide valuable insights to social, economic, and land use planning problems to the areas of interest.

7.3.2 Perris Valley Land Use

The land use survey in the Perris Valley has been confined to a sample area of one census tract, number 426, located centrally to Perris Valley and adjacent to the future Lake Perris. Because we were unable to secure NASA assistance in obtaining photography of the study area under the present research program, we were required to rely on other photography through local sources and supported by sources other than the present funding. The photography consisted of high altitude (1:50,000 and 1:100,000) color infrared metric imagery flown in May 1970 (see Figure 7.1). Availability of the photography was a determining factor in the selection of the sample area, i.e., census tract 426. Therefore, only about 20% of the Perris Valley area is being sampled. Additional photography, regardless of source, should be obtained immediately so the Perris Valley land use survey may remain within the present project goals of utilizing and evaluating remote sensing techniques for studying California resources.

The study area is largely agricultural in land use and contains all or portions of three important agricultural producing areas in Riverside County:

Figure 7.1. Black and white uncontrolled mosaic made from 1:50,000 metric color infrared photography obtained over the Perris Valley in May, 1970. March AFB is shown at center left and part of the future area of Lake Perris is at center right.

Hemet, Perris-Elsinore, and Moreno. In 1970 these three areas produced in excess of $26.4 million in agricultural crops. Leading crops in each producing area were: Hemet - potatoes, grapefruit, and alfalfa; Perris-Elsinore - potatoes, alfalfa, sugar beets, and onions; and Moreno - carrots, navel oranges, and grapefruit.

Census tract 426 was chosen as the sample area to discern what percentage of the land immediately surrounding Lake Perris is being dry farmed, irrigated, or left fallow (unused). The total area was 29.81 square miles or 19,081.11 acres which is included in the area delineated on Map 7.1. Land use survey is being accomplished by field observations and interpretations of aerial photography.

Preliminary estimates indicate a total of 7,319.4 acres, or 38.4% of the total area is irrigated in census tract 426. Irrigation is either by furrow irrigating or by the use of portable aluminum sprinklers, the latter predominating. In general, most irrigation takes place away from the hill areas and towards the western section of the census tract. Water sources are either private wells or MWD (Metropolitan Water District) water (which one farmer has complained to be overly saline). Crops commonly grown are onions, carrots, melons, and legumes, the last to be used for adjoining horse farms.

Approximately 9,637.04 acres or 50.5% of the area of census tract 426 is estimated (preliminary) to be dry farmed. This essentially constitutes land flanking the Bernasconi Hills and Russell Mountains (see Map 7.1). Crops commonly dry farmed in this area are wheat and barley.

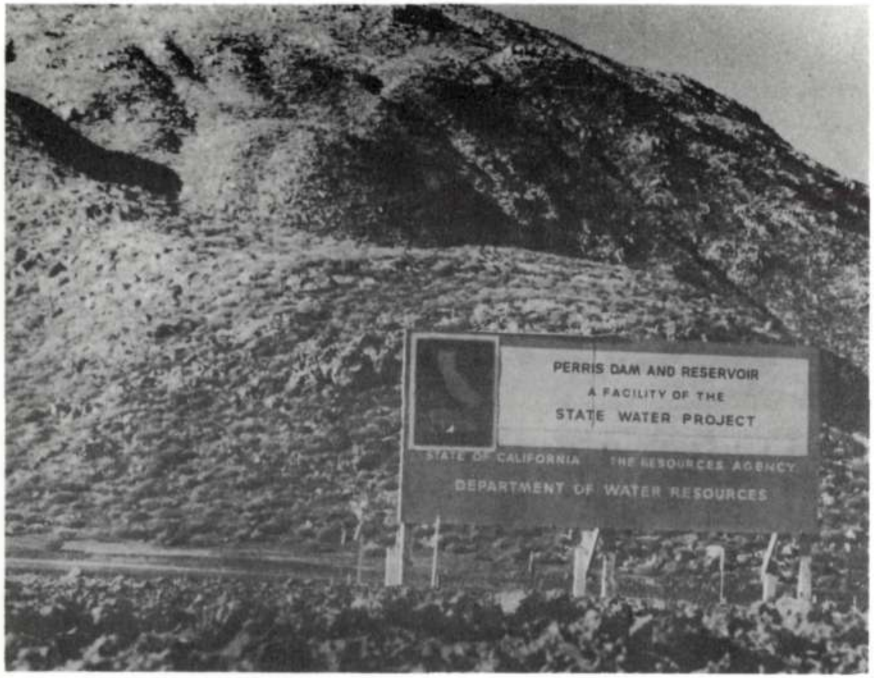
Some 2,124.65 acres or 11.1% of the census tract sample may be classified as "presently unused" in the preliminary analysis. This classification refers to land not planted to a specific crop, but regularly harrowed over and left fallow. The unused land found, largely along Perris Boulevard, appears not to have been used for some time. It is typified by an overgrowth of volunteer vegetation, or weeds, especially tumble weeds (Russian thistle).

In considering the potential for future land around Lake Perris, it is suspected that specific agricultural crops or seasonal agricultural changes do not indicate the long term significance of more important land use changes which indicate either capital investment in the land or changes in economic activity on the land. Examples of change would include non-irrigated land to irrigated land, or the manifestation of a land speculators' market with the accompanying subdivision of land for non-agricultural purposes -- fallow land being only an interim in the process of continuation. In recent months land developers have established a number of locations for the promotion of present agricultural land for non-agricultural purposes and at non-agricultural prices (Figure 7.2 through 7.7), an activity directly related to recreation and development potentials created by the future Lake Perris. It appears that land developers and speculators perform a significant role in future land use developments in the Perris Valley, including immediate changes in the region's land use patterns and activities. In addition to the completion of the present land use survey of Perris Valley, coincident analysis will attempt to survey the role and activities of land developers and concurrent economic change towards future land use patterns. Land taxation has not yet played a significant role in changes projected for the Perris Valley.

7.3.3 Questionnaire Survey

Concurrent to the preliminary land use survey, a questionnaire was distributed. Attempts were made to assess by limited sample how people (who would be most affected by Lake Perris) felt about the California State Water Project. The western half of census tract 426 excludes any towns or urban-like developments. It was concluded the situation was good because the area contains persons actually working the land around Lake Perris and who will feel the

Figures 7.2 through 7.5. These photographs of the area surrounding Lake Perris were taken in January, 1971. They reflect the tremendous change in land use emphasis from agricultural to urban-like subdivisions. Figure 7.2 (top left) shows a real estate office located immediately in front of future Lake Perris, at the intersection of Perris Blvd. and Martin Expressway. Stanifer Realtors are active throughout the Lake Perris area and signs, such as the one in Figure 7.3 (top right) along the southeast flank of the Bernasconi Hills, are commonplace. Figures 7.4 (bottom left) and 7.5 (bottom right) show evidence of land for sale by private owners; in Figure 7.4, rich agricultural land west of the proposed dam location, and in Figure 7.5, poor rocky land on the east slope of the Bernasconi Hills.



Figures 7.6 and 7.7. Figure 7.6 (left) shows the only progress to date in construction of Lake Perris although operations were scheduled to begin last Fall. Contractors began moving on-site during the first week of 1971. The sign is located at the eastern entrance to Lake Perris. Figure 7.7 (right) is a view looking west across the future site of Lake Perris. "Allessandro Island" is visible in the center and the Bernasconi Hills are to the left.

impact of its creation. A total of fifty questionnaires were distributed -- a convenient but arbitrary number and one designed to contact most involved people about the above objectives and effects. To the best of our knowledge, the questionnaire was not distributed to persons who were laborers or merely home owners; the main occupations of those chosen were farming (dry and irrigated), horse ranching, and poultry raising -- those most affected by land prices, property assessment and taxes with the ensuing creation of Lake Perris. The consequences of these probable developments in terms of potential population growth, industrial developments and recreational activities were of prime concern.

Forty-six percent of the questionnaires were returned by mail. The questionnaires were manually distributed and the interviewers personally talked to the local residents in order to interest them in the fulfillment of the survey. The results seem to represent the attitudes of residents in the surveyed area. The questionnaire, and results, are presented in Table 7.1. (Note: sums do not necessarily equal 100% due to normal rounding procedures.)

7.3.4 <u>Survey Analysis</u>

Of the 23 responses, 48% indicated that they rent, 39% own, and 8% both own and rent. The average length of residence for both renters and owners is about ten years, though the range is from one to forty-six years.

In question 3, "Do you support the California State Water Project (Feather River Project)?", the response was 78% "yes", 22% "no". Though it may not have any significance, the 22% who answered "no" all rented. Only 36% of the renters favored the project; all owners favored it. Owners feel they stand to gain in terms of economics. Land prices in the last year have more than doubled and no doubt property taxes will follow suit. The renters' only hope is for cheaper water either from the MWD or through the refilling of their wells by

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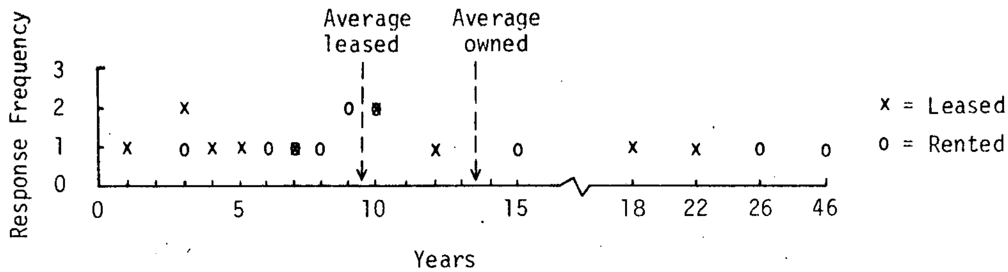
TABLE 7.1

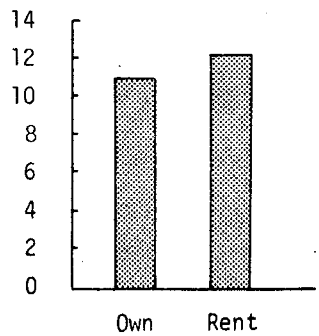
RESULTS OF QUESTIONNAIRE: PERRIS VALLEY

QUESTIONNAIRE

1. How long have you lived in this area?



2. Do you own or rent the property you are now farming?



	% Yes	% No	% No Response
3. Do you support the California State Water Project (Feather River Project)?	78%	21%	0
4. Do you think the population of the area will grow due to Lake Perris?	95%	4%	0
5. If the population of the area grows, do you think industry will expand?	69%	26%	4%
6. If the population of the area grows, do you feel air and land pollution will increase?	86%	13%	0
7. Do you favor industry in the area?	47%	43%	8%
8. If the population and industry grow, would you move from the area?	60%	30%	8%
9. Do you think that Lake Perris should be used for recreation?	91%	8%	0
10. Do you think the money brought in by tourists will benefit the area?	78%	13%	8%
11. If you dry farm, would you change to irrigation if Lake Perris water rates were reasonable?	47%	21%	30%
12. Would the population growth increase the market for your products?	34%	47%	17%

ground water percolation from Lake Perris. Interestingly enough though, the 22% who responded "no" said they would not use water from Lake Perris (see Question 11). All the owners who answered question 11, "If you dry farm, would you change to irrigation if Lake Perris water rates were reasonable?", said they would use the water.

All but 4% felt that the population will increase because of the lake. Only 26% did not feel that industry would expand into this area, but there was a definite split in feelings as to whether this was good or bad. Forty-seven percent favored industry, 43% did not, 8% did not respond. Eighty-six percent of the people responding, despite their feelings on questions 3, 4 and 5, felt more environmental pollution was inevitable with the presence of Lake Perris in the near future.

Sixty percent wanted to move if population and industry grew, 30% did not, 8% did not respond. Of the 30% who would not move, 85% were owners. The 8% who did not respond wrote in "undecided".

Only one person felt Lake Perris should not be used for recreation; 78% felt money brought by the tourists would benefit the area, 13% did not, 8% did not respond.

For question 12, "Would the population growth increase the market for your products?", 47% did not think the growth of this area would expand the market for their products, 34% felt it would, 17% did not respond.

7.3.5 Conclusions of Questionnaire Survey

There are several conclusions that can be drawn regarding the responses and the worthiness of the questionnaire and sampling technique in the present study. The responses have shown that most of the people favor the project, they feel the area will grow, yet a good many of them will move because of this. It is a bit of a paradox, but perhaps one explanation is that the people really cannot comprehend what the coming of Lake Perris implies for the future development of the area. Or perhaps, if they are owners, they may be in the position to reap a small fortune because of rapidly increasing land prices.

The questionnaire was not perfect. Perhaps one of the reasons some questions were left blank is that several were vague and difficult to interpret. For instance, in question 5, "If the population of the area grows, do you think industry will expand?", what do these people consider "industry"? Probably they think of heavy industry, such as steel production, whereas one might also think more of "light industry" such as trailer fabrication, or the manufacture of precision instruments. In question 10, "Do you think the money brought in by tourists will benefit the area?", there was very probably doubt concerning the meaning of tourist money benefiting the area. It is fairly clear if one sells liquor, groceries, or gasoline, but if one is a farmer, the benefit is very indirect, if a benefit at all. Also, question 12, "Would the population growth increase the market for your products?", seems to be related to question 11 exclusively. However, this excludes poultry farmers, horse ranchers, and farmers who have irrigated crops.

There are other drawbacks to this questionnaire, of course, but it apparently had appeal to those who answered it. It was short and fairly simple and gave them a chance to express their feelings. In addition to the questions posed, the questionnaire encouraged each participant to express and expand his personal feelings about the impact of the California State Water Project upon the future economy and land use of the Perris Valley. None of the people had ever been asked their opinion of Lake Perris or the California State Water Project in any official or semi-official manner. The responses, regardless of content, were encouraging. The sample survey has accomplished enough response to indicate a need and worthiness in expanding the distribution of a revised survey which is planned to accompany the completion of the present land use survey of the Perris Valley in coming months.

7.3.6 Hardware Integration

To date, the primary technical accomplishment in the study of Lake Perris has been the integration of the Hewlett-Packard Calculator and Plotter, the Dell Foster Digitizer, and the IBM keypunch for the survey and mapping of present land use. A program has been developed such that all photography can be rectified to a planimetric base. This program can be used to draw a given polygon and/or calculate the acreage of that given polygon. The result has been to tremendously expedite land use survey and mapping. Further discussion of this system is found in Section 7.5 of the present report.

7.3.7 Analog Simulation Models

Preliminary techniques for analyzing population potential, capitol development expansions, and increasing land values resulting from the creation of Lake Perris have recently been considered using conductive sheet analog models. Analog simulations were accomplished on an ISI Field Plotter using multiple electrical current inputs representing population centers with data from preliminary 1970 census estimates and the plotting of iso-potential contour on a sheet of conductive paper. A selection of preliminary models is presented in the following pages along with cursory interpretations of the resulting patterns and their possible implications. Although only preliminary exercises, it appears clear that such simulated models potentially provide valuable insight into analyzing and evaluating future land use developments and related economic activity in the Perris Valley study area. The models require further sophistication, both of the input data and analysis of resulting patterns. They can, and will, be accomplished in further use of the conductive sheet analog of the field plotter in the near future.

The field plotter characteristically provides a valuable device for the analysis of flow data and study of impact of such phenomena. Specifically applicable is the simulation and modeling of California State Water Project waters for surface distribution of agricultural use. Estimates of impact, manifested in land use, can be made and then subsequently monitored by aerial photography and other remote sensing techniques. Such simulations have begun in the Antelope Valley and Mojave Desert areas crossed by the California Water Project. Due to the preliminary nature of these simulations and the input data used, and more importantly the lack of any current aerial photography or other remotely sensed imagery available to the project for these areas, it is premature to report results.

7.3.8 Preliminary Analog Simulation Models in the Perris Valley

The following four illustrations are examples of conductive sheet simulations for modeling in the Perris Valley. Each assumes a grounded rectangular boundary and four points of influencing electrical current input representing the four major urban areas in the Perris Valley. Data used for adjusting relative values for these input points were preliminary 1970 census of population figures, as shown in Table 7.2.

Figure 7.8A illustrates the readily accepted assumption that, all other things considered equal, population potential, land values, etc. will diffuse from urban centers relative to their size and with the highest potential at those centers. The interactive equal potential contours from the four urban point sources are plotted for 10, 20, 30, 40 and 50 percent values. The highest potentials center around the Sunnymead-March Air Force Base complex and Hemet-San Jacinto which are in close proximity with each other. A 30% island encloses the city of Perris while the 20% iso-potential encloses all urban points.

Table 7.2

INPUT DATA VALUES POTENTIAL SIMULATION MODELS

POINT SOURCE	POPULATION	% SCALING FACTOR
1. March AFB	14,924	10.0
Urban portions of two census tracts, including Edgemont, Sunnymead, & Moreno.		
2. Perris	4,070	2.7
City portions of four census tracts.		
3. Hemet	12,350	9.3
City portions of four census tracts.		
4. San Jacinto	4,307	2.9
City portions of two census tracts.		
5. Lake Perris		10.0
(area defined by State property boundary)		

* Population values from Preliminary 1970 Census of Population.

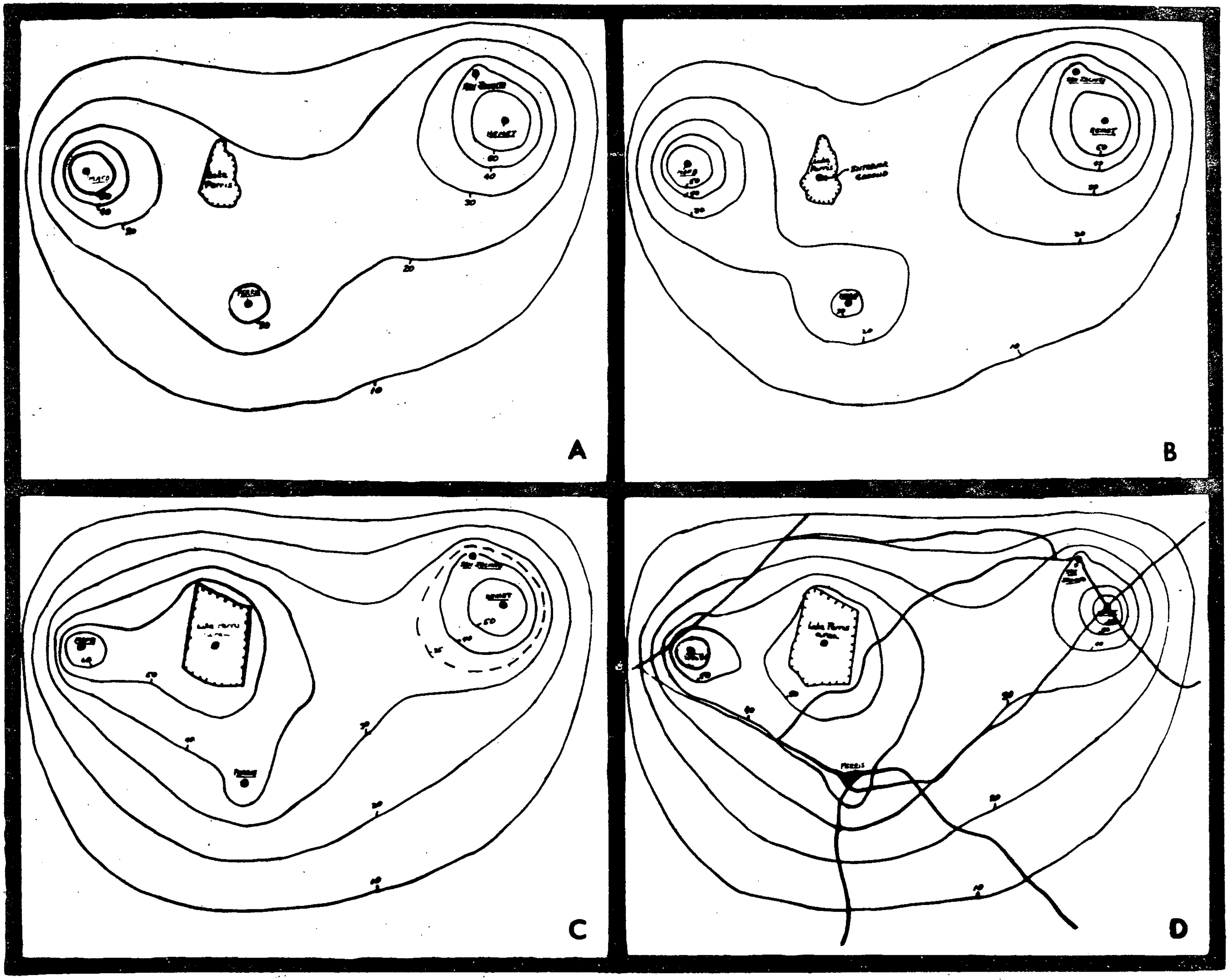


Figure 7.8 - Preliminary analog simulation models in the Perris Valley.

The model in Figure 7.8B slightly modifies the preceding example by adding Lake Perris as an interior ground, or "sink". The effect of an interior ground is to influence potential in that direction realizing, of course, that potential will approach zero near the ground. The results, as shown in the pattern of iso-potential contours, is to influence the contours toward the Lake. Similarly, it may be hypothesized that population growth, development intensification, land values, etc., while still diffusing from their highest values in the urban centers, will be influenced in the direction of Lake Perris development.

While Lake Perris will influence potential towards it from population centers, it will also create a center of influence from which potentials diffuse, similar to an urban center. The effect is simulated in Figure 7.8C, in which the lake is a source in addition to the urban centers. Areas of low potential in Figure 7.8A revert to a high potential resulting from the new source of influence, Lake Perris. In addition, the city of Perris, relatively insignificant in the first two examples, has greater importance in Figure 7.8C due to its proximity to Lake Perris.

In Figure 7.8D, the assumption of a homogeneous surface is relaxed by adding state highway routes with higher conductive materials. Because these routes provide greater accessibility, the distribution of potentials across the surface is modified. Again, Lake Perris is a source of influence over the area interacting with similar sources at the four urban centers.

Each subsequent example in the above series adds some modification and sophistication to the simulated model. These, however, are no more than preliminary exercises. The value given to Lake Perris as a source of input, for example, needs considerably more analysis, as do values for other point sources in the model. Future roads need to be included and all roads need to be weighed according to their relative function as routes of potential development and accessibility. Finally, the homogeneous plane assumption must be further relaxed by voiding those areas in the model of Perris Valley not available to future development or fluctuating market land values, e.g., March Air Force Base, University of California experimental farm, and areas of topographic relief which prohibit development. With such modifications through further experimentation of the modeling process, interpretation and analysis of the resulting patterns will be more meaningful in planning and analyzing future land use developments and processes in the Perris Valley. As construction of Lake Perris nears completion and changing developments in the surrounding Perris Valley proceed, analog simulation models may then be further evaluated on the basis of those changes as monitored from the interpretation and analysis of suitable aerial photography and other remotely sensed imagery.

7.3.9 Future Study: Perris Valley

It will be several years before the full impact of the California Water Project and the terminal, Lake Perris, will begin to be felt in the land use of the Perris Valley. Indications of the changes to come, however, are already -- but only recently -- beginning to be expressed on the landscape. The present study objectives are to record the "pre-reservoir" current land use of the Perris Valley by May 1, 1971. This will provide a base from which to evaluate future land use changes which accompany the development and completion of the California Water Project and terminal Lake Perris. To further meet the objectives, however, it is emphasized that a fulfillment of the task is greatly dependent on the availability of suitable and current aerial photography of the Perris Valley area.

Attitudes of local population are important considerations in the complete analysis of present and future developments of any area. A continued survey, following the pattern of the sample questionnaire discussed above, is planned.

For analysis to be meaningful it is important that this type of activity be designed for update and revision, and that future surveys be conducted to reflect for analysis of attitude changes accompanying land use and development changes. Therefore, a survey sample conducted one year following the first complete survey is planned.

Land use and other environmental changes will surely follow development and completion of the California State Water Project in the Perris Valley. These changes, which reflect capital investment, i.e., non-irrigated to irrigated agricultural land, are responses to increased economic water availability, and/or changes in economic activity on the land, such as agricultural land to non-agricultural uses. Another important consideration is the determination of how these changes are related to the availability of water rather than speculative land development with a newly created recreation potential incentive. An important environmental change which will rapidly follow development in Perris Valley will be atmospheric quality, e.g., air pollution. The application of remote sensing techniques to the monitoring and analysis of atmospheric quality in the Perris Valley needs to be fully investigated and exploited in a continuing study of this region.

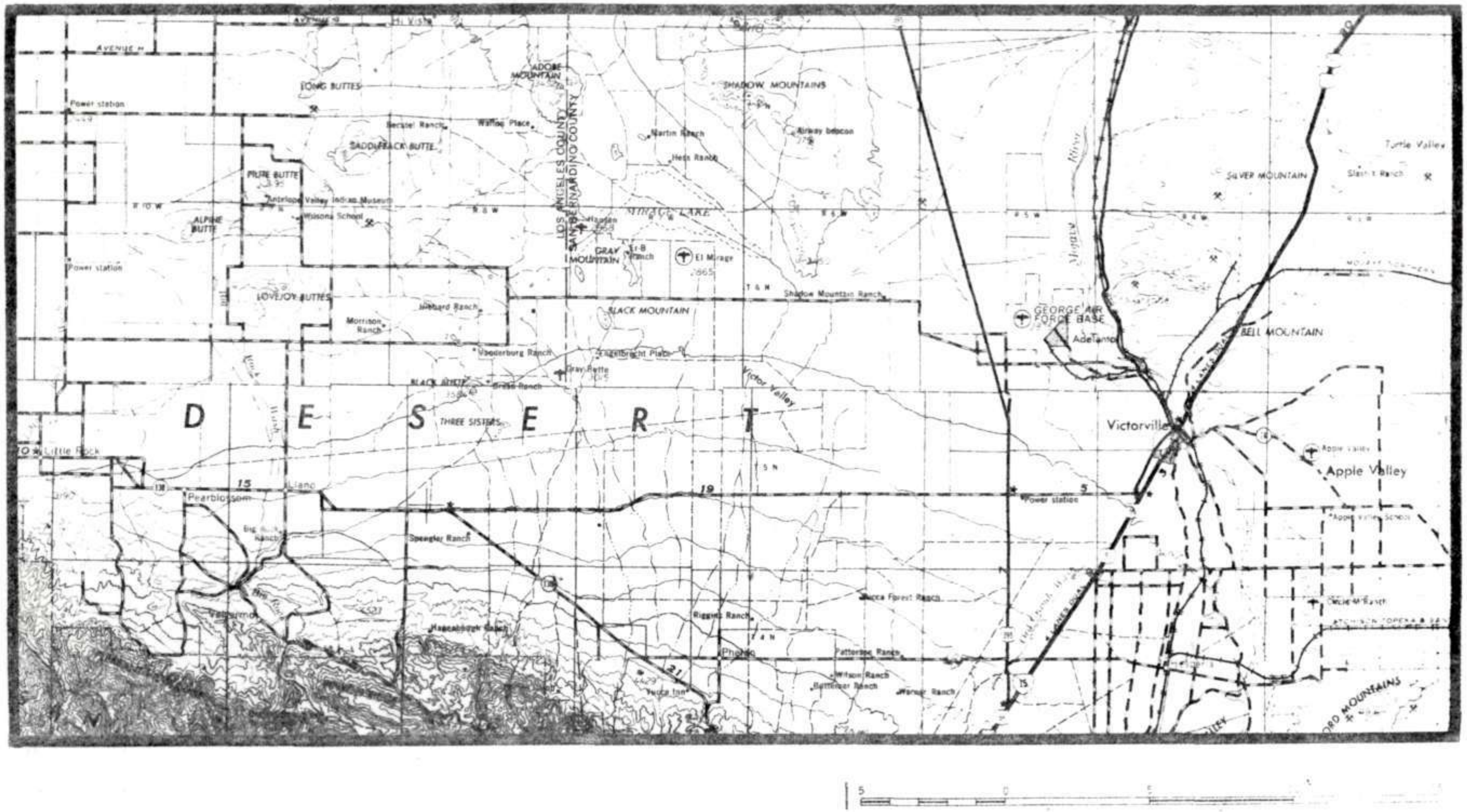
In addition to future objectives discussed above in the Perris Valley, certain changes and developments within the area of Lake Perris will be of social and economic importance to Southern California. An extensive recreation facility, for example, will accompany the creation of Lake Perris. It is proposed that remote sensing techniques may provide valuable contributions to the effective planning, development, and management of recreational facilities and activities such as those to be associated with Lake Perris. The need for intensive investigations into the application of remote sensing techniques to the broad field of recreation has been reinforced by numerous recreation planners and manager, including the California Department of Parks and Recreation who will be directly responsible for the development of recreation facilities associated with Lake Perris. Investigations to exploit these potential applications are planned in the coming year's research program and are among the considerations to be included while continually monitoring and analyzing land use change and development in the Perris Valley. Again, the fulfillment of this task will be greatly dependent on the future availability of aerial photography and other remotely sensed data to meet the objectives of this project.

7.4 HIGH DESERT STUDY AREA

7.4.1 Introduction to Study Area

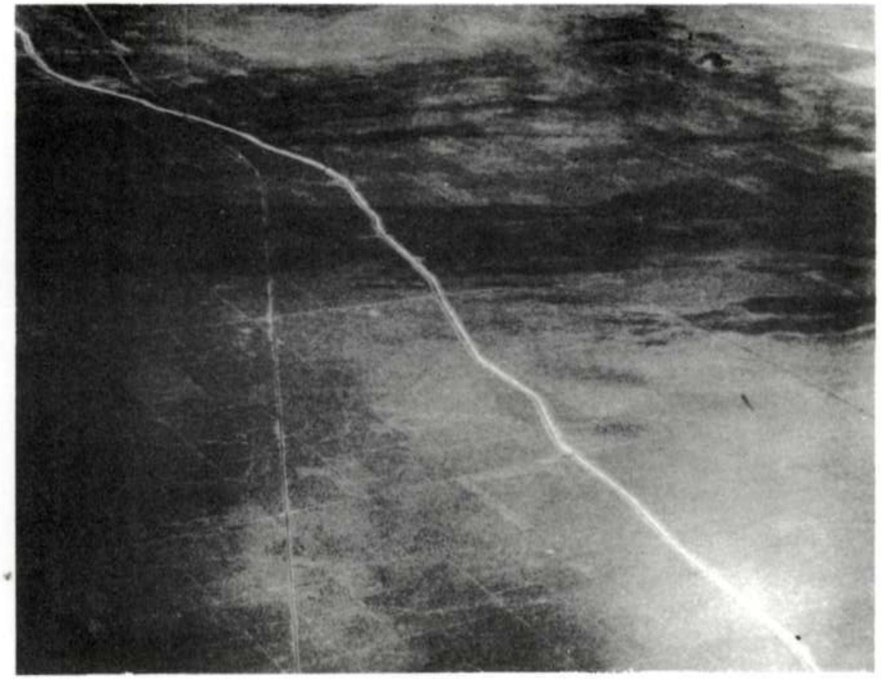
The next area affected by Feather River water logically to be inventoried by the University of California, Riverside is the "High Desert", that portion of the northern alluvial piedmont of the San Gabriel Mountains crossed by the California Water Project canal. The area here defined stretches westward from Hesperia and the Mojave River Valley to approximately the town of Pearblossom and northward from the mountain base to include the basin of El Mirage Playa (see Map 7.2 and Figures 7.9 through 7.12).

The High Desert provides an exceptional test site for monitoring change wrought by Feather River water. Currently development is minimal with embryonic weekend or farm-residential type of subdivisions in the Phelan area west of Hesperia, one fairly large alfalfa raising operation near the floor of El Mirage basin and the town of Adelanto. The general lack of a more intensive land use is the result of past water deficiency. A water district has now been established which will correct this deficiency and permit an increase in settlement density. Other factors which would appear to favor this type of change are the possible development of a large air terminal immediately to the west in the Palmdale sector, the steady improvement of roads over recent



Map 7.2. The "High Desert" study area is shown in this area along the northern alluvial piedmont of the San Gabriel Mountains and NNW of Cajon Pass. The California State Water Project canal is presently under construction across this area.

Figures 7.9 and 7.10. Figure 7.9 (left) - the northern alluvial piedmont of the San Gabriel Mountains, here termed the "High Desert". The fan of Sheep Creek, at the base of which lies El Mirage Basin, shows in the foreground. Embryonic subdivisions already appear in the Phelan area in the foreground. The Feather River aqueduct, still without water, crosses the piedmont as a white line. Figure 7.10 (right) - El Mirage Basin, enclosed by remnants of an old erosional surface, is one of several playas to which streams of the San Gabriels contribute. These playas form the northern edge of land easily watered from the aqueduct. The edge of the town of Adelanto lies in the lower left hand corner of the view.



Figures 7.11 and 7.12. Figure 7.11 (left) - Sheep Creek and Swarthart Valley, source area for present water in the El Mirage Basin. The valley lies along the San Andreas fault, the breccia from which comes the distinctive soil of Sheep Creek fan. The town of Wrightwood lies in the valley. Figure 7.12 (right) - the poorly watered mid-section of the alluvial piedmont is the location of the Feather River aqueduct. Historic lack of water is responsible for the minimal development of settlement patterns here. With the advent of water, change to this sector of the piedmont should be significant.

years that has given the area easy access to metropolitan Los Angeles, and the construction of a railroad across the piedmont.

In the past, the water deficiency has been most severe in the mid-sections of the alluvial fans. Alluvial fill from the San Gabriel Mountains covers an old land surface which originally sloped southward. The rocky hills or "buttes" which surround the El Mirage Basin and which in places protrude through the alluvial apron are remnants of this old erosional surface. Because this old and new buried bedrock surface slopes southward while the San Gabriel bajada slopes northward, alluvium rapidly deepens toward the base of the mountains. Well-water therefore has been available either close to the mountain canyon mouths or near the basin floor. In the mid portion of dominating Sheep Creek fan, for example, wells have been drilled to 800 feet without tapping a water supply. This mid-section will be watered by the new aqueduct.

7.4.2 Historical Developments

Historically, the area has had more settlement than today. Prior to World War I, considerable land was patented on the floor of El Mirage Basin under the Homestead Act. Land was placed under cultivation with alfalfa and fruit orchards as typical crops. The town of Adelanto, just east of the basin, was established as a latter-day agricultural colony. Most of the homestead settlers were drawn away during World War I by war-related employment in the Los Angeles area and did not return after the war, although homestead land was available during the 1920's. At that time difficult access to Los Angeles and to markets for products made farming an unprofitable venture even on the basin floor where water was comparatively plentiful. Few structures remain from this period, most having been destroyed by fire, and thus the older phase of settlement has little effect upon the present, except for possible land titles. Adelanto has persisted as a town, supported by George Air Force Base and the fact that it is on Highway 395, although its former apple raising prominence has all but disappeared.

It is proposed that some sort of renewed settlement will occur in the High Desert with the advent of water. The cost of the water may prohibit agriculture, although soils on the alluvial piedmont have in the past proved favorable. Comparative freedom from smog, and the appeal of the high desert landscape to many as weekend retreats may provide one type of impetus. The piedmont is now crossed by a major line of the Southern Pacific Railroad as well as Power lines from Hoover Dam and light industry could develop with related permanent residential settlement. This potential for change combined with the ever increasing pressure for vacant land near Los Angeles, would appear to make an inventory of the present conditions pertinent as a basis from which to monitor inevitable change in the future. Much like the west side of the San Joaquin Valley, settlement starts from a present low level of land utilization. But whereas the initial development of the San Joaquin Valley will be agricultural, water-related change on the High Desert will more likely be non-agricultural.

7.4.3 Future Study: High Desert

To date no progress in the inventory of this High Desert study area has been accomplished due to the combined lack of available funds and suitable remotely sensed imagery. Because this is one of the first areas to be affected by the California State Water Project in Southern California, it is important that thorough investigations in this area begin as soon as possible, e.g., early in the next year of study. It is proposed that initial investigation under this grant use remote sensing to ascertain present settlement patterns, existing land use and assess the general environmental quality of the area both by remote and ground methods. Color infrared photographic coverage should provide the necessary surrogates to inventory soil and land surface quality. Should scanning radiometers capable of calibration be available, such factors as air drainage on the fan and the pooling of cold air in El Mirage Basin can be readily determined from aloft or such studies can be made by ground observations. As is common with many Mojave Desert areas, ground inversions may persist during winter months. The concommitant pollution danger makes such assessment highly desirable prior to more intensive non-agricultural settlement. In brief, the inquiry into the High Desert will be concerned with (1) inventory of that which exists prior to expansion of more intensive land use and (2) an assessment of the problems of environmental quality that may result from an expansion of settlement.

Closely related to the studies in the High Desert, and in immediate proximity to that study area, is the future Cedar Springs Reservoir (also referred to as Silverwood Lake), located in Summit Valley on the north slopes of the San Bernardino Mountains. Water will be siphoned into Cedar Springs Reservoir where it will be stored before being tunnelled through the San Bernardino Mountains, dropped down Devils Canyon to the Devils Canyon hydropower plant, then to distribution in the San Bernardino Valley and Lake Perris in the Perris Valley. Cedar Springs Reservoir will be a multi-purpose facility, including major recreational activity developments. In Section 7.3 it has been proposed that remote sensing techniques may provide valuable contributions to the effective planning, development, and management of recreational facilities and activities. The chaparral and coniferous forest covered mountains surrounding the future Cedar Springs Reservoir contrast sharply with the grass covered hills and valleys surrounding the future Lake Perris. These differences in the local environments will require different and contrasting considerations in the associated planning, development, and management of recreational facilities. In addition to Lake Perris, therefore, applications of remote sensing technology in recreational developments of Cedar Springs Reservoir are proposed in the coming year's research program.

7.5 COMPUTERIZATION OF THE CALIFORNIA EARTH RESOURCES INVENTORY

7.5.1 Introduction

To provide for rapid updating of the California Earth Resources Inventory it becomes necessary to develop a method to quickly compile (primarily from remotely sensed imagery), store, and automatically reproduce in map or statistical form various types of land use and land pattern data. The requirement obviously calls for the use of a large scale computer. However, Earth Resource data are obtained quite often in a form (i.e., a photograph) that is difficult and time-consuming to convert to digital form for computer processing. Through associated research efforts at the University of California, Riverside we have developed and made available a hardware system that permits an operator to convert or digitize remotely sensed image data for computer use. Through the availability of this equipment we can now proceed on to the further development of an automated California Earth Resources Inventory system.

7.5.2 UCR Image Data Conversion System

The image data conversion system developed at the University of California, Riverside requires the human operator to be an integral part of the interpretation-decision making process. To enable the operator to make these decisions, an on-line desk top computer is incorporated into the system design (Figure 7.13). The principal component is the X-Y coordinate table and digitizer which permits the operator to read the coordinates of a map or image to a 0.001" accuracy. The coordinate data along with any other information the operator desires to place in storage in transferred to one of two computers through some type of recording media (e.g., keypunch, tape recorder). The other data, such as land use codes, are entered into the system by a manual remote keyboard.

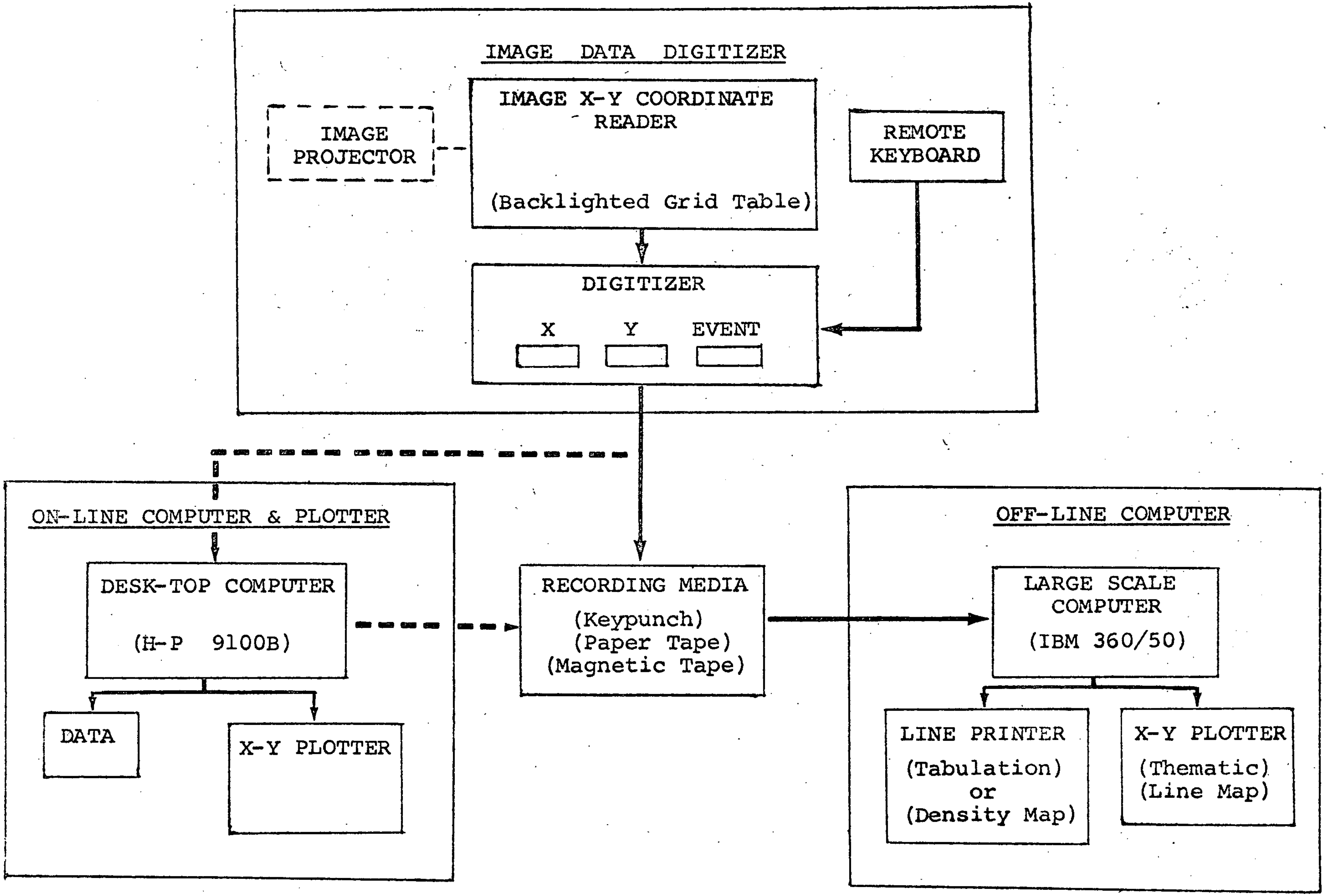


Figure 7.13. Block diagram of the semi-automatic image data conversion, storage, and mapping system. The four major components are 1) Image data digitizer, 2) Recording media, 3) On-line computer and plotter, and 4) Off-line computer and plotter.

Normal method of operation is to enter either point location coordinates or a series of coordinates defining a specific polygonal area.

The on-line desk top computer is used to (1) rectify and resection the image points to a planimetric base map, (2) calculate various area or linear measurements (i.e., planimetric acreages), and (3) monitor the readout process by plotting the points or lines being digitized. The latter procedure saves considerable computer time and money by enabling detection of errors at they occur and not after a finished computer map has been expensively drawn. The monitoring process also enables the operator to make decisions on how to proceed further with the analysis.

The off-line large scale computer provides the means for storage of the large data bank and the ability to automatically plot updated thematic maps. Figure 7.14 is a coarsely prepared computer-drawn land use map of central Los Angeles using high altitude aerial photography. Updating of this computer stored map can be accomplished in a matter of a few hours as compared to several days by manual redrafting. The actual plotting of the map by the computer took less than one-half hour on a slow speed plotter.

7.5.3 Future Requirements

With the availability of equipment to convert image data to computer format we are now ready to proceed to develop the software for the data bank of the California Earth Resources Inventory (i.e., A Geographic Information System). The system design will include the development of a format compatable for (1) interchange of information, and (2) registration of locational data to other map projections. Complete system and program design is required. While a sample computer prepared map has been produced there exists a requirement to redesign the computer mapping program to the needs of our particular requirements. Primary changes in the mapping program are for (1) plotting

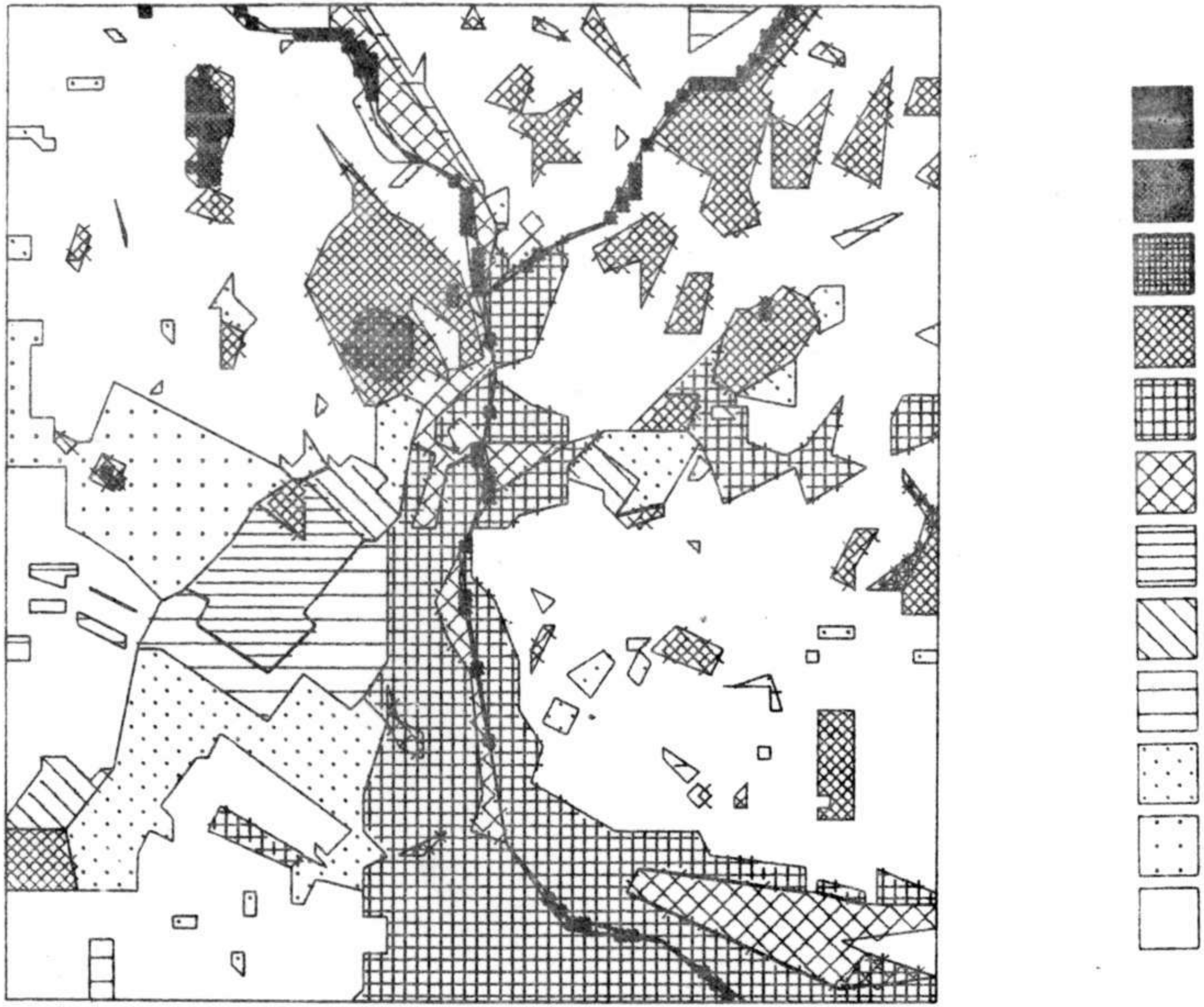


Figure 7.14. Computer prepared land use map of Central Los Angeles.

resolution of 0.01" rather than the present 0.1", and (2) expansion and refinement of the current 12 legends. Redesign of the mapping program will also permit full release of the program which is now held on proprietary rights of the developer of the program.

The present hardware system will permit only 9" x 9" format imagery to be analyzed satisfactorily. It would be economically desirable to be able to analyze and convert image data from both 35 mm and 70 mm format imagery. Therefore, a requirement exists to develop a projection system that will allow these formats to be presented on the coordinate digitizer table by means of rear view projection. Considerable investigation into the design and/or availability of projection equipment has been made so that completion of this modification of the hardware system can be made in a relatively short time.

The image data conversion system developed at the University of California, Riverside, has been developed and supported entirely by funds from sources other than NASA. Researchers involved in the current NASA program have been fortunate during the past eight months to have utilized this equipment and associated personnel services at no expense to NASA. The image data conversion system has proven extremely useful to the rapid analysis, interpretation, and mapping from remotely sensed imagery in the study of California resources and will play an integral part in continued studies. Several items are very important, however, to the continuing program. First, the sources presently supporting the image data conversion and mapping system cannot continue to provide no-cost facilities and services to the current NASA project. These are step-declining sources and will provide for no additional developments to the hardware system and components. Second, continued use of this integral system to the current NASA project will require additional hardware, and particularly software developments to the existing system. These developments will be primarily to provide adaptability for HI-FLT and ERTS type data formats into the system and supporting software. Continued development of the image data conversion and mapping system and progress in integrating its application into the inventory, analysis, and monitoring of California resources requires NASA support. Included in the proposed budget request for 1971-1972 are funds for this purpose.

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Chapter 8

DIGITAL HANDLING AND PROCESSING OF REMOTE SENSING DATA

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An important part of the integrated study of Earth Resources carried out by the University of California is the combined use of all available sensing devices which provide information of interest to earth resource scientists. Two considerations influence the use of multisensor data. Firstly, the data collected at each of several different dates will need to be analyzed in various combinations. Secondly, with the launch of the ERTS A and B Satellites a specific set of multisensor data in an electronic format will become available to the project as one of the major data sources. Thus a significant component of our work is the efficient or optimal use of the large amount of data available which has bearing on the study of specific earth resources. Three approaches are used in the analysis of the available data:

Human Photo Interpretation

Electronic Image Enhancement

Automatic Data Processing

These three approaches complement one another and are all pursued within our study. However, we recognize the interdependency of the work at the University of California with the work and the facilities in the data processing of earth resources done elsewhere in the country, specifically at the laboratory for remote sensing (LARS) of Purdue University and at the Center for Research of the University of Kansas. The first question which arises is whether, by establishing at the University of California, certain facilities for electronic image enhancement and automatic data processing we will be guilty of needlessly duplicating facilities already in existence elsewhere. The data processing facility being established as part of the University of California program emphasizes man-machine interaction rather than bulk processing of data. It uses as a central processing element a digital computer and thus the development or use of data processing algorithms becomes principally a problem in computer software development. With this approach it becomes possible to make use of the very extensive digital computation facility already available at the University of California. By the acquisition of a very modest number of specialized computer peripherals an extremely versatile and flexible facility is being made available to the program. Thus the academic setting of the integrated study within the University of California allows a very substantial electronic processing facility to be established, at a very modest cost.

The on-going work in data handling and data processing has the following objectives:

1. To provide a data processing facility for the use of the earth resource scientists within the program.
2. To provide to the earth resource scientists the assistance of data processing specialists.
3. To make available and to implement the data processing algorithms developed within the University of California or elsewhere.
4. To carry out some independent research and study of algorithms or data processing techniques of direct interest to the earth resource scientists within the program.
5. To provide, to the earth resource scientist within the program, the means for processing and making use of the electronic data which will become available with the launch of the ERTS satellites.

The data processing facility is being assembled on the Berkeley Campus of the University of California. Two complementary efforts are being pursued. (1) In the Department of Electrical Engineering and Computer Sciences, personnel from the Department of Electrical Engineering, Davis Campus, and of the Department of Electrical and Computer Science at Berkeley are concentrating on the question of multisensor data combination and electronic enhancement. They make use of a versitile digital signal processing facility, also used on other NASA-sponsored image processing work. This facility is described more fully later on in this report and will be connected this year to the CDC 6400 digital computer of the Campus Computer Center. (2) The group on automatic data processing of the Forestry Remote Sensing Laboratory at Berkeley concentrates on problems of automatic classification, making use fully of work already done at Purdue and Kansas. To carry on their work they have a limited, but adequate, computing capability, also connected to the Campus Computer Center. Their work and facility is also described more fully in Chapter 4.

These two efforts on the Berkeley Campus are being carried out in a spirit of full cooperation and are indicative of the range of talent and competence brought together in this integrated program. Both efforts interact with the personnel trained in Photo Interpretation of the Forestry Remote Sensing Laboratory and of the Departments of Geography on the Santa Barbara and Riverside Campuses.

8.1. PROGRESS TO DATE AND PROJECTED WORK TO MAY 1, 1971.

The progress to date on this part of the project can be divided into the following broad categories:

1. Familiarization with some of the relevant activities and personnel working in similar or related areas.
2. Reorganization and detailed specification of the digital processing

facility which is at the heart of our current and future activities.

3. Preliminary work on means and programs for data acquisition and handling.

4. Preliminary work on digital signal processing algorithms of broad relevance to feature enhancement of remote sensing data.

In the following we expand on each of these categories of work and indicate the work that we believe will be accomplished by May 1, 1971.

8.1.1. Familiarization with other related activities and workers.

At a number of general meetings of the participants in this integrated project and at several specific meetings that we initiated we became better acquainted with the activities and specific goals of various groups in this integrated project, notably the Forestry Remote Sensing Laboratory in Berkeley, the Geography Department at University of California, Santa Barbara and the Meteorology group in Davis. We solicited advice from Gene Thorley, Jerry Lent and Don Lauer of Forestry Remote Sensing Laboratory and Jack Estes of University of California, Santa Barbara, on desirable parameters and configurations for interactive image display and have incorporated their suggestions into our planned System. We anticipate that our interactions with other participants of the project will increase steadily with time.

Outside the project, by special trips we gained familiarization with the image processing facilities at the Jet Propulsion Laboratory in Pasadena, and with some of their software packages for digital picture handling and processing. A visit to NASA Goddard Space Flight Center in September 1970 allowed us to get acquainted with the activities of Drs. McLeod and Hovis related to the Earth Resources Technology Satellite project. Further trips are planned in the coming months, to Jet Propulsion Laboratory and Aerojet General in the Los Angeles area probably before May 1, 1971 and to a number of other NASA and non-NASA image processing centers later on.

8.1.2. Work on the Digital Processing Facility.

The major share of our time has been devoted to that aspect of our work. Some redirection of our efforts has occurred, which we believe will improve our effectiveness in the project.

Although our original plans called for the use of the computing facility at the Space Sciences Laboratory at Berkeley on a part-time basis we have now decided to center our efforts on the computing facility of the Systems Laboratory, Department of Electrical Engineering and Computer Science, on the Berkeley Campus.

The SDS Sigma 7 computer at the Space Sciences Laboratory, although a substantial machine, lacks a broad softwave package back-up. Further, the work of interfacing the computer with the specialized computer peripherals we require would have interfered seriously with the major user of the facility at the Space Sciences Laboratory who was generously making access to the machine and computer time available to us.

We shall make use for our work of an IBM 1800 Computer which has been modified by the addition of an array processor designed and built for the specific task of digital signal processing. The array processor speeds up by a factor of 20 a number of operations of interest in signal processing. Thus this small digital computer has a substantial computing power for the type of processing of prime interest to the integrated project. Further, the IBM 1800 will be connected by a high rate data link (64,000 words per second) to the CDC 6400 of the Computer Center at Berkeley. Thus we have a highly desirable situation in which data acquisition, simple data processing and image display can be done in a dedicated facility available for real time and interactive work, while a large computing facility and a large software system

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can be used for large computations and elaborate processing.

The diagram of the overall system configuration is shown in Figure 8.1. The schedule of assembly of the image processing system has been modified, principally in order to speed up the time at which the facility can be put to full use in the project. To this end we are concentrating this year's work on the acquisition of equipment and the design of hardware and software packages for an interactive color display. Because of budget limitations this means postponing some other parts of the system, such as the image scanner and digitizer. It is anticipated that the digitization of images will be done commercially or by some alternate methods for the present and near future.

It is worth pointing out the major advantages of the color processing and display system being assembled. Firstly, once the multispectral images are digitized, all the processing is done digitally on the corresponding electrical signals, without going back to photographic film as an intermediary step. Thus the uncertainties and inaccuracies of photographic processing are eliminated and the quantitative information available in the multispectral imagery can be extracted. Secondly, the digital processing provides an extremely versatile approach to the large number and diversity of requirements relevant to the study, and is thus an ideal research tool. Thirdly, in our dedicated digital computer the successive processing iterations needed to achieve a desired goal, such as feature boundary enhancement, can be carried out in real time in a most efficient manner.

Image Storage and Display System

After careful examination of the alternative ways of displaying at a suitable high rate (30 frames per second) multispectral images processed digitally we decided to use as a storage and output device an analog video disk. This video disk stores 400 black and white images or 133 color images

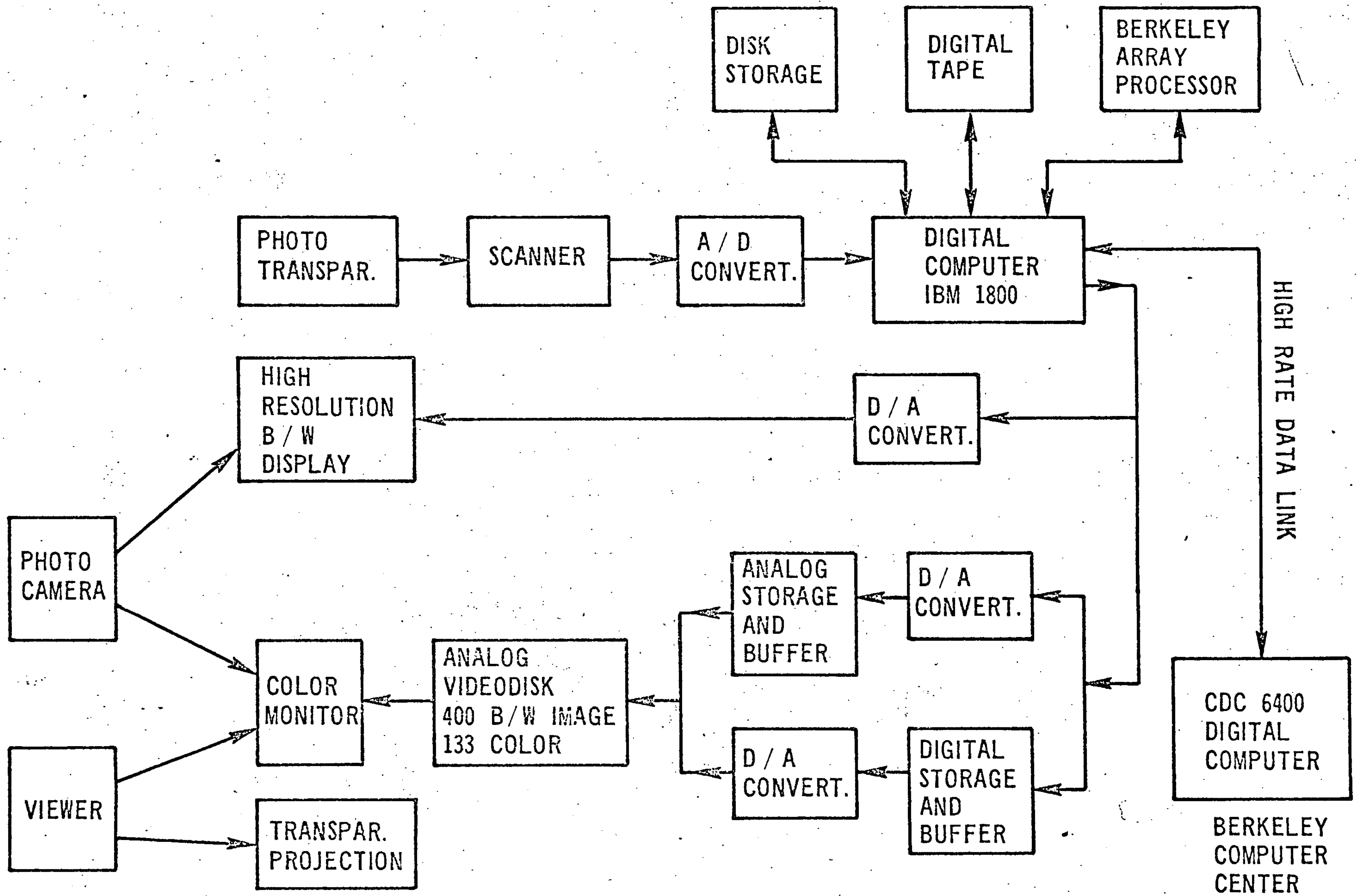

Figure 8.1. DIGITAL IMAGE PROCESSING FACILITY

and can output any of them repeatedly at a high rate. Thus a substantial file of images processed by different techniques can be stored and displayed in rapid succession on a cathode ray tube monitor for comparison by an observer. This valuable feature should reduce in many cases the need for extremely rapid processing. Work is currently underway to design and build the interface of the analog video disk with our digital computer.

The problem is to match the slow output rate of the computer to the high input rate required by the video disk. Two approaches will be used. The first one uses an analog buffer available commercially which requires little additional hardware but results in a loss of image quality. The use of this buffer will shorten the time to an operational display system. The second approach is digital buffering which should lead to no loss of image quality but requires a substantial time to assemble and bring into service.

Concerning the output of the video disk, the work is currently underway to determine whether a sequential color monitor using a rotating color wheel will be acceptable to a viewer, or if a three gun color tube with a higher color frame rate is needed to reduce flicker. The image, processed digitally, will be viewed on a monitor side by side with a full color transparency of the image being processed for digital enhancement.

This phase of the work requires careful deliberation at each step to make the best use of our limited resources and we expect to get part of the system in operation during the summer.

8.1.3. <u>Preliminary work on means and programs for data acquisition and handling</u>.

As seen in Figure 8.1 the input of digital data into our processing system is done either by digitizing a multispectral image, or by means of digital tape. The image scanner and digitizer will not be built this year as mentioned before and the digital tape unit is currently being interfaced to the digital computer. This interface work is being done with non-grant funds, and will allow us to input into our processing system images digitized for us by outside commercial suppliers.

The specific methods, the hardware requirements, the software needs of the high rate data link to the digital computer at the Berkeley Computer Center are currently being specified and will engage an appreciable amount of our effort for several months to come.

We have available some of the programs for image handling and processing, notably a two-dimensional Fast-Fourier-Transform program which has been developed with non-grant funds and personnel. We are pursuing the development of these programs which are fundamental to all types of digital image processing. We have also available a good quality, quite slow, 1,000 line black and white CRT display with the required software which is used on our work on image encoding not supported by the grant. We shall be making use of this display in the coming months for some preliminary work on image enhancement.

8.1.4. Preliminary work on digital signal processing algorithms.

Some work has been done on the development of processing algorithms and the writing of the corresponding programs for the design of filters. Most of this work has been done by a Ph.D. student (not supported by the grant) at the Lawrence Radiation Laboratory in Livermore. In connection with this work a short paper, "Optimum Design of Two-Dimensional Non-Recursive Digital Filters," has been presented at the Fourth Asilomar Conference on Circuits and Systems in November 1970. This paper is reproduced in the appendix. This work provides a technique for the design of a class of digital filters of direct interest in our project. Specifically we plan to make use of these results to perform digital enhancement of boundaries between features and hope to have some preliminary results by May 1, 1971. Other digital enhancement by level slicing of multisensor imagery will also be undertaken in the coming months, specifically, directly to assisting the work of Kinsell Coulson and his group on the Davis Campus, in their study of the polarization derived information.

8.2. FUTURE PROPOSED WORK

The work proposed for the coming year follows logically from the overall objectives of this part of the integrated program and from the on-going work described earlier. The priorities in the schedule of work are set so that the electronic image and data processing facility can be brought into operation as soon as feasible during the year 1971. Most of the components of the facility have been described before. The approximate time table, Figure 8.2, indicates the proposed concurrent work on hardware acquisition and design, system assembly, development of supporting software packages, development of application oriented programs and the type of data used in the work.

We anticipate some readjustment of our digital processing system requirements both in terms of hardware and general software packages as the interactive color display system becomes operational. These readjustments will be made to improve the convenience in the use of the interactive system or the speed of its operation if such a need becomes apparent from the specific application studies. As an example, it will require some experience to determine the best combined use of our specialized computing facility and of the interconnected CDC 6400 of the Berkeley Computer Center for the specific tasks undertaken.

A very important part of our work in the coming year will be in the interaction and exchange of views and ideas with several groups of people. The most important group consists of the other participants of this integrated study, and the interaction with this group is expected to increase very rapidly during the summer of 1971 along lines which have been described before. The interaction

		SPRING 1971	SUMMER 1971	FALL 1971	SPRING 1972
DIGITAL IMAGE PROCESSING FACILITY	System Design. Equipment Acquisition.	Video Disc Color Display Slide Projector	Photo Equipment. High Speed Data Link to CDC 6400.	High Precision B/W Display. Image Digitization	
	Interface Design and Construction	Digital Tape unit (non grant)	Video Disc. Color Display.	High Speed Data Link to CDC 6400	High Precision B/W Display Image Digitization
GENERAL SUPPORT SOFTWARE		Two-Dimensional FFT. Filtering. Level Slicing.	Image Formatting. Multi-Image Manipulation and Combination. Color Presentation of Multisensor Data.		
SPECIFIC PROGRAM FOR APPLICATIONS		Preliminary work Based on Theory and basic considerations	Development of specific programs for application to study of polarization effects, determination of hydrologic parameters, land use, etc. Iteractive work using real-time processing and display.		
TYPE OF DATA USED		A few digitized photographs and spectral scans from various sources	Operational Work Using Scanned Photographs		ERTS DATA Work
ORIGINAL PERTINENT RESEARCH					

Figure 8.2. PROPOSED WORK AND TENTATIVE SCHEDULE
DIGITAL HANDLING AND PROCESSING OF REMOTE SENSING DATA

with the other remote sensing centers will be conducted either directly, for the NASA facilities at Goddard and Houston and for the Jet Propulsion Laboratory in Pasadena, or principally by making use of the information gathered by other workers in this integrated program. This refers specifically to the well-established ties of the personnel at the Forestry Remote Sensing Laboratory with the remote sensing centers at the University of Michigan, Purdue University or the University of Kansas.

8.3. APPENDIX

OPTIMUM DESIGN OF TWO-DIMENSIONAL NONRECURSIVE DIGITAL FILTERS

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Abstract

An algorithm is presented for the design of two-dimensional nonrecursive digital filters. The filter input and desired output are random fields with known covariance arrays. The design is based on minimizing a mean-square error criterion subject to constraints on the orders of the filter. The numerical aspects of the design algorithm and implementation of the filter are treated extensively.

1. INTRODUCTION

Numerous applications in the areas of image and geological data processing involve the discrete filtering of two-dimensional signals.(1,2,3) One approach to the processing of such two-dimensional data is line-by-line filtering of the data arrays using one-dimensional digital filters. This is convenient because the filter can be implemented easily and some fairly classical design methods, set in the frequency domain, are available.

However, this approach ignores the two-dimensional coherence of the data and may result in an unsatisfactory performance. Although some techniques have been proposed recently for the design of two-dimensional digital filters,(4) these are direct extensions of the one-dimensional frequency domain methods and subject to similar performance limitations. In the design applications we consider, the filter performance cannot be meaningfully specified in the frequency domain. Also, the difficulties in implementing two-dimensional filters lead us naturally to limit the complexity of the filter.

With these considerations in mind, we present in this paper an algorithm for the optimum design of two-dimensional nonrecursive digital filters of constrained dimension. The filter input and desired output are assumed known in a statistical sense and are characterized by their respective covariance arrays. The output is estimated by a weighted, linear combination of input samples. These weights comprise the impulse response array of the digital filter. With this model, mean-square estimation techniques are applied to derive the optimum filter array. This approach leads to the solution of a matric equation for the two-dimensional filter.

The most substantial numerical problem in the design routine is the inversion of a dense matrix. This problem is avoided in two special-case design problems where the covariance arrays are taken to be decomposable. The implementation of the designed filter using a two-dimensional FFT also is discussed.

2. PROBLEM STATEMENT

The digital filter design problem is shown schematically in Figure 1. We consider the desired

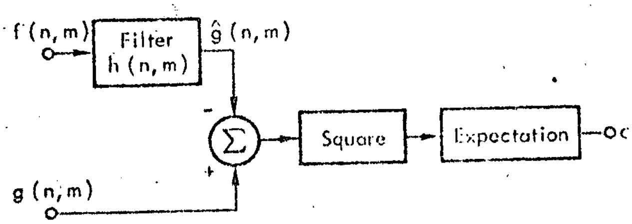

FIGURE 1. DIGITAL FILTER DESIGN PROBLEM

output array $\{g(n,m)\}$ to be defined on a sampling grid in the entire n,m plane.* The estimate of each member of this array, $\hat{g}(n,m)$, is restricted to be a shift-invariant linear combination of a finite number of past and future values of the input array $\{f(n,m)\}$. Specifically, we write

$$\hat{g}(n,m) = \sum_{i=A}^{B} \sum_{j=C}^{D} f(n-i, m-j)h(i, j) \tag{1}$$

for all n,m.** The array $\{h(n,m)\}$ is the filter impulse response or point spread function[5] and has been constrained to be of finite memory and anticipation. It is confined to the region

$$\begin{aligned} n &= -A, \ldots, 0, \ldots, B \\ m &= -C, \ldots, 0, \ldots, D. \end{aligned} \tag{2}$$

The input, $\{f(n,m)\}$, is taken to be a sample array from a zero-mean, homogeneous random field with the two-dimensional autocovariance array $\{R_{ff}(n,m)\}$. Its crosscovariance with the input is given by $\{K_{gf}(n,m)\}$.

*For simplicity in notation, the sampling grid has been normalized; consequently, n,m are integers.

**A, B, C, and D are taken to be positive integers.

3. DESIGN ALGORITHM

Given the statistical nature of the input array the mean-square error criterion* of Figure 1 is a natural measure of the digital filter performance. In the filter design, we determine an estimate $\{\hat{g}(n,m)\}$ of $\{g(n,m)\}$ which minimizes the mean-square error

$$\epsilon = E\{[g(n,m) - \hat{g}(n,m)]^2\} \quad \forall n,m \tag{3}$$

in which E{ } is an expectation taken over the ensemble of possible input arrays. To solve for the weighting array $\{h(i, j)\}$ which minimizes (3) for all i, j as in (1), we make use of the orthogonality principle:[7]

> For each n,m, the filter array $\{h(i, j)\}$ which minimizes the mean-square error ϵ is such that the difference
>
> $$g(n,m) - \sum_{i=-A}^{B} \sum_{j=-C}^{D} f(n-i,m-j)h(i, j)$$
>
> is orthogonal to each of the elements in the input array used in the estimate. That is,
>
> $$E\{[g(n,m) - \hat{g}(n,m)]\, f(n-\lambda, m-\tau)\} = 0 \tag{4}$$
>
> $$\begin{aligned} \lambda &= -A, \ldots, 0, \ldots, B \\ \tau &= -C, \ldots, 0, \ldots, D. \end{aligned}$$

We substitute (1) into (4) to give

$$E\left\{\left[g(n,m) - \sum_i \sum_j f(n-i, m-j)\, h(i, j)\right] \times f(n-\lambda, m-\tau)\right\} = 0. \tag{5}$$

Taking the expectation operation inside the double summation, we have

$$E\{g(n,m)\, f(n-\lambda, m-\tau)\} = \sum_i \sum_j E\{f(n-i, m-j)\, f(n-k, m-l)\}\, h(i, j)\,. \tag{6}$$

*A weighted mean-square distortion measure[6] may be more meaningful for some types of data. It can be shown that the optimum digital filter minimizes both the weighted and unweighted mean-square distortion measures.

However, these expectations are simply values of the covariance functions:

$$E\{g(n,m)\, f(n-\lambda, m-\tau)\} = K_{gf}(\lambda, \tau) \tag{7a}$$

$$E\{f(n-i, m-j)\, f(n-\lambda, m-\tau)\} = R_{ff}(\lambda-i, \tau-j). \tag{7b}$$

Thus we have the following set of equations to solve for $\{h(i, j)\}$:

$$K_{gf}(\lambda, \tau) = \sum_{i=-A}^{B} \sum_{j=-C}^{D} R_{ff}(\lambda-i, \tau-j)\, h(i, j) \tag{8}$$

$$\lambda = -A, \ldots, 0, \ldots, B$$
$$\tau = -C, \ldots, 0, \ldots, D.$$

To complete the design algorithm, we write the system of equations given in (8) in matric form* as

$$\underline{k}_{gf} = \underline{R}_{ff}\, \underline{h} \tag{9a}$$

$$\begin{bmatrix} \underline{k}_{gf}^{-A} \\ \underline{k}_{gf}^{-A+1} \\ \vdots \\ \underline{k}_{gf}^{B} \end{bmatrix} = \begin{bmatrix} \underline{R}_{ff}^{0} & \underline{R}_{ff}^{1} & & \underline{R}_{ff}^{A+B} \\ \underline{R}_{ff}^{1} & \underline{R}_{ff}^{0} & & \\ \vdots & & \ddots & \\ \underline{R}_{ff}^{A+B} & & & \underline{R}_{ff}^{0} \end{bmatrix} \begin{bmatrix} \underline{h}^{-A} \\ \underline{h}^{-A+1} \\ \vdots \\ \underline{h}^{B} \end{bmatrix} \tag{9b}$$

where the general form of each of the subvectors and submatrices is

$$\left(\underline{k}_{gf}^{W}\right)^T = [K_{gf}(W, -C) \ldots K_{gf}(W, 0) \ldots K_{gf}(W, D)] \tag{10a}$$

$$(\underline{h}^{W})^T = [h(W, -C) \ldots h(W, 0) \ldots h(W, D)] \tag{10b}$$

$$\underline{R}_{ff}^{W} = \begin{bmatrix} R_f(W, 0) & R_f(W, 1) & \ldots & R_f(W, C+D) \\ R_f(W, 1) & R_f(W, 0) & & \\ \vdots & & \ddots & \\ R_f(W, C+D) & & & R_f(W, 0) \end{bmatrix}. \tag{10c}$$

*Underlined lower and upper case letters represent column vectors and matrices, respectively.

The elements of these subvectors and submatrices can be identified directly from (8) and (10); $\underline{k}_{gf}^{W}$ is a column vector made up of the Wth row of the crosscovariance array $\{K_{gf}(n, m)\}$. Similarly, $\underline{h}^{W}$ corresponds to the Wth row of the filter impulse response array. Each of the submatrices of $\underline{R}_{ff}$ is a covariance matrix constructed from the appropriate row of the input covariance array.

The optimum digital filter response or point spread array $\{h(n, m)\}$ for all n, m follows formally from (9) by inverting $\underline{R}_{ff}$:

$$\underline{h} = \underline{R}_{ff}^{-1}\, \underline{k}_{gf}\,. \tag{11}$$

The design algorithm as given in (11) is capable of treating a very broad class of problems requiring only a priori knowledge of the covariance arrays. In an actual design, the dimensions assigned to the filter represent a balance between conflicting design objectives that deal with filter implementation and performance. Although it is clear that a digital filter of smaller dimensions will be easier to implement, it should be clear also that the filter performance generally will improve with increasing dimensions.

Unfortunately, a dimensional constraint is also imposed by the design algorithm. The difficulty arises in the numerical realization of (11). $\underline{R}_{ff}$, the matrix to be inverted, is of dimension (A+B+1) (C+D+1), which for moderate to large filters may be quite sizeable. For example, the design of a 50 X 50 filter requires the inversion of a dense matrix of dimension 2500. Even for low-order filters (< 20), the storage and inversion of $\underline{R}_{ff}$ may lead to long computations and numerical instabilities. In some useful special cases, however, filters of larger dimensions can be designed with this algorithm.

4. REALIZATIONS FOR DECOMPOSABLE COVARIANCE ARRAYS

The numerical realization of the design algorithm is substantially simpler when the various covariance arrays are decomposable; i.e., at each point of definition

$$R(n, m) = R_x(n)\, R_y(m)\,. \tag{12}$$

With the grid of sample points a Cartesian product, the two-dimensional function space of this class of covariance arrays is a direct product space.[8] It follows that the block covariance vectors factor into direct products of smaller dimensioned vectors.

The decomposibility condition is of great practical importance in that it eliminates most of the numerical problems mentioned above.* Before considering these cases, we introduce the direct or tensor product of matrices and list a few of its properties which will be useful in the development to follow.

4.1 MATRIX DIRECT PRODUCT

We consider the square matrices A and B of dimension u, v, respectively. The direct product of $\underline{A}$ and $\underline{B}$, written $\underline{A} \otimes B$, is defined by the partitioned matrix

$$\underline{A} \otimes \underline{B} = \begin{bmatrix} a_{11}\underline{B} & a_{12}\underline{B} & \cdots & a_{1u}\underline{B} \\ a_{21}\underline{B} & a_{22}\underline{B} & & \\ \vdots & & & \\ a_{u1}\underline{B} & \cdots & & a_{uu}\underline{B} \end{bmatrix} \tag{13}$$

of dimension u · v where

$$\underline{A} = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1u} \\ a_{21} & a_{22} & & \\ \vdots & & & \\ a_{u1} & \cdots & & a_{uu} \end{bmatrix}. \tag{14}$$

As the direct product is a particular kind of general matrix product, it satisfies all the algebraic properties of ordinary matrix multiplication. This follows directly from the definition (13). The two identities involving the direct product which we will use in the sequel are

$$(\underline{A} \otimes \underline{B})^{-1} = \underline{A}^{-1} \otimes \underline{B}^{-1} \tag{15a}$$

$$(\underline{A} \otimes \underline{B})\,(\underline{C} \otimes \underline{D}) = \underline{A}\,\underline{C} \otimes \underline{B}\,\underline{D} \tag{15b}$$

where the dimensions of the matrices are assumed to be such that the operations are defined.

4.2 AUTOCOVARIANCE DECOMPOSABLE

For the autocovariance array $\{R_{ff}(n,m)\}$ decomposable, we have

$$R_{ff}(n,m) = R_x(n)\,R_y(m) \tag{16}$$

$$n = 0, 1, \ldots, A+B$$
$$m = 0, 1, \ldots, C+D.$$

To determine the effect of (16) on the numerical realization of (11), we first note that each of the submatrices of $\underline{R}_{ff}$ can be written as

$$\underline{R}_{ff}^{W} = R_x(W) \begin{bmatrix} R_y(0) & R_y(1) & \cdots & R_y(C+D) \\ R_y(1) & R_y(0) & & \\ \vdots & & \ddots & \\ R_y(C+D) & & & R_y(0) \end{bmatrix} \tag{17}$$

$$= R_x(W)\,\underline{R}_y\,.$$

Consequently the fully matrix to be inverted, $\underline{R}_{ff}$, can be written in partitioned form as

$$\underline{R}_{ff} = \begin{bmatrix} R_x(0)\,\underline{R}_y & R_x(1)\,\underline{R}_y & R_x(A+B)\,\underline{R}_y \\ R_x(1)\,\underline{R}_y & R_x(0)\,\underline{R}_y & \\ \vdots & & \ddots \\ R_x(A+B)\,\underline{R}_y & & R_x(0)\,\underline{R}_y \end{bmatrix} \tag{18}$$

Letting

$$\underline{R}_x = \begin{bmatrix} R_x(0) & R_x(1) & \cdots & R_x(A+B) \\ R_x(1) & R_x(0) & & \\ \vdots & & \ddots & \\ R_x(A+B) & & & R_x(0) \end{bmatrix}, \tag{19}$$

the block covariance array $\underline{R}_{ff}$ is clearly a direct product form (in keeping with our previous vector space interpretation of the decomposability), and

$$\underline{R}_{ff} = \underline{R}_x \otimes \underline{R}_y \tag{20}$$

*It also occurs frequently in applications. For instance, the covariance of images are decomposable to a good approximation.[9]

where $\underline{R}_x$ and $\underline{R}_y$ are covariance matrices.

Using the direct product identity (15a), we determine the filter array given in (11):

$$\begin{aligned} \underline{h} &= (\underline{R}_{ff})^{-1}\, \underline{k}_{gf} \\ &= (\underline{R}_x \otimes \underline{R}_y)^{-1}\, \underline{k}_{gf} \\ &= (\underline{R}_x^{-1} \otimes \underline{R}_y^{-1})\, \underline{k}_{gf} \,. \end{aligned} \qquad (21)$$

The computational differences in calculating (21) and (11) are quite significant. Rather than invert a matrix of dimension (A+B+1) (C+D+1), we need only invert two smaller matrices, $\underline{R}_x$ and $\underline{R}_y$, of dimension A+B+1 and C+D+1, respectively. This is, of course, a simpler task (i.e. numerically feasible). Further, the matrices to invert not only are smaller but are of a form more easily invertible. Both $\underline{R}_x$ and $\underline{R}_y$ are covariance matrices and are members of a general class of matrices, finite-dimensional Toeplitz forms. An efficient algorithm, due to Trench,[10] exists for the machine inversion of such matrices.

As a concluding comment here, we note that while the matrix inversion is now much simpler, we still must store the full inverse, $\underline{R}_{ff}^{-1}$, in calculating $\underline{h}$. Fortunately, (21) can be written and calculated in a partitioned form. This allows the row-by-row computation of the filter array with relatively small amounts of rapid-access storage and efficient use of backing storage (for block transfers).

4.3 AUTO- AND CROSSCOVARIANCE DECOMPOSABLE

In addition to the decomposibility of $\{R_{ff}(n,m)\}$, let us assume that the array $\{K_{gf}(n,m)\}$ takes the form

$$K_{gf}(n,m) = K_x(n)\, K_y(m)$$

$$n = -A, \ldots, 0, \ldots, B$$
$$m = -C, \ldots, 0, \ldots, D. \qquad (22)$$

Proceeding as before, we now note that the cross-covariance vector $\underline{k}_{gf}$ can be written as the direct product of two vectors. Letting

$$\underline{k}_x^T = [K_x(-A), \ldots, K_x(0), \ldots, K_x(B)] \qquad (23a)$$

$$\underline{k}_y^T = [K_y(-C), \ldots, K_y(0), \ldots, K_y(D)], \qquad (23b)$$

it follows that

$$\underline{k}_{gf} = \underline{k}_x^T \otimes \underline{k}_y^T \,. \qquad (24)$$

When we use (15b) and (24), (21) becomes

$$\begin{aligned} \underline{h} &= (\underline{R}_{ff})^{-1}\, \underline{k}_{gf} \\ &= (\underline{R}_x^{-1} \otimes \underline{R}_y^{-1})\, (\underline{k}_x \otimes \underline{k}_y) \\ &= (\underline{R}_x^{-1}\, \underline{k}_x) \otimes (\underline{R}_y^{-1}\, \underline{k}_y) \,. \end{aligned} \qquad (25)$$

This may also be written as

$$\underline{h} = \underline{h}_x \otimes \underline{h}_y \qquad (26)$$

with

$$\underline{h}_x = \underline{R}_x^{-1}\, \underline{k}_x \qquad (27a)$$

$$\underline{h}_y = \underline{R}_y^{-1}\, \underline{k}_y \,. \qquad (27b)$$

As might be expected, the general two-dimensional problem has degenerated to two each one-dimensional problems. In addition to the computational advantages due to decomposability of the autocovariance, the storage requirements are now drastically reduced, since (25) can be computed by one-dimensional vector storage. It is interesting to note that (27) represents the specialization of our synthesis techniques to problems of one independent variable.

5. FILTER IMPLEMENTATION

The usual method of implementing one-dimensional nonrecursive digital filters involves the use of the Fast Fourier Transform (FFT).[11] The filtering operation, a discrete aperiodic convolution, is formulated first as a periodic convolution of appropriately defined sequences. The convolution is then calculated in the transform domain (as a product) by means of the FFT.

Our implementation of the filtering operation defined in (2) was developed by extending this method to two dimensions. While the numerical details are somewhat more involved, conceptually the two-dimensional case follows directly from the one-dimensional as introduced by Stockham.[12] A periodic equivalent to (2) is developed by augmenting the input and filter-impulse-response arrays with "grace" borders to prevent spatial aliasing. With this extended region of definition, each of the augmented arrays is transformed via the FFT, the transformed arrays are multiplied together, and the product array is inverse-transformed to give the filter output, $\{g(n, m)\}$, for all n, m, as in (1).

The primary operation, the two-dimensional FFT, is performed by repeated application of a one-dimensional FFT routine. By means of a base-2 FFT algorithm, the machine calculation of the above transform requires 2NM rapid-access memory locations and a computing time proportional to NM $\log_2$NM. The filtering operation may be timed accordingly.

With reference specifically to the processing of pictures by computer, the results presented here apply to noise removal or filtering, to edge enhancement in the presence of noise, to the reduction of quantization effects, and to the restoration of images degraded by the modulation transfer function of optical systems and by noise. Our experience in applying the design algorithm to the reduction of quantization noise may serve as an example. An image was degraded by quantization of the grey scale to 3 and 4 bits. An 11 × 19 filter was designed and implemented on the CDC 7600 computer by means of the FFT. The filtering resulted in a notable improvement of image quality, principally in the high detail regions of the image. The computation time was on the order of one minute for a 512 × 512 image array.

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Chapter 9

ORIGINAL CONTAINS
COLOR ILLUSTRATIONS

INVESTIGATION OF ATMOSPHERIC EFFECTS IN IMAGE TRANSFER

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Progress in the investigation has been good in spite of some delays in obtaining personnel during this initial period. Staffing of the project is now well in hand, however, and a significant increase in accomplishment during the coming months is anticipated. The main progress made during the period which has elapsed since initiation of the work is summarized below in accordance with the format of the original proposal.

9.1. THEORETICAL WORK

The first requirement for a study of atmospheric effects on image transfer is to define the characteristics of the atmosphere itself. The main problem in such a definition is to represent in a realistic manner the characteristics of dust, haze, clouds, and other aerosol particles in the atmosphere. To this end, a literature survey with compilation of a bibliography on atmospheric aerosols is well underway on the project. The literature on atmospheric aerosols is extensive, so this will be a continuing task for some time to come.

Several computations of radiation emerging from the atmosphere for different aerosol models have been performed during the period. This is the first step in determining the radiation background against which surface objects are seen from high altitudes. The Junge aerosol model, with variable size frequency distributions and amounts of absorption, has been used for the computations. The present computer program, which was developed on a previous project,

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takes account of single scattering of light by aerosol particles but neglects the photons which have undergone two or more scattering events in their paths in the atmosphere. In an effort to take account of all orders of scattering, a study of the "doubling technique" derived by van de Hulst has been started. It is expected that a computer program based on this more general method will be developed during the remaining part of the first year investigation. This will permit a much more realistic description of radiation backgrounds and image transfers for the actual atmosphere (which always contains a significant aerosol component) than is possible with the single scattering approach.

Much thought has gone into a consideration of the properties of light reflected from surfaces, be they plant surfaces, soil surfaces, or other surfaces of interest in earth resources. One can consider the specific intensity of light incident on a surface as a vector intensity I (θ_o, ϕ_o) from a direction defined by zenith angle θ_o and azimuth ϕ_o. This incident intensity is represented in its most general form as a four-element column matrix of the well-known Stokes parameters. Thus

$$\underset{\sim}{I}^{i}(\theta_o, \phi_o) = \begin{bmatrix} I \\ Q \\ U \\ V \end{bmatrix}^{i} (\theta_o, \phi_o)$$

where I is the total intensity and elements Q, U, and V define the state of polarization of the incident light. Similarly the light reflected into the outward direction at zenith angle θ and azimuth ϕ is

$$\underset{\sim}{I}^{r}(\theta, \phi) = \begin{bmatrix} I \\ Q \\ U \\ V \end{bmatrix}^{r} (\theta, \phi)$$

This reflected intensity is given in its most general form by multiplication of the original intensity by a sixteen-element reflection matrix $\underset{\sim}{R}(\theta_o, \phi_o; \theta, \phi)$ which is characteristic of the particular surface in question. Thus

$$I^r(\theta, \phi) = \begin{bmatrix} I \\ Q \\ U \\ V \end{bmatrix}^r (\theta, \phi) = \begin{bmatrix} r_{11} & r_{12} & r_{13} & r_{14} \\ r_{21} & r_{22} & r_{23} & r_{24} \\ r_{31} & r_{32} & r_{33} & r_{34} \\ r_{41} & r_{42} & r_{43} & r_{44} \end{bmatrix} \cdot \begin{bmatrix} I \\ Q \\ U \\ V \end{bmatrix}^i (\theta_o, \phi_o)$$

This means that by knowing the characteristics of the incident light and measuring the Stokes parameters of the reflected light, it is theoretically possible to define each of the sixteen elements of the reflection matrix of a given surface and thereby obtain sixteen signatures by which a surface can be identified. In fact, by combining elements for additional signatures and using the wavelength dependence of matrix elements it is possible to get an extremely large number of different reflection signatures to characterize a surface or distinguish among natural surfaces of various types. This gives a much more flexible and powerful method for remote sensing than the traditional method in which simple scalar intensity (one of the sixteen elements of the reflection matrix) is the observed quantity.

In order to use this more powerful method, one must have the capability of sensing the polarization, both plane and circular, of the reflected light. Coulson et al (1965) have shown that natural surfaces introduce various amounts of plane polarization into the reflected light. Typical results of those measurements are shown by the plot of degree of (plane) polarization versus angle at which the surface is viewed in Fig. 9.1. A very considerable variation of polarizing properties among the surfaces is shown by the curves. Although no similar measurements of the circularly polarized component are available, it is expected that circular polarization will show similar large variations with type of surface.

It is expected that the plane and circular polarization signatures can be combined with the intensity signature to uniquely specify the type of surface responsible for the reflection. Measurements of the entire array of Stokes

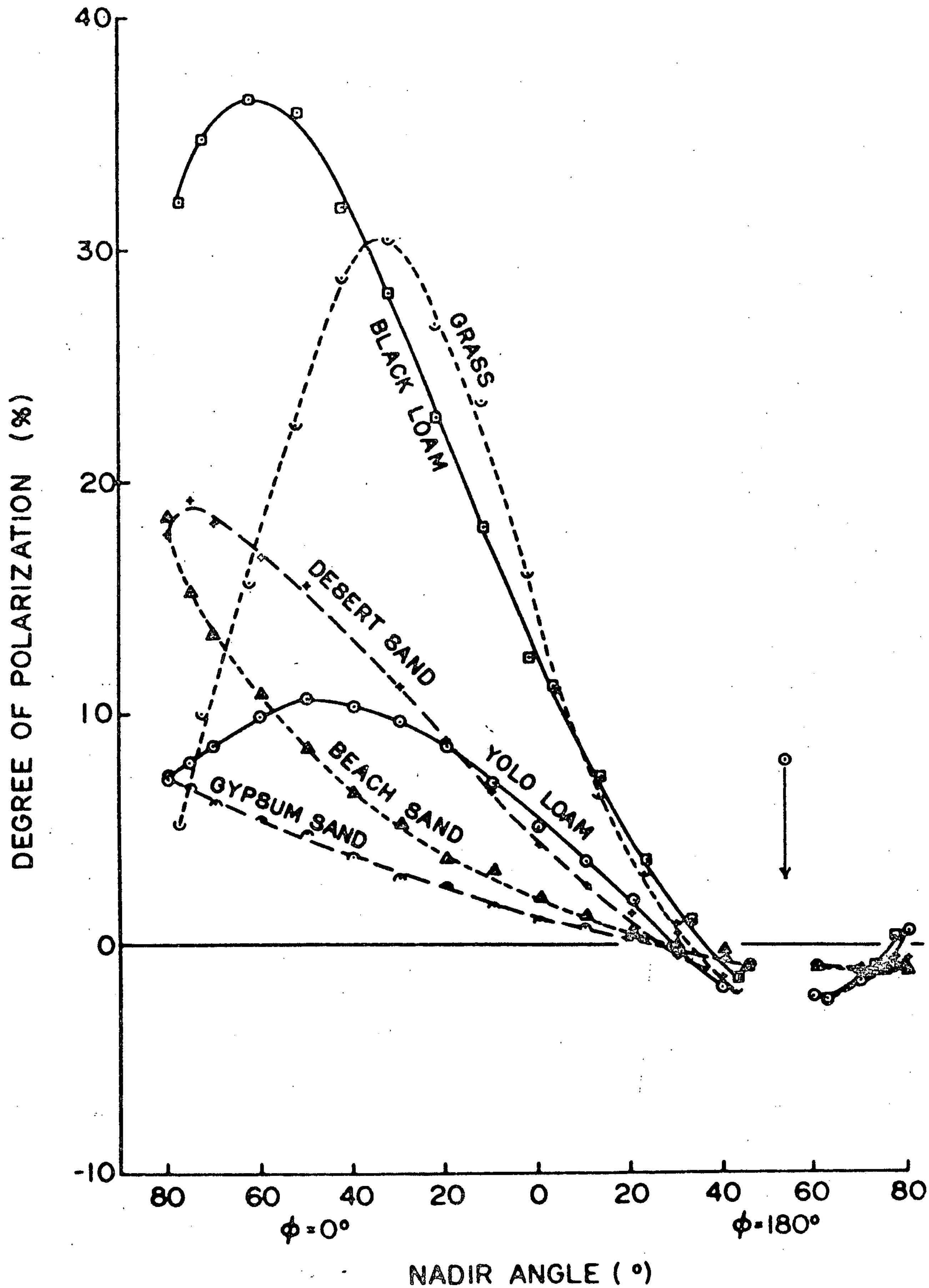

Figure 9.1. Degree of polarization of light reflected from natural surfaces.

parameters of the reflected light will be necessary in order to accomplish such a separation of types of surfaces. The new instrument now in design will have the capability of making the required measurements.

9.2. EXPERIMENTAL WORK

Instrumentation

A two-channel polarimeter is being constructed to measure the Stokes parameters. The instrument will use photon counting to make high precision measurements, and will be under the control of an available PDP-11 portable computer for high-speed acquisition of data. The two channels of the instrument are designed to be used independently in either an asynchronous or synchronous mode.

A block diagram of one channel of the instrument is shown in Figure 9.2. The only shared feature of the two channels is the direction in which the instrument points. Thus, the goniometric controls are common to both channels. The part of the instrument above the dotted line comprises the instrument package. The rest of the instrument, consisting of hardware computer interfacing and the computer itself, can be removed from the instrument package by a long signal cable. Each block of the diagram in the top row represents a modular component of the instrument package. After the modules are bolted together, a light tight shield can be slipped over the entire package.

The path of a beam of light to be analyzed can be traced from right to left in the top row of boxes in Figure 9.2. After the beam is collimated it passes through a shutter which can be closed for dark-current measurements. A quarter wave retardation plate can be inserted into the beam which then passes through a rotatable linear polarizer. Following the polarizer are a set of interference filters for removing all but a particular color from the beam, and a set of neutral density filters for attenuating the light intensity. A

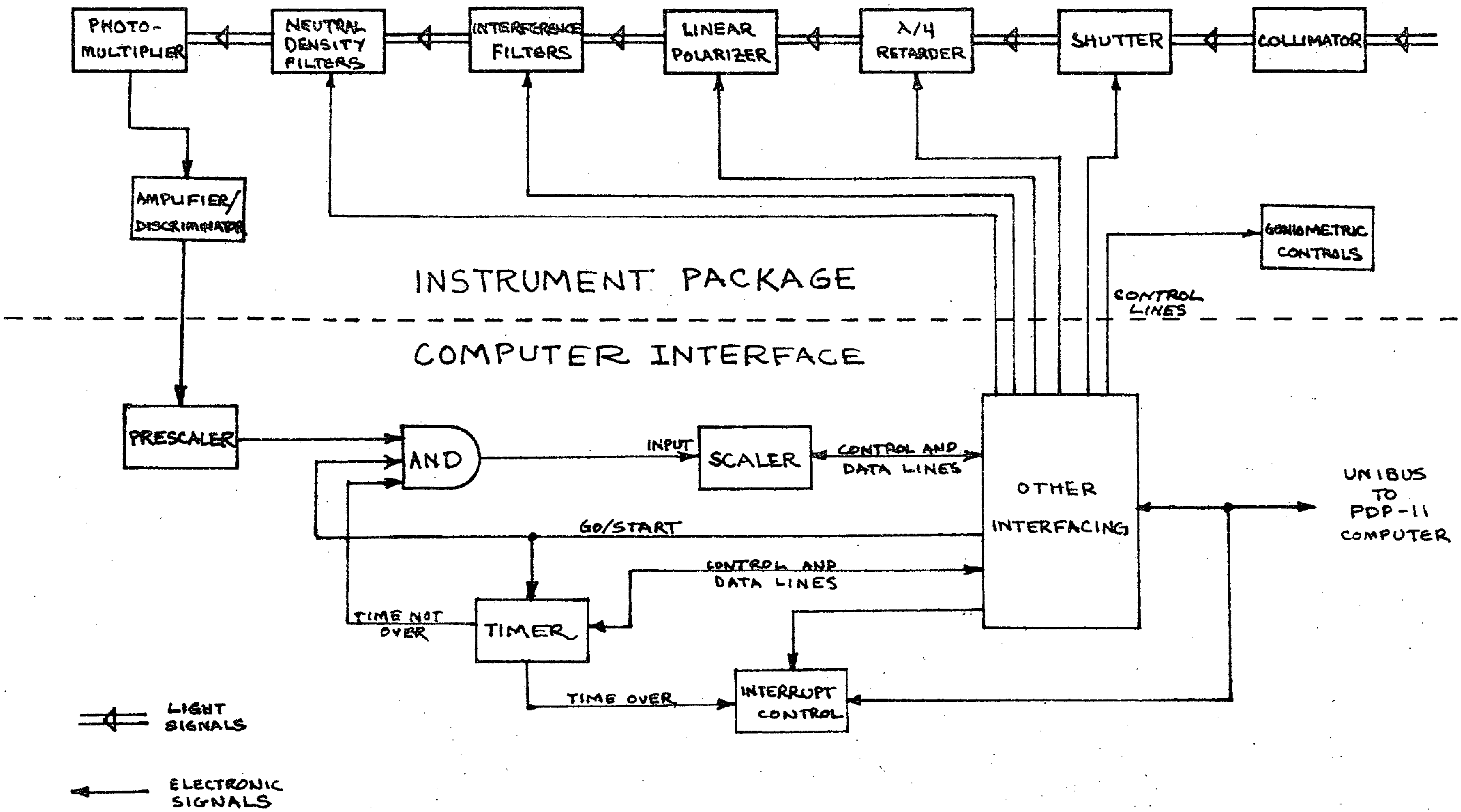

Figure 9.2. Schematic diagram of computer-controlled dual channel polarimeter.

conventional high-gain photomultiplier tube converts the remaining light into electronic information. Each channel of the instrument will have a tube with different spectral response so that the whole visible spectrum can be measured with good efficiency.

Since light by nature is quantized into photons, the output of the photomultiplier tube will be pulses which correspond to single photons. If the photomultiplier tube is followed by a wide-band high-gain amplifier and a low-level discriminator, standard logic pulses can be obtained corresponding primarily to single photons. These standard pulses are typically as narrow as 10 nanoseconds, allowing counting rates up to 10^8 per second. Several advantages of photon counting over conventional dc (analog) techniques are as follows: (1) excellent long-term stability, (2) linearity of response over a wide dynamic range, (3) discrimination against both dc surface leakage and low amplitude events not originating from the photocathode, (4) high-speed digital processing capability without the use of analog to digital conversion, and (5) optimum signal-to-noise ratio for quantum limited signals. The combined function of wide-band amplifier and discriminator is provided by a rugged commercial state-of-the-art solid-state unit. The entire instrument package except for the photomultiplier tube and amplifier-discriminator will be constructed by the Agricultural Engineering Shop at Davis at no cost to the project.

The full capability of the instrument can only be realized if it is controlled automatically. This function will be provided by a PDP-11 computer which will be available in mid-February. The PDP-11 is a 16-bit computer which was designed for easy interfacing. The entire computer, except for a teletype, fits in a 5-foot equipment rack. The interface of the instrument package to the computer is shown in Figure 9.2. A prescaler divides the counting rate by four and converts the pulses to standard transistor logic. A timer can be loaded with a time from the computer. A start command then starts the timer and allows counts from the prescaler to go to the main scaler. When the timer has counted for the specified time, an interrupt signal is sent to the computer and the scaler input is interrupted. The interrupt signal to the computer causes it to interrupt its present task if it is busy and go to a special routine to read and reset the scaler, load the timer, send control signals to the instrument package, and restart the system. The computer then returns to its lower priority job--reducing previous data.

The entire interface has been designed around digital integrated circuits and PDP-11 hardware. Construction of the interface will begin as soon as the computer arrives at Davis in mid-February. The complete instrument is expected to be operational by May.

The theory of operation of the polarimeter is well understood. Let I, Q, U, and V be the Stokes parameters describing the light to be analyzed, and I^1 be the intensity transmitted by the linear polarizer. If the quarter wave retardation plate is removed from the beam, then the transmitted intensity is

$$I^1 = 1/2 \; [I + Q \; Cos^2\psi + U \; Sin^2\psi],$$

where ψ is the angle between the axis of transmission of the linear polarizer and an appropriate reference axis. By rotating the linear polarizer and measuring I^1 the three Stokes parameters I, Q, and U can be determined. The remaining parameter, V, can be determined by inserting the quarter-wave retardation plate. If the angle of the transmission axis of the linear polarizer is $\pm 45^o$ with respect to the fast axis of the quarter wave plate, then

$$I^1_{\pm} = 1/2 \; (I \pm V),$$

or $$V = I^1_+ - I^1_- \; .$$

Thus, a complete description of the beam to be analyzed, which is characterized by the four Stokes parameters, is obtainable with the polarimeter.

Reflection measurements

In an effort to better distinguish surface characteristics, a relatively large number of measurements of surface albedo have been made for different types of natural surfaces. Although many of those measurements were sponsored by a different project, they have been extended under this grant and all are available for use as necessary. Up to the present time surface albedo has been measured in six wavelength ranges in the ultraviolet, visible, and near infrared spectral regions continuously from before sunrise until solar noon for six different vegetated surfaces (bluegrass turf, alfalfa, immature rice, mature rice, sugar beets, and sorghum), four soil surfaces (disked Yolo loam,) puddled Yolo loam, wet Yolo loam, and Sacramento clay), and two roadway surfaces (concrete and blacktop). These data are the subject of a paper to be presented at a scientific meeting in March, 1971. A copy of the paper will be included in the annual report of this project.

9.3. IMAGE ACQUISITION IN POLARIZED LIGHT

Some preliminary work on the acquisition of images in polarized light has yielded a considerable number of color slides and prints, black-and-white prints, and sixteen hundred feet of 16-millimeter movie film. The movie film was obtained by personnel (Earl Petersen) at NASA Ames Research Center from the Convair 990 aircraft flying at various altitudes above the surface. The light directed upward at aircraft altitude was analyzed by a sheet polarizer which was rotated by a motor-driven mount installed in front of the camera lens. By this means the intensity of light incident on the film was changed by the rotating polarizer, the change of intensity being proportional to the degree of plane polarization of the incident light. By projecting the movie in the normal manner, one can see the effects of polarization by changes of the intensity of the projected images and determine which objects or areas of the image are most strongly polarized.

A second polarization effect can be seen by the use of color slides, as shown in Figures 9.3a and 9.3b. The pictures were taken with an ordinary 35-mm camera with a rotatable polarizer in front of the lens. The change of the image, which was particularly pronounced for the image of the lake, is produced by a change of orientation of the axis of transmission of the polarizer. In Figure 9.3a this axis was oriented horizontally, and thus transmitted preferentially the horizontally polarized light reflected from the lake surface. In Figure 9.3b the transmission axis was oriented vertically, in which case the horizontally polarized component was intercepted and the vertically polarized component was transmitted. Since the vertically polarized component was much weaker than the horizontally polarized component, the image of the lake is much darker in Figure 9.3b than in Figure 9.3a. The change is much less for the surrounding terrain than for the lake, with a result that the contrast is considerably enhanced by the use and proper orientation of the polarizer in front of the camera lens. This is one example of possible image enhancement by the use of polarizing optics. Effort is continuing to investigate in greater detail the advantages to be gained by the method for the case in which the images are obtained on photographic film. It is expected, however, that the maximum benefit will be gained by the use of electronic scanning of images. Development of the required techniques by Dr. V. Algazi at Davis and by Jerry Lent at Berkeley as a part of this overall investigation is being monitored with great interest and anticipation.

Figure 9.3A. Photo of Gold Lake taken in polarized light with plane of polarization oriented horizontally.

Figure 9.3B. Photo of Gold Lake taken in polarized light with plane of polarization oriented vertically.

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Chapter 10

COASTAL ZONE AND RIVER DELTA STUDIES

Although the title of our multi-campus study indicates that an "integrated study of earth resources in the state of California" is to be undertaken, it was recognized at the outset that emphasis on one resource initially (i.e. the water resource) was desirable. The previous chapters have documented our progress to date in our attempt to define the role of remote sensing in this area, using the California Water Project as a case study.

Our discussions with California Resource Managers this first year have served to reemphasize the need for similar studies in other critical resource areas, most notably in the coastal zone and river deltas of California. We feel that case studies in these two resource problem areas can be carried out efficiently under our current structure. In fact, these studies appear ideally suited to our integrated approach (see Figure 10.1) and are complementary to our ongoing program of research centered around the California Water Project. In addition, we have attempted to familiarize ourselves with other ongoing programs in these areas, e.g. the studies being carried out in San Francisco by members of the Geographic Applications Program, U.S.G.S.

Rationale for this recommended extension of work in California is provided in the following sections.

10.1. APPLICATION OF REMOTE SENSING IN TIDAL ESTUARIES AND RIVER DELTAS

Contained within the NASA California Test Site, in what has been referred to as the Central Section, is the Sacramento-San Joaquin River Delta. The sug-

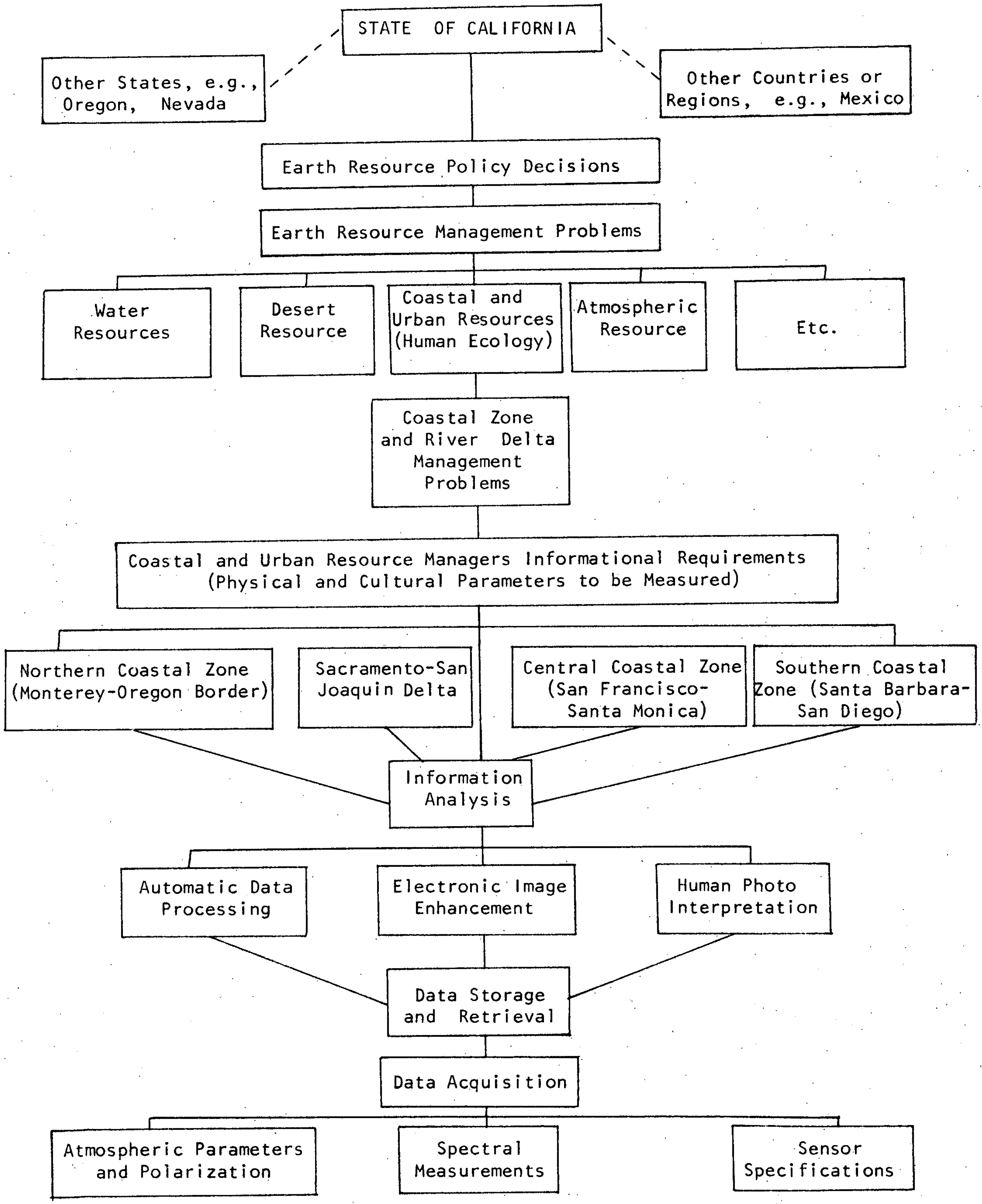

Figure 10.1. Diagram illustrating the structure of the proposed integrated project and its relation to other critical resource problems in California.

gestion for inclusion of the Delta in the gross research effort was made initially in September 1970 in the integrated work statement prepared jointly by the six-campus participants.

The Delta is a complex hydrologic system which links the saline waters of San Francisco Bay and the fresh waters of the Central Valley watershed. While serving as the hub of contemporary water development in the State of California, its principal role is seen as a point of redistribution and allocation among competing uses for (1) export to the San Joaquin Valley and southern California; (2) agricultural, municipal, industrial and recreational uses within the Delta; and (3) as a hydraulic and ecological regulator in the extreme western Delta and San Francisco Bay.

The areal extent of the Delta and its relationship to the Central Valley and San Francisco Bay are shown on Figures 10.2 and 10.3.

10.1.1. Research Objectives

The inclusion of the Sacramento-San Joaquin Delta as a study element in the on-going Integrated Study of Earth Resources in the State of California Using Remote Sensing Techniques is a logical extension of the research prototype, the California State Water Project, into one of its key facility areas. The Peripheral Canal, the Delta Pumping Plant, the North Terminus of the State Aqueduct, and the North Terminus of the San Joaquin Valley Master Drain are all project works located in the Delta area.

As the State Water Project becomes fully operational, the Delta system will, hydraulically speaking, become almost fully regulated by the work described above. Predictions have been made to anticipate what full regulation, steady-state conditions might have on water quality, aquatic biota and sediment transport and deposition. The physical model of the Delta, constructed and operated by the San Francisco District of the U.S. Army Corps of Engineers, as well as mathematical models formulated by others, have been employed as predictive

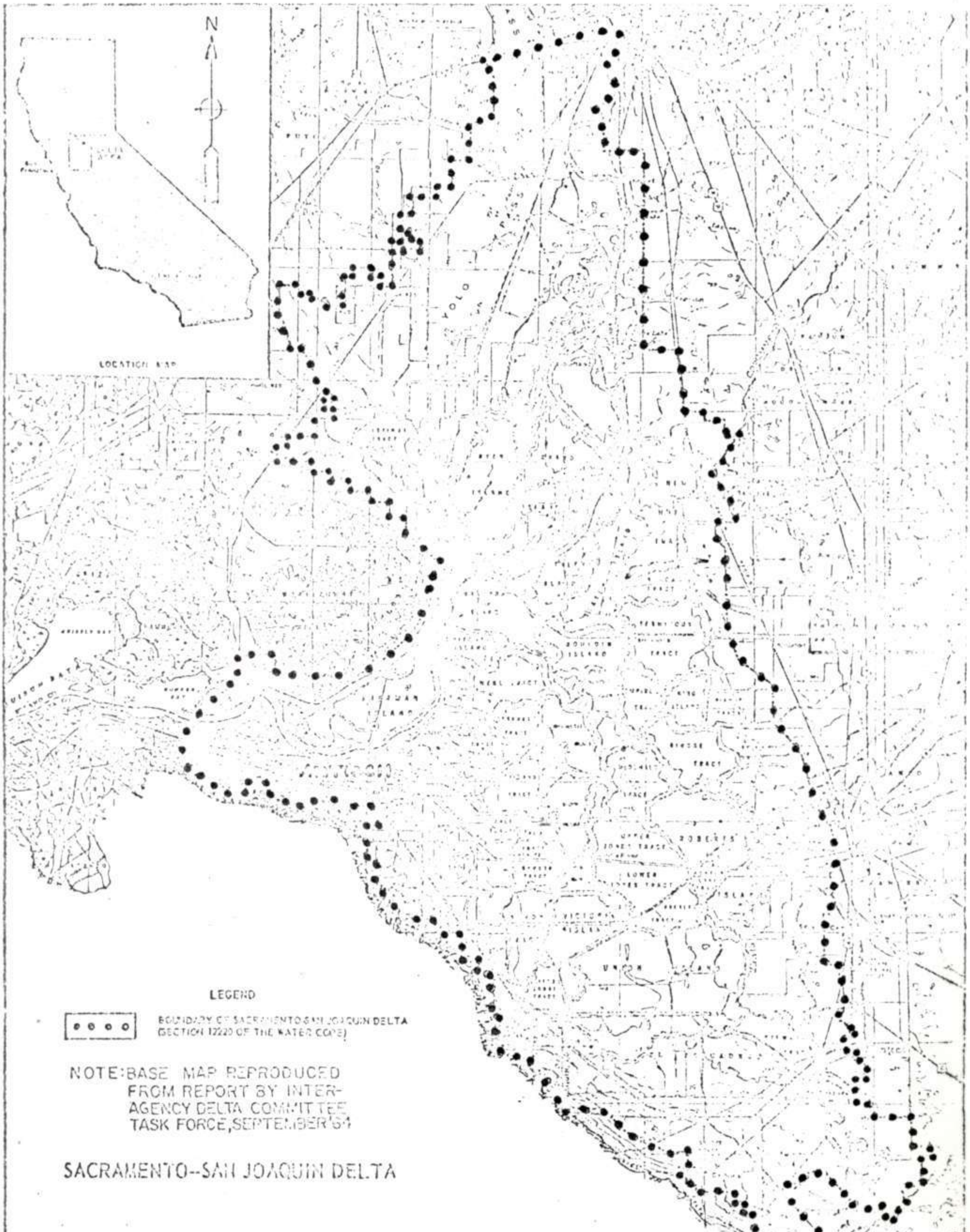

Figure 10.2. Map of the Sacramento-San Joaquin Delta.

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Figure 10.3. Artist conception of the Sacramento-San Joaquin Delta.

tools; however, verification of model results in the prototype has been often expensive and inexpedient.

It is recommended that work in the Sacramento-San Joaquin Delta be an expansion of Burgy's (UCD) task in the integrated study. Limited research objectives in the Delta, compatible with other on-going remote sensing user-research and within the framework of the overall statewide study by the University of California, is seen as a necessary adjunct to specific user applications. The following procedure is proposed:

(1) Select a representative Delta sector where pre-project ground truth can be obtained, but which will be hydrologically altered with full implementation of the State Water Project. (a) Hog Slouth has been proposed as a test locale (see Figure 10.2).

(2) In cooperation with FRSL (UCB), examine possibilities for the use of remote sensing techniques in assessing quantitative and qualitative aspects of hydrologic, hydro-biologic, and terrestrial features of the Hog Slough test locale.

(3) Integrate with on-going UC Davis campus efforts in defining, classifying and establishing user applications for hydrologic parameters.

10.2. COASTAL ZONE STUDIES

California's Coastal Zone is an important resource. One has only to go to a public beach on a warm summer's afternoon to see how much this great natural resource means to the state of California. On any given summer Sunday the crowds at our beaches exceed those gathered at any sporting event or enjoying any national park. Indeed, some 75% of the population of the state of California reside within a one-hour drive of the shoreline. It is estimated that by 1980, 20 million people will live within close proximity to coastal areas.

The pressure on California's coastal resources is increasing. As of

1965, only two coastal counties in California had 50% or more of their coastline under public control and no county controlled more than 71% of its coastline.

The state's total shoreline is approximately 1,224 miles in length. Of this figure, only 335 miles of shore are open to public access and of this 335 miles, 219 miles are in state parks. California's seashore can generally be divided into three physiographic categories: (1) beach, which may vary in composition from fine sand to cobbles or shells: (2) bluff, bank or cliffed areas that may be immediately adjacent to a narrow beach; and (3) marsh that may be either tidal or non-tidal. Of the state's 1,224 miles of shoreline, 535 miles are rocky shore unsuited for overall general public recreational use. The need for public recreational facilities is not the only pressure on the coastal margins of the state. Industrial and urban development, as well as our public utilities, are all vying for coastal space. Developmental pressures along the shore are matched by the pressure for offshore developments such as oil drilling and the harvesting of kelp.

The coast of California then serves many purposes and as a prerequisite for rational planning of the multi-purpose use of the coastal zone a detailed inventory of California's coastal lands should be initiated. This inventory should include a description of the natural and cultural features of the coastal zone. It should be so organized as to provide for rapid retrieval and to provide means for continuous updating. Coastal lands as defined here should include both publicly and privately owned lands from the seaward boundary of California's tidelands to a boundary of variable distance inland from the beaches and the margins of the bays.

It is perhaps apparent that all members of the current integrated study will not, and should not, participate in Coastal Zone studies. Certain of our investigators (e.g. Algazi and Coulson on the Davis campus) are developing techniques which are basic to <u>any</u> remote sensing application. Others (e.g. Churchman of the Berkeley campus) have been considering the problems of development in the Coastal Zone since the inception of the study, due to the interrelationship of this resource with others in California. Hence, this recommended extension of research in California will be carried out principally by the applied groups in the integrated study (i.e., FRSL at Berkeley, Estes' group at Santa Barbara, and Bowden's group at Riverside). Examples of the types of studies to be carried out are provided by the following statements of work in the central and southern portions of the Coastal Zone. Similar studies would be undertaken by the Forestry Remote Sensing Laboratory of the Berkeley Campus in the Northern Coastal Zone (i.e. Monterey to the Oregon border).

10.2.1. Central Coastal Zone Studies

It is proposed that under this integrated study Santa Barbara would assume the responsibility for that portion of the California coast extending south from San Francisco to Santa Monica. The present landscape is characterized by small, scattered urban nuclei amidst an essentially rural setting. The area is, however, moving in the direction of urbanization at an increasing rate. A study of this environment must be termed coastal/urban rather than simply coastal. The portion of the California coast so defined is a logical extension of the existing West Side San Joaquin Valley study presently being conducted by personnel on the Santa Barbara Campus.

Coastal cities, with an inordinate percentage of the state's population concentrated in small areas, are heavily dependent on interior agricultural areas for food, raw materials, and other economic considerations. Furthermore, water from the California Aqueduct will be transported to selected points on the coast to supply increasing demands and improve the quality of existing water facilities. It should also be pointed out that both areas, interior and coastal, are in a dynamic state of change and growth. There is a significant probability that the relationship between them will not only be strengthened by current events, but that the relationship will have a decided influence on their respective modes of development.

The coastal California zone is a highly complex environmental system in its own right. There are characteristics, peculiarities, potential, and problems in the coastal environment that need to be investigated more thoroughly for planning and development purposes. Landforms, vegetation associations, the rural sector, urban nuclei, and the general ecology of the area are undergoing dramatic changes. Incomplete or misleading data are severely handicapping rational decision-making and planning for these transformations.

Remote sensing could make a positive contribution to the inventory, evaluation, and policy-making decisions on the present and future of such coastal/urban complexes. Research at the Santa Barbara campus would concentrate on the following problem areas:

1. Coastal land use.
2. Coastal hazards, i.e., slope slippage, fire and flood potential, and pollution.
3. Rural/urban dynamics.
4. Settlement patterns.
5. Accessibility along coasts.
6. Recreation: current status and potential.
7. Structure and function of coastal activities.
8. Coastal ecosystems.

The major emphasis during the initial phase of the study would be the development of a coastal land-use classification system which depicts and reflects essential parameters of environmental conditions and quality. The basic components of such a classification scheme should be identifiable from remote sensing imagery and be compatible with requirements of accuracy and timeliness. Furthermore, the system should lend itself to computer processing and automated mapping techniques. This system at its most elementary level might include a series of basic single category maps with information stored according to a geographic coordinate system. By interfacing these series correctly, multiple categories could be generated and displayed for any or all of the coordinate points. Factors could be added to this type of system which would negate mutually exclusive land-use categorizations from considerations in planning new developments by listing those uses which would enhance or detract from the environmental system as it presently exists.

In addition to overall land-use mapping, an effort would be made to assess environmental hazards affecting the coastal environment. We would attempt to delimit those areas prone to earthquakes, floods, earth slippage, fire, and pollution (both air and water). Other studies, such as those mentioned in the previous listing, would be conducted as additional inputs to a fuller understanding of the character, problems, and potentials of this complex coastal environmental system.

10.2.2. Southern Coastal Zone Studies

Within the framework of this integrated study, the Department of Geography, Riverside, would assume responsibility for that section of California coast reaching from Santa Barbara south to San Diego. Because the present landscape is dominated by urbanization, the study must be termed coastal/urban rather than just coastal.

The geographic area described includes about 12 million people that live in the coastal "Mediterranean" environment of southern California. One way to describe the location is "the area from the Pacific shoreline, inland to the limit of the sea breeze." Another physical determinant is "all that land drained by tributaries to the Pacific Ocean between Santa Barbara and

San Diego." By using the above definitions, a satisfactory overlap is obtained with the prominent "sink" areas under influence of the California State Water Project. (All but the High Desert and north slope of the San Gabriel and San Bernadino Mountains are included.)

The expertise to handle such an area exists at the University of California, Riverside. Three previous research contracts have contributed significantly: (1) Remote Sensing of Southern California and Related Environments, funded by Geography Applications Program of USGS with NASA funds. The emphasis and research reported concentrated on the Salton Sea area, San Bernardino Mountains, and the City of Los Angeles. (2) Remote Sensing of Coastal Baja California and selected areas of Southern California funded by the Geography Programs, Office of Naval Research. The research program consisted of remote sensing of both physical and cultural environments along the coast of the entire peninsula of Baja California plus an intensive study of Santa Cruz Island (offshore from Santa Barbara) with remote sensing techniques. (3) Project THEMIS--part of which was funded to do a series of investigations into obtaining Geographic Information from middle, high and space altitude imagery and data. Several selected studies on energy balance, transportation networks, residential housing quality, fire and flood danger and morphology, form and function of the city in general were conducted. Most important of the outputs under Project THEMIS was the development of an automated image data conversion and mapping system (described in Section 7.5) which can now be made available to future research projects.

All of the above projects are completed or in final stages. One of the reasons the University of California, Riverside, group played such a minor role in the original proposal on the "Integrated Study of Earth Resources in the State of California Using Remote Sensing Techniques" was the heavy commitment to the three described projects. We are now in a position to assist the present project in a more formative and beneficial manner.

The study of coastal southern California is a "knotty" and difficult undertaking. Man's influence on the natural environment is present along the entire coast. Coastal landforms, coastal plant communities, and the general ecology have been dramatically changed within the last few decades. Erosional forms such as sea cliffs and wave-cut platforms, and depositional forms such as beach ridges and sand dunes, have been modified by bulldozers and sprawling, low-density settlements. The environmental conditions in terms of human occupancy are rapidly deteriorating.

The land-water-air interface represents a complex environmental phenomenon. Resource use and management and maintenance of environmental quality suitable for human habitation are of prime concern. Remote sensing can play a significant role in the inventory, evaluation, and policy-making decisions on the present and future of coastal/urban complexes.

Of prime concern, but with little actual data to back them up, are some of the following:

1. Coastal land use.
2. Accessibility and maneuverability along coasts.
3. Settlement density and patterns.
4. Inflows and diffusion of natural and man-made discharges.
5. Function of coastal activities.
6. Morphology of coastal area.
7. Energy exchange at near shore, shore, and inland sites.
8. Location and function of industry, commerce and services.
9. Survey and prediction of disasters and hazards, i.e. slope slippage, brush fire, flood potential, pollution.
10. Monitoring of erosion, deposition, siltation, etc.

11. Recreation: present assessment and potential location.

The list can be almost endless, but the above serve as guidelines to research tasks. Some can only be sampled while others can be done in entirety. Remote sensing, because of its ability to look at the whole coastal/urban complex and do it rapidly, can play an important role in obtaining vital and currently unavailable data.

Remote sensing, in fact, may make it possible to begin studies of a new kind of coastal/urban ecology, viewing the coastal megalopolis as a complex system of interconnecting and interacting elements with inputs and outputs of energy and matter.

Case study

Rather than expound on all 11 items listed above, we will develop and discuss a representative study in the following section. Item number seven (7), energy exchange and the natural energy budget of coastal southern California, is the example.

It is proposed here to study the natural energy budget of southern California by the use of suitable sensors that measure the amounts of heat reaching and leaving the earth's surface. In distinction to the instruments used in conventional weather observation, an energy budget analysis tracks the pathways in which all forms of heat are handled at the earth-air interface. These pathways must be measured if mistakes are to be avoided in decisions important in a variety of ways to the present and future development of California. Only a few examples are mentioned here.

(1) California, even southern California, maintains a large and prosperous agricultural industry based on the cultivation and processing of a wide variety of plants and animals used in food and industry. The growing urban population has enforced change both in the location and type of agricultural

activity. The removal of frost-sensitive subtropical crops to new localities, and the heat tolerances of cattle, are examples of two large income-producing sectors of California agriculture for which enhanced knowledge of the natural heat balance would lead to increased efficiency of production and decrease of climate-related losses.

(2) In southern California, as elsewhere, the per capita use of electrical energy is increasing; this in the face of increasing population numbers foretells a large increase in future electricity consumption. Air-conditioning needs form a large part of the consumption pattern of electricity in summer. However, substantial differences in the need for air-conditioning exist in southern California, according to regional differences in the natural heat budget. As a part of wise regional planning, analyses should be made of the savings possible through location of future population in areas with minimum energy needs. This analysis seems all the more necessary in view of impending limitations on the rate of growth of additional power generation in southern California.

(3) As population concentrations involve ever greater numbers of people, and increased property value, the natural hazards created by fire, flood, and wind also increase in importance. Heat budget analyses apply to a number of important considerations with respect to natural hazards, including evaporation losses of water, growth of native vegetation in watershed slopes, and ignition temperatures of natural fuels.

Given these considerations of the importance of energy budget studies in California, we may now consider several aspects of the nature of the problem and the approach proposed for investigating the energy budget as part of the proposed "Southern Coastal Zone Studies."

Energy exchange or earth energy balances (i.e. budgets) are based on the premise that the intake of energy must always equal the output if thermal equilibrium is to be maintained. For the planet, the relationship in principle is simple: the solar energy absorbed is equal to the energy emitted when short-term cyclic variations are averaged out and energy sources other than the sun are considered negligible. At the surface, and particularly at the land-water-air interface, the balance involves a number of indiscrete energy flows and fluxes because the interface is the transfer surface among three important planetary energy reservoirs. Any consideration of energy exchange at the surface, then, must involve not only the direct receipt of solar radiation and its re-emittance but the transfer of energy to and between the energy reservoirs as well. The manifold nature of the energy flows has rendered complex past examinations of the energy budgets of the earth because measurements have been made at or close to the earth-air interface.

A problem that has made observation difficult and conclusions often lacking meaning is the three-dimensional nature of the interface at the surface of energy exchange. Simple soil or water surfaces may well have a two-dimensional form, but where a vegetation canopy exists or tall buildings rise as in an urban environment the observer may well find himself within an "interface zone" rather than at the place of basic energy transfer to the atmosphere. Further, the interface is a mosaic of many energy transfer conditions necessitating the taking of many samples in order to try to gain an energy exchange picture of the larger system of which the sample is a part. Even though great care is taken with the individual observations to minimize possible error, the gross estimates that must be made in order to assign spatial value to the various samples may make the final integrated result hit wide of its true mark. For these reasons and for reasons of simplicity, speed, and direct mapability, the use of information sensed remotely above the interface zone has strong appeal. Yet at this time, the correlation of remotely sensed thermal radiation data to surface environments is in only an embryonic stage of understanding. Until the meaning of information provided by existing sensors is more fully understood or more compatible sensing systems are devised, the use of remote sensing techniques for the study of energy exchanges at the interface is handicapped. Those of us in the Department of Geography at the Riverside campus of the University of California who have worked with data acquired from the Southern California Test Site of NASA and Project THEMIS have become acutely aware of this fact. Explanation of some of the modulations of thermally scanned images, for example, are not completely clear both as to the temperature relationships of the emissions and as to the nature of the energy movements that have produced the surface temperature variations recorded on the scan. If surface environments can be interpreted accurately from this type of data, rapid surveys of the many earth energy balances can be made which will have significant ramifications into coastal environments, oceanography, climatology, and urban dynamics, to name a few.

It is proposed, then, that the investigators under this grant commence a definitive study aimed at better correlation of remotely sensed radiation data with the surface environments they are sensing. This will logically involve:

1. The development of surface correlation for energy exchange measurements that will supply surface environmental data compatible with that obtainable with existing remote sensors.

2. The development of an array of instruments, suitable for the above observations, that will supply as much pertinent energy information as is possible and practicable for making correlations.

3. The conduct of initial work with the instruments using simulated remote sensing and a backlog of thermally-scanned imagery of local sites in order to make tentative working models for both measuring methods and the analysis of data.

4. The development of new methods of measurement that may involve the

design of new instruments and the correlation of these with existing instruments, and

5. The making of overflights with remote sensors, to provide information regarding coastal energy exchanges and to correlate airborne with surface readings.

The above tasks imply the need for:

1. An array that includes the standard radiation measuring instruments such as net radiometers, pyranometers, hemispherical all-wave radiometers, soil heat flux measuring systems, and thermistor arrays, all with recording capabilities.

2. A hand-held, narrow bandpass, limited field of view radiometer that can be used both for routine energy measurements and as remote sensor simulators, both on the surface and at various distances above the interface.

3. Means to measure the sensible-latent heat flux in order to complete energy balances with which to check other measurements and instruments that may be developed.

4. Flight support with aircraft equipped with compatible radiation sensors to accomplish the above.

Although flight support is requested, initial information and possible working models may be derived from thermal infrared scan images that are already on hand in the image library of former remote sensing projects funded by USGS/NASA. Since the recorded emission modulations are only relative and not absolute due to the automatic gain control of some instruments, it is felt that conditions at specific sites can be closely enough matched to obtain a great deal of additional information to interpret the images. Conversely, the scan images can be used to help establish ground measurement models and aid in the tentative interpretation of the data so obtained.

Although the primary objectives of this part of the proposal are outlined above, there is always the possibility of new breakthroughs as regards both methods and instruments. Such methods, essentially remote sensing, would permit rapid surveys of the advection of water vapor with its latent heat load inland from coastlines as well as the effect of water vapor on the radiation balance of coastal areas. Initial investigations of the possibility can be carried out with the hand-held radiometers used as remote sensor simulators.

Instrument arrays for correlation of ground measurements with remote sensing have already been established and are operating in the semi-arid and montane environment of southern California. Correlation and recording are now needed for the coastal area. Much of the expertise developed resulted from experiments during Project BOMEX. The present project would benefit from fairly low cost of equipment because design, purchase procedure and "de-bugging" resulted from the funding from earlier sources. We plan to work closely with investigators from UC Davis on this particular experiment.

Conclusion

All other coastal studies mentioned in the previous listing will be done with the best available sensors. However, the majority will result in output through the automated image data conversion and mapping system and will be oriented toward application of ERTS and Skylab data at the appropriate times.

Coastal land use is of high priority in the study. The use of the land is a key to the outcome of all other study items listed. The research will, of course, require aircraft support from NASA or related agencies. In some instances, because of need for "on-time" or "opportunity" sensing, modest aircraft support will be supplied from the requested budget.