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AN INTEGRATED STUDY OF EARTH RESOURCES

IN THE STATE OF CALIFORNIA

USING REMOTE SENSING TECHNIQUES

A report of work done by scientists
of 5 campuses of the University of
California (Davis, Berkeley, Santa
Barbara, Los Angeles and Riverside)
under NASA Grant NGL 05-003-404

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UNIVERSITY OF CALIFORNIA, BERKELEY

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Chapter 1

INTRODUCTION

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I. BASIC CONSIDERATIONS

Since May 1970, personnel on several campuses of the University of
California have been conducting a NASA-funded investigation which seeks
to determine the usefulness of modern remote sensing techniques for
studying various components of California's earth resources complex.
From the outset most of this work has been concentrated on California's
water resources, but with some attention being given to other resources
as well and to the interplay between them and California's water resources.

The studies reported upon in the present Progress Report have been
designed in such a way as to build upon the foundation which our earlier
work has established. Emphasis continues to be given in these studies
to California's water resources as exemplified by the Feather River
project and other aspects of the California Water Plan. With respect
to California's water resources, the present study is designed so as to
consider in detail the supply, demand and impact relationships.

The specific geographic areas studied during the present reporting
period are the Feather River drainage in northern California, the Chino-
Riverside Basin and Imperial Valley areas in southern California, and
selected portions of the west side of San Joaquin Valley in central
California.

Among the products which we are in the process of developing in
this study are models and block diagrams designed to indicate more
clearly than heretofore the various components of the water system in
California by virtue of which water needs currently are being met. Such
materials are enabling us to indicate quite specifically where remote
sensing inputs can facilitate the management of California's water
resources.

Also in our study we are seeking to identify at each step the
critical parameters and "drivers" the better to make sensitivity
analyses where appropriate. With respect to the present and possible
future uses of remote sensing techniques for the gathering of informa-
tion needed in managing California's water resources, we are about to
embark upon benefit-cost studies as detailed in later sections of this
report. In fact we already have added to our team an expert on such
studies who has written an analysis (appearing later in this report)
of the uses and limitations of benefit-cost studies, as applied to
remote sensing. He also has given his analysis of how an effective
benefit-cost study of remote sensing in relation to California's water
resources might best be made.

In performing the various kinds of studies just described we are specifically giving attention to each of the following considerations:

a. an account of the factors which currently are contributing to decisions that are being made on a real-time basis relative to the impounding, transport and use of water within the California Water Plan,

b. an analysis of the legal and regulatory provisions relative to the California Water Plan,

c. an analysis of present commitment restraints (based on promises already made to supply specific amounts of water to various users),

d. an analysis of the public policy factors which are related to the California Water Plan, and

e. an analysis of the economic factors which are involved in the California Water Plan.

For each of the three aspects of our study (supply, demand and impact), we are in the process of developing two models:

a. the model that is applicable or in operation today, and

b. the improved model that might be implemented, based at least in part on our remote sensing studies, i.e. on our findings as to useful data inputs to the model that might best be obtained through the intelligent use of modern remote sensing techniques.

Also, in the course of our study we are preparing:

a. an account of how the items of information currently used in managing California's water resources are measured and how they presently interrelate.

b. an account of how these items, or some modification of them, might best be measured in the future and how they might interrelate within a revised model that would make optimal use of modern remote sensing capabilities.

c. a comparison of the relative cost-effectiveness of the present model vs. the revised one, with special consideration to sensitivity analyses based on a determination of the critical parameters.

d. an assessment of the potential impact (economic, social, cultural, and political) that would result if the revised model were to replace the presently used one.

II. NATURE OF THE CALIFORNIA WATER PROJECT

Because of the emphasis that is being given in our present study to the California Water Project, it is deemed appropriate to provide here a brief historical review and synopsis of that project.

The California Water Project is the first major water resource development under the California Water Plan. The master plan 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 use of the land and water resources of the state as per Bulletins 1 and 2 of the DWR.

The State Water Project (see Figure 1.1) eventually 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 facility, 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 and the California Aqueduct for delivery to the southern San Joaquin Valley and southern California. At the south end of the California Aqueduct 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 Metropolitan Water District (MWD) and a number of smaller contractors, and an East Branch for delivery to the Antelope Valley-Mojave Desert water agencies and the balance to the MWD commitments. The terminal reservoirs for the project are Castaic in the East 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 kilowatt-hours of electricity annually and consume 13.4 million kilowatt-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 to 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 as of the present time is over 95 percent completed or under construction. As early as 1969 it was
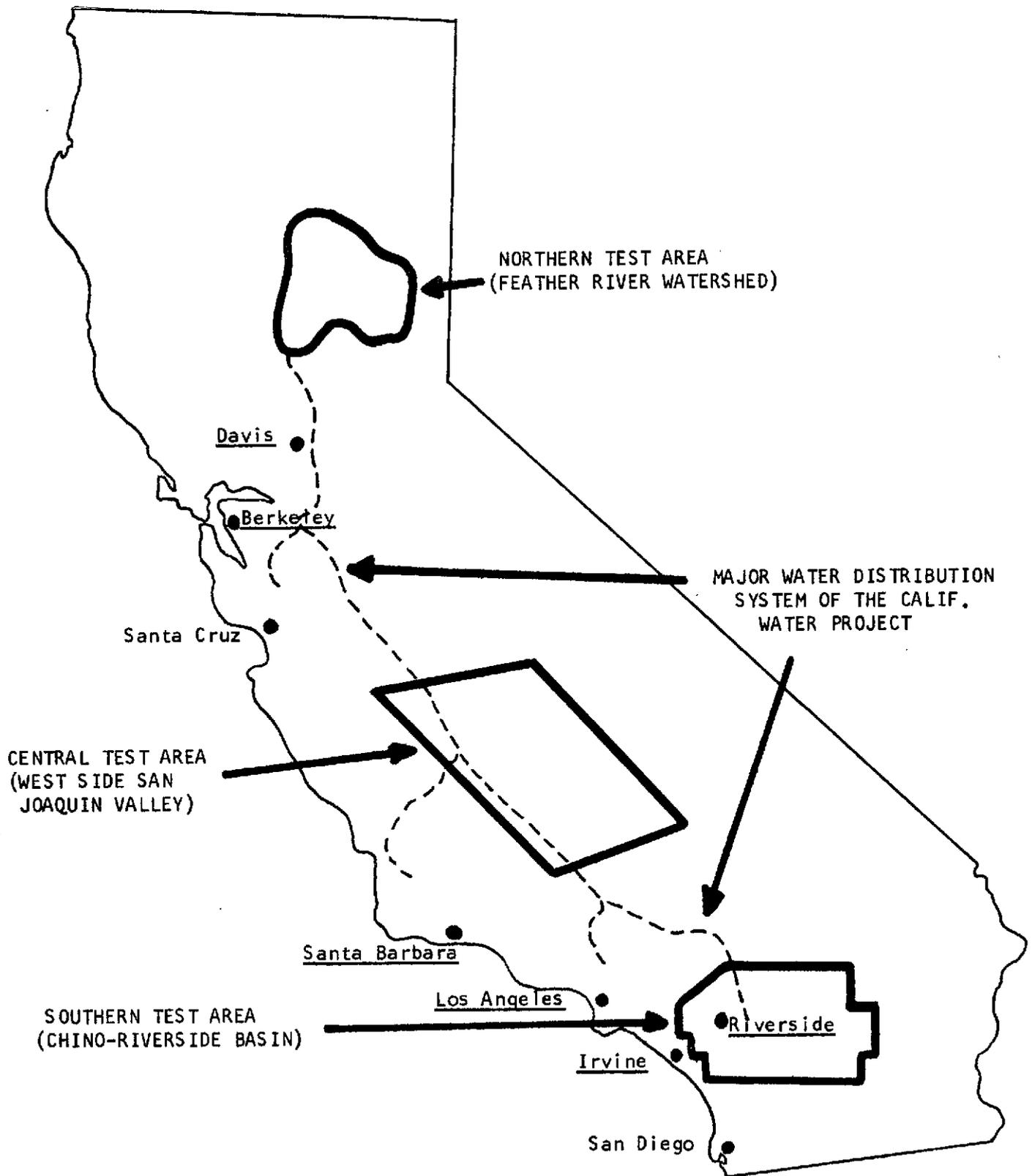
Figure 1.1. Location of campuses of the University of California that either have been involved (underlined) or seek in the coming year to become involved in our Integrated Study, and their relation to the California Water Project. Also shown are the three test areas dealt with in this proposal.

NORTHERN TEST AREA (FEATHER RIVER WATERSHED)

MAJOR WATER DISTRIBUTION SYSTEM OF THE CALIF. WATER PROJECT

CENTRAL TEST AREA (WEST SIDE SAN JOAQUIN VALLEY)

SOUTHERN TEST AREA (CHINO-RIVERSIDE BASIN)

Davis

Berkeley

Santa Cruz

Santa Barbara

Los Angeles

Riverside

Irvine

San Diego

operational to northern Kern County. The tunnels through the Tehachapi Mountains are completed and most of the construction on the pumping plants has been completed, with the result that the first water from this project was delivered to southern California in October, 1971. 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 delivery of water to Los Angeles County is soon to be followed by delivery of water to both San Bernardino and Riverside Counties.

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 began 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. Today the conservative cost estimates of the DWR amount to $2.8 billion, while more liberal estimates project a cost of $4.0 billion. Project customers will repay those amounts allocated to water supply, hydroelectric power and agricultural waste disposal amounting to 90 percent. The remaining 10 percent 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 over-draft 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, the general efficacy of water redistribution, and the efficiency of water use.

Figure 1.1 shows the location of the major canal system for distributing Feather River water under the California Water Project. It also shows the location of each of the several campuses of the University of California from which the research scientists come who either have been participating or wish in the near future to participate in our multi-campus study.

In light of the background that has just been given, the bulk of the research we have been conducting during the present reporting period is described in Chapters 2 and 3, dealing with water supply

factors and water demand factors, respectively. In view of the progress which we have made in these two areas, we can now proceed intelligently to the third major study area, viz. that dealing with "Impact" considerations.

A diagram indicating the factors which relate to water supply, demand and impact with special emphasis on their relations to remote sensing appears as Figure 1.2.

III. SOME SPECIFIC ASPECTS OF THE PRESENT PROGRESS REPORT

In Chapters 2 and 3 of this progress report the parameters which are of value in making water supply and water demand estimates, respectively, are listed. An indication is given in each case as to the means by which information relative to each parameter currently is obtained and incorporated into various hydrologic models.

This work has set the stage for defining several specific experiments which would establish the extent to which modern remote sensing techniques might facilitate the acquiring of information relative to these parameters. As a result, during the period covered by this report, several such studies have been designed and carried out. For example, three such studies, as reported in Chapter 2, deal respectively with (1) estimating the areal extent of snow, (2) mapping vegetation/terrain conditions and (3) inventorying various parameters by means of multistage sampling schemes which use ERTS-1 data as the basic input.

Due to the necessity for performing several kinds of work concurrently, each of these three studies has been conducted even while we were in the process of basic problem definition, as previously described. It is believed, however, that no inefficiency resulted from this seemingly illogical procedure because all that was needed initially was assurance that the parameters proposed for investigation from the remote sensing standpoint were truly meaningful ones. In the process of conducting remote sensing studies relative to these particular parameters certain basic investigative techniques have been developed, and certain important individuals and groups involved in the management of California's water resources have been cultivated. Such techniques and contacts are sure to stand us in good stead when, in the near future, we are able to acquire more definitive information as to the "drivers" that are of primary significance in relation to the management of California's water resources.

We realize that the making of sensitivity analyses of the proper kinds can lead to a better understanding of California's water resources and of how remote sensing might facilitate the management of such resources. Consequently we are in the process of devising plans for the making of such analyses during the next reporting period.

WATER SUPPLY CONSIDERATIONS — | WATER TRANSPORT | — WATER DEMAND CONSIDERATIONS —

| MEASUREMENT TECHNIQUES AVAILABLE | FACTORS TO BE MEASURED | MODEL FOR ESTIMATING WATER SUPPLY | WATER SUPPLY ESTIMATE | WATER TRANSPORT ESTIMATE | WATER USE ESTIMATE | MODEL FOR ESTIMATING WATER DEMAND | FACTORS TO BE MEASURED | MEASUREMENT TECHNIQUES AVAILABLE |

Remote Sensing Techniques
Multiband
Multidate
Multistage
Multi-Polarization
Multi-Enhancement

Other Techniques
Direct On-Site measurement;
Use of Historical Data

Meteorological Factors
Precipitation
snow
rain
season of occurrence
Temperature
Humidity
Wind

Watershed Factors
Geology
Soils
Vegetation
Topography
Slope
Aspect

(Model is still To Be Developed)

Prediction of Water that is Available for Transport

in terms of
Quantity
Quality
Seasonal Characteristics
Storage and Release Costs

Model for Estimating Water to be Transported

in terms of
Quantity
Quality
Seasonal Characteristics
Transport Costs

(To Be Developed)

Prediction of Water That Users Want Transported

in terms of
Quantity
Quality
Seasonal Characteristics
Distribution Costs and Revenues

(Model is still To Be Developed)

User Factors
Agricultural Needs
Industrial Needs
Domestic Needs
Geographic Location of Users

Other Factors
Legal Considerations
Regulatory Measures
Commitments to Specific Users
Mechanism for Establishing Price Per Unit Volume

Remote Sensing Techniques
Multiband
Multidate
Multistage
Multi-Polarization
Multi-Enhancement

Other Techniques
Direct On-Site Measurement;
Use of Historical Data

Socio-Economic Studies
Impact of Using Remote Sensing Techniques in Water Supply Problems

Socio-Economic Studies
Impact of Using Remote Sensing Techniques in Water Transport Problems

Socio-Economic Studies
Impact of Using Remote Sensing Techniques in Water Use Problems

Model for Estimating Overall Impact of Using Remote Sensing Techniques in Water Supply, Transport and Use Problems
(To Be Developed)

OVERALL IMPACT
Economic, Social, Political, Cultural

Figure 1.2. Block diagram indicating the factors which relate to water supply, water transport, water use and water impact. For a discussion of the proposed remote sensing studies in relation to this diagram, see text.

Chapter 2

WATER SUPPLY STUDIES

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       Paul F. Krumpe, James D. Nichols, Michael J. Gialdini

I. INTRODUCTION

A. Location, Scope and Objectives of the Water Supply Studies

The primary test site for our water supply studies continues to be the Feather River watershed in northeastern california. This test site includes all of the area draining into and including the Oroville Reservoir.

The principal objective of these water supply studies can be stated as follows: to determine the extent to which remote sensing techniques, when properly employed, can provide information useful to those persons concerned with the management and planning of lands and facilities for the production of water, using the Oroville Reservoir and the California Water Project as the focus for the study. In particular, emphasis is being placed in these studies on determining the cost-effectiveness of information derived through remote sensing as compared with that currently being derived through more conventional means.

The most obvious, and probably most easily accomplished aspect of the study involves an analysis of the ways in which remote sensing might be incorporated into the present information-gathering and management system in the Feather River area. It is recognized, however, that the true usefulness and economic justification of these remote sensing techniques is to be found only by allowing for a much broader application of them. Specifically: (1) The greatest value of these techniques might conceivably be realized through the creation of some entirely new information gathering and interpretation system. (2) The information derived from by remote sensing might well have one value at the present time, given the current water supply and demand situation, and quite another value at some future time when increased demands for water are likely to require a much more critical manipulation of supply facilities. (3) While the Feather River is being used as the primary test site for the study, it is apparent that our findings there could be applied to a large number of other areas also, many of which are less well managed than is the Feather River, and for which use of these new techniques could be even more beneficial. Thus in some cases in our present study, the value of remote sensing will be postulated for the general case rather than solely for the Feather River as it exists today.

The Feather River and the California Water Project were chosen as the focal point for this study largely because they represent a very advanced state-of-the-art situation in terms of water supply management. Hence they provide a frame of reference within which to evaluate the potential usefulness of remote sensing techniques in the planning and management of water supply systems in general and in many parts of the globe. In seeking to estimate the ultimate benefit of remote sensing for the management of water resources this global view obviously must be taken in order to match the global view afforded by ERTS-1, which provided much of the remote sensing data on which the present study is based.

B. Investigation Tasks

Within the general scope of the study discussed above, the more specific tasks which it was recognized needed to be undertaken will now be listed and described. This listing essentially outlines the study to completion and thus indicates not only work under way at the present time, but also proposed work. This work is in all respects consistent with the revised work statement which our group submitted to NASA on September 30, 1973 and which our NASA monitors have since approved.

1. An extensive review of existing projects and management policies relative to the Feather River area has been undertaken by the Burgy and Algazi groups and is now nearing completion. It entails consultation, both in Sacramento and in the field, with personnel of the California Department of Water Resources who are responsible for managing the overall California Water Project. In addition personnel from other agencies involved in management of some of the individual watershed areas and water control developments are being consulted.

The primary goal of this step is to determine both the specific kinds of information that currently are needed and/or used by those agencies in the planning and conduct of their operations, and the particular environmental parameters used to generate such information. In addition consideration is given to information that probably will be needed in the future to math the increased intensity of water resource management in California.

The study is concerned not only with the types of information required, but also with the amount, timing, and format required as an input. In this phase of our study, not only are the physical water supply "drivers", and the parameters that currently are of primary importance in making predictions and estimations that affect water supply management defined, but also sensitivity analyses of such parameters are made.

In so doing it is necessary to work closely with the various land management agencies and other public and private groups that are concerned with water supply and distribution within the watershed area. These include the U.S. Forest Service, the Bureau of Land Management, the Pacific Gas and Electric Company, and the Flood Control Forecast Center.

Professional associates of Burgy and Algazi, currently working with the Water Resources Institute on the Davis Campus of the University of California, are providing assistance in this phase of the work. In addition, Dr. Peter Castruccio, as authorized by NASA, is working with us to a limited extent on these water supply aspects of our study, and on comparable aspects described under a subsequent section dealing with water demand.

2. Concurrent with the above, an analysis of the probable economic effects that would result from changes in either the quality or quantity of information made available to those responsible for management of the Feather River water supply is being made. Wherever possible, estimates as to the value of various kinds of water supply information also are being made, the better to assess these economic effects.

Initially this step is being undertaken by the Burgy and Churchman groups, with assistance where requested from Algazi and CRSR (Center for Remote Sensing Research, formerly the Forestry Remote Sensing Laboratory). It is envisaged, however, that ultimately an economist whom we propose be added to the team would be quite active in this area. As with other phases of our project, much of the work involved in this phase involves consultation with persons currently involved in the water management process here in California.

Some skeptics have expressed serious doubts that it would ever be possible to make a meaningful analysis of the economic effects that would result from using remote sensing as an aid to water resource management. Consequently our group is giving careful attention to the report which a newly acquired member of our team, Dr. Leonard Merewitz, has just completed. His report is entitled: "The Feasibility of Benefit - Cost Analysis Applied to Remote Sensing Projects" and it appears as Supplementary Study No. 1 in Chapter 5 of the present report.

Dr. Klaus Heiss has been authorized by NASA to consult with us to a limited extent on these economic studies, as well as in the other economic aspects discussed in the remainder of this proposal. His comments relative to the Merewitz analysis currently are being solicited.

3. Through use of the information acquired in (1) and (2) above, and mindful of the comments of Dr. Merewitz and Dr. Heiss, an attempt will soon be made to ascertain the economic costs and benefits which might be realized from the use of various remote sensing techniques in the collection of information.

It is now apparent that, in making this economic analysis we will find it necessary to employ a somewhat indirect process. In some cases remote sensing already has demonstrated that it can supply certain kinds of information about water supply more rapidly or more cheaply than is possible through the use of conventional techniques. Furthermore, remote sensing can provide several kinds of information not currently available. The real benefits only accrue, however, if this information can be used to effect some positive change through the management/decision-making process involved in water supply allocation or control. Thus the economic analyst must look "downstream" in the management process for the dollar costs or benefits. Then, through his understanding of the role that the various bits of information have played in the process, he should be able to relate them back to the remote sensing system. The concluding portion of the analysis made by Dr. Merewitz (Chapter 5) describes the procedure which he believes will best permit us to make a benefit-cost analysis of remote sensing in relation to water supply aspects of the California Water Project.

4. Given the background work performed by the Burgy and Algazi groups discussed above, our research of the past several years will be continued, and modified as necessary, in order to determine the relative worth of various remote sensing systems for supplying the desired information. The CRSR, working with the Algazi and Coulson groups will devote the bulk of its effort to this phase of the study.

Investigations will concentrate on those parameters found to be particularly important from the economic standpoint, and will consist of a two-step process. Initially, for each parameter, tests will be conducted to ascertain the most promising techniques for gathering the required data. For the Feather River watershed much progress already has been made by our group on this phase, beginning several years ago with our study of simulated space photography, and now nearing culmination with our study of actual space photography as acquired by ERTS-1 and Skylab. This phase also entails the acquisition of limited amounts of conventional aerial photography, and seeks to determine the optimum mix of on-the-ground, aerial, and satellite data collection to satisfy the data acquisition and interpretation requirements at the least cost.

Once a data collection interpretation system has been chosen, more extensive tests will be carried out to determine the operational feasibility of collecting the required data over large areas while satisfying the accuracy and timing constraints. During this phase, an attempt will be made to gather data as to expected costs of performing these tasks operationally and also as to the expected accuracy and quality of information obtained through the use of such a system. Admittedly there are some difficulties in extrapolating from the research context to the operational context, but an attempt will be made through the means described above to ascertain the probable cost and accuracy figures.

5. A necessary input to an economic analysis of any new information-gathering system is the cost-effectiveness of conventional systems.

Obviously, as pointed out by Merewitz in Chapter 5, a remote sensing system can only be justified if it can be shown that the <u>net</u> benefit of the system exceeds that of alternative systems. Thus an effort will be made to determine as accurately as possible the performance and costs of conventional data-acquisition programs. This step will be conducted as a cooperative effort involving both the Burgy group and the CRSR.

6. The next step in the evaluation of remote sensing as a potential information source will be the economic evaluation of the remote sensing contribution as compared with conventional methods of gathering information. Thus the data generated in step 4, above, on remote sensing system performance will be converted into economic terms by drawing on the information generated in steps 1 through 3 regarding the effects of changes in information. At the same time the costs incurred using the remote sensing techniques will be compared with the costs of conventional methods generated in step 5. The final end-product then should be an evaluation, in definite economic terms, as to the usefulness of remote sensing in providing information needed for making water supply management decisions, and a quantitative estimate of the cost-effectiveness of the data collection/interpretation systems.

7. This phase of our proposed study will conclude with a quantitative estimate of the potential impact of using remote sensing techniques in water supply problems, first in a purely economic sense but later in the light of various social, political and economic considerations, as previously described.

C. Work Plan

Figure 2.1 shows in diagrammatic form the relationships among the tasks just described.

Figure 2.2 provides a listing of these tasks, along with the investigators that are involved in performing them, and the periods of time when they will be performing them.

As can be seen from Figure 2.2, during the period covered by this report (through December, 1973), the bulk of the effort has been carried out on work items 1, 2, and 4. The Burgy Algazi, and CRSR groups have been involved in defining the state of the California Water Project as it functions in the Feather River area, ascertaining exactly how decisions regarding water supply management are made, and attempting to understand the functioning of the supply models that are currently being used by management personnel. From this study it is becoming possible to ascertain the factors of importance in affecting water supply decisions, both at the present time and in the future, and hence to steer the study in a direction most likely to yield worthwhile results. Furthermore, the analysis of supply models forms the basis for a determination of the specific kinds, amount, and timing of information required. This obviously constitutes an essential preliminary step in the evaluation of potential remote sensing inputs.

Figure 2.1   Block diagram showing sequence of steps involved in the study of water <u>supply</u> problems as discussed in the accompanying text.
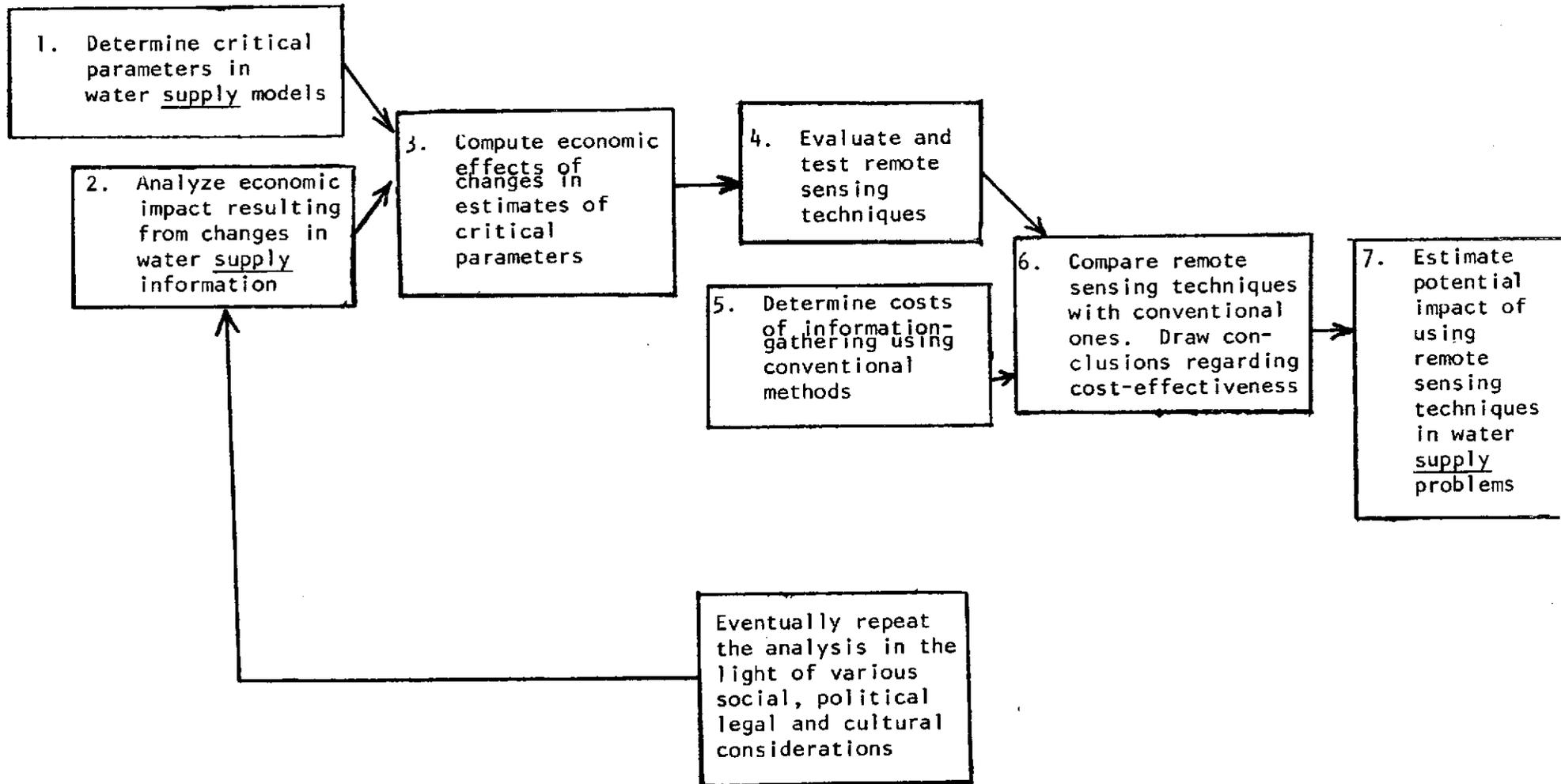
Figure 2.2 Chronological Plan for the Performance of Water <u>Supply</u> Studies

Work Item	Investigators	Period of Performance	
		Next Funding Year M J J A S O N D J F M A	Next Funding Year M J J A S O N D J F M A
1. Determine critical parameters in water supply models	Burgy-Algazi CRSR	→ →	
2. Analyze economic impact resulting from changes in water supply information	Churchman Economist Burgy Lawyer Public Policy	→ ⊢─⊣	→ →
3. Compute economic effects of changes in estimation of critical parameters	Burgy-Algazi Economist Churchman	→ → →	
4. Evaluate and test remote sensing techniques	CRSR Algazi	───────────────────→ ───────────────────→	
5. Determine costs of information-gathering using conventional methods	Burgy-Algazi CRSR	→ →	
6. Compare remote sensing techniques with conventional ones. Draw conclusions regarding cost-effectiveness	CRSR Burgy-Algazi Economist		→ → →
7. Estimate potential impact of using remote sensing techniques in water supply problems	CRSR Burgy Economist Churchman		→ → → →

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Again referring to figure 2.2, it can be seen that during the remaining portion of the current funding year the bulk of the effort will continue to be in the area of defining information requirements and in evaluating the potential effects of changes in the information supplied relative to critical parameters. Concurrent with this effort, both the CRSR and Algazi groups will continue the development of promising remote sensing analysis techniques.

During the next funding year it is planned that the study will progress into a phase of application of particular pertinent remote sensing techniques to specific information gathering problems as defined during the current year. In addition, our economic studies, benefiting from the guidance provided by Merewitz and Heiss, should then be at the stage where direct quantitative evaluations of the cost-effectiveness of the remote sensing applications will be possible.

II. THE CALIFORNIA WATER PROJECT IN PERSPECTIVE

A primary objective of our integrated study is to determine the usefulness and cost effectiveness of remote sensing information in the management of water supply. In this portion of our report, we undertake an examination of all factors directly affecting watershed management and/or reservoir strategy, with emphasis on elucidating what system presently is being used, what decisions currently are being made relative to both watershed management and reservoir strategy, and what factors presently enter into the making of those decisions. This review of existing projects and policies has been undertaken with the cooperation of personnel of the California Department of Water Resources who are responsible for managing the overall California Water Project.

A. Underlying Thinking

To understand current operating policies, it is mandatory to put the California Water Project in perspective. While the actual engineering and construction activities are substantially complete, only a few of the planned uses of the California Water Project are fully operational at the present time. That is to say, although the physical facilities for the control and management of water in the supply area are substantially complete and operational, the present delivery of contracted water to user agencies is considerably below future contracted deliveries. The management of water rights, the management of water contracts, the current and future project operations, and the financing can only be understood within the framework of the actual plan and schedule of the California Water Project for which construction started in 1957. Up to the present time more than 2 billion dollars has been expended in construction of facilities extending from the Oroville Dam in the Sierra foothills of Northern California, to Perris Lake some 400 miles to the south. It is anticipated that the total will reach nearly 3 billion dollars by the year 1997. It is not possible nor probably even desirable to elucidate or discuss here all salient factors of a project having such magnitude. It is important, however, to acquire a clear insight into some of the actual plans and operating conditions of the project. Only by this means can we hope to relate the present and future benefits of remote sensing to the management of water supplies for the State of California.

At the present time we have not fully achieved even that limited objective. However, we are able in this section of our report to provide most of the pertinent background information needed relative to this matter by the participants of our integrated study. In so doing we will seek to summarize the most pertinent information which we have obtained from published documents or by direct contact with personnel of the Department of Water Resources.

B. Purposes of the California Water Project

We shall briefly discuss the status and put in historical perspective each of the following purposes of the California Water Project, (1) Flood Control (2) Water Supply (3) Power Generation, (4) Water Quality Control (5) Recreation and Fish and Wildlife Management, and (6) Drainage. It will become apparent that, for our objective, only a few of these purposes require a detailed examination.

1. Flood Control

Use of the California Water Project for flood control purposes has been fully operational for a number of years. Flood control operations have already been highly beneficial to Northern California. The most notable instance to date is the prevention of an estimated 30 million dollars of flood damage in the Winter of 1964-65. Flood control operations are explained in more detail in a later section of this report. In addition to the obvious economic impact of preventing flood damage, flood control operations set definite limits on water storage by setting requirements on flood control space, and also by setting release requirements related to precipitation and conditions of the watersheds.

2. Water Supply

Three aspects that are especially important relative to management of the California Water Project are the development of adequate water supply and conservation facilities, the development of a realistic schedule of contracted water deliveries, and the establishment of a suitable basis for changing water users.

Construction of most of the essential water conservation and supply facilities has now been completed. The notable exception is the proposed Peripheral Canal in the Delta Region. The social, economic and political aspects of this proposed instruction are dealt with later in this report. With regard to the Peripheral canal, the Department of Water Resources has stated: "It is our current [1972] estimate that the Peripheral Canal will be needed in 1980 to protect the water supply and quality functions of the State Water Project and the Federal Central Valley Project aqueducts to the South and West of the Delta . . . . The decision to proceed with construction will probably have to be made early in 1975." Environmental impact considerations, particularly those relating to the control of water quality, are of prime importance in relation to the Peripheral Canal and will affect the constraints on the amount and schedule of water releases from the Oroville Dam. As will be discussed more fully later, the monitoring and control of water quality appears as an area in which additional information, possibly acquired by remote sensing, would have a significant regulatory and economic impact.

With respect to water requirements and deliveries, a long-term water contracting program was initiated by the Department of Water Resources in 1960. By 1968 the California Water Project annual delivery capability of 4.23 million acre-feet of water had been fully contracted for. Long-term water supply contracts with 31 local agencies currently are in force. Each contract is for a period of at least 75 years and sets a schedule of annual water amounts which the agencies are entitled to receive. The amount of this "entitlement water" increases, in general, every year until about 1990. In addition to scheduled entitlement water, surplus water (available but not contracted for) can be acquired by long-term contractors and by some noncontractors. In 1972, 1.1 million acre-feet of water, 0.6 million of which was entitlement water, was delivered by the State Water Project. In 1974 it is estimated that a total of 1.7 million acre-feet will be delivered.

We show in graphical form in Figure 2.3 the annual entitlements under long-term water supply contracts, both in total and for the two principal user areas. For comparison purposes, it is worth pointing out that the Feather River Drainage Basin (3,611 sq. mi.) has a mean annual project impaired flow at the Oroville Damsite of 3.5 million acre-feet (average 1921-1951). It is clear from these figures that for the present time the principal problem in the management of the Oroville Dam and other water reservoirs in the Feather River Basin is not water conservation, nor will it be for several years to come. For the present, the maximization of the amount of water that can be made available to water user agencies by the supply area definitely is not a "driver" because it plays a role secondary to flood control, power generation, control of water quality, and even to fish and wildlife management in the operation of the water supply area. The manner in which this situation is likely to change with the increase of contracted water deliveries in the coming few years, will be a matter for further examination by our group in the near future. However, it is clear that, even now, operation of the Oroville Dam and the water supply area has some economic impact on water user agencies through the agreed computation formulas for water charges.

With respect to matters of water entitlement and the making of water payments the following is a highly relevant excerpt from Bulletin No. 132-73, published by the California Department of Water Resources:

> "Water Contractor Payments Under Longterm Water Supply Contracts: Water supply contracts provide for payments of two charges: (1) a Delta Water Charge and (2) a Transportation Charge.
>
> The Delta Water Charge is a charge for each acre-foot of water the contractors are entitled to receive; it is computed so as to return to the State during the contract term all appropriate costs of project conservation facilities, together with interest thereon.

Calendar Year	Annual Entitlements Under Long-Term Water Supply Contracts						
	Feather River Area	North Bay Area	South Bay Area	San Joaquin Valley Area	Central Coastal Area	Southern California Area	Total
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
1962	0	0	0	0	0	0	0
1963	0	0	0	0	0	0	0
1964	0	0	0	0	0	0	0
1965	0	0	0	0	0	0	0
1966	0	0	0	0	0	0	0
1967	0	0	11,538	0	0	0	11,538
1968	550	0	109,900	81,050	0	0	191,500
1969	620	0	98,700	168,075	0	0	267,395
1970	700	0	114,200	207,700	0	0	322,600
1971	890	0	116,200	258,500	0	0	375,590
1972	970	0	118,300	420,766	0	201,723	741,759
Subtotal actual for 11 years 1962-1972	3,730	0	568,838	1,136,091	0	201,723	1,910,382
1973	1,100	0	120,400	390,800	0	472,400	984,700
1974	1,230	0	122,400	434,800	0	588,220	1,146,650
1975	1,610	0	124,500	480,900	0	704,250	1,311,260
3 years, 1973-1975	3,940	0	367,300	1,306,500	0	1,764,870	3,442,610
1976	1,990	0	126,500	535,600	0	824,780	1,488,870
1977	2,420	0	128,600	594,100	0	942,201	1,667,321
1978	2,850	0	130,700	651,600	0	1,060,722	1,845,872
1979	3,280	0	132,700	707,700	0	1,177,873	2,021,553
1980	4,710	19,250	134,800	765,000	2,200	1,304,914	2,230,874
1981	10,390	21,750	137,000	828,500	3,300	1,425,865	2,426,805
1982	12,270	24,400	139,200	889,200	6,600	1,546,806	2,618,476
1983	14,200	27,050	141,400	955,500	9,900	1,668,557	2,816,607
1984	16,130	29,600	143,600	1,017,900	14,900	1,790,398	3,012,528
1985	19,060	32,750	145,800	1,079,100	24,800	1,912,549	3,214,059
10 years, 1976-1985	87,300	154,800	1,360,300	8,024,200	61,700	13,654,665	23,342,965
10 years, 1986-1995	340,420	587,500	1,650,200	13,032,300	688,000	23,869,646	40,168,066
10 years, 1996-2005	386,460	670,000	1,878,000	13,550,000	827,000	24,975,000	42,286,460
10 years, 2006,2015	393,170	670,000	1,880,000	13,550,000	827,000	24,975,000	42,295,170
10 years, 2016-2025	398,000	670,000	1,880,000	13,550,000	827,000	24,975,000	42,300,000
10 years, 2026-2035	398,000	670,000	1,880,000	13,550,000	827,000	24,975,000	42,300,000

Figure 2.3 Annual water entitlements under California Water Project long-term contracts.

Project conversation facilities are defined as those facilities which conserve water, including Lake Oroville, Delta Facilities, additional conservation facilties and San Luis Reservoir and a portion of the California Aqueduct leading thereto from the Delta. Costs allocated to flood control and recreation and fish and wildlife enhancement are not paid under the water supply contracts. Both debits for power costs and credits for power revenues of project conservation facilities are included in the determination of the Delta Water Charge.

The Transportation Charge is computed so as to return to the State during the contract term the costs of the aqueducts necessary to deliver water to the respective contractors, together with interest thereon. Such costs exclude in addition to those allocated to flood control and recreation and fish and wildlife enhancement, the costs of the Devil Canyon and Castaic Facilities allocable to power.

Each year's costs of each aqueduct reach are allocated among contractors whose deliveries are or will be conveyed through that reach. For contractors with predominately municipal and industrial water use, the allocated amounts of each year's construction expenditures are required to be repaid, together with interest, in 50 equal annual installments. For contractors with predominately agricultural water use, allocated construction costs are repaid by a uniform charge per acre-foot of water entitlement, computed so as to return to the State during the contract term such costs with interest."

As stated elsewhere in that bulletin, the operation of supply areas, costs for which are included in the Delta Water charge, will determine debits for power cost and credits for power revenue, which are dependent on short-term and long-term contracts with power companies.

3. Power Generation

With respect to power supply and demand considerations, the following excerpts from the previously - cited Bulletin No. 132-73 are relevant:

"Power costs are the largest single annual operating expense of the Project. Under ultimate water delivery conditions, power costs are presently estimated at $73 million annually, including costs of transmission service.

Project pumping energy requirements will continue to increase over the next 20 years at an average rate of about 350 million kilowatt-hours annually, ultimately reaching 13 billion kilowatt-hours by the year 2020. Presently, the Project has three sources of purchased power; Canadian Entitlement, Bonneville Power Administration, and the California Suppliers. The unit rates for Canadian Entitlement and California Suppliers' power sources are fixed until March 31, 1983. Bonneville Power Administration rates are subject to change in 1974 and every five years thereafter.

The long-term outlook in the electric power industry continues to reflect a rising trend in electric power costs. Higher power costs can be expected in the future due to (1) environmental factors resulting in siting problems and construction delays, (2) more stringent licensing and safety requirements, (3) escalation of labor and materials costs, and (4) rising fuel costs. The combined effect of these factors will have a major impact on project power costs after March 1983 when new rates will become effective under the Suppliers' Contract."

Still with regard to power supply and demand considerations, the graph of figure 2.4 illustrates the transitional period represented by the 1970's.
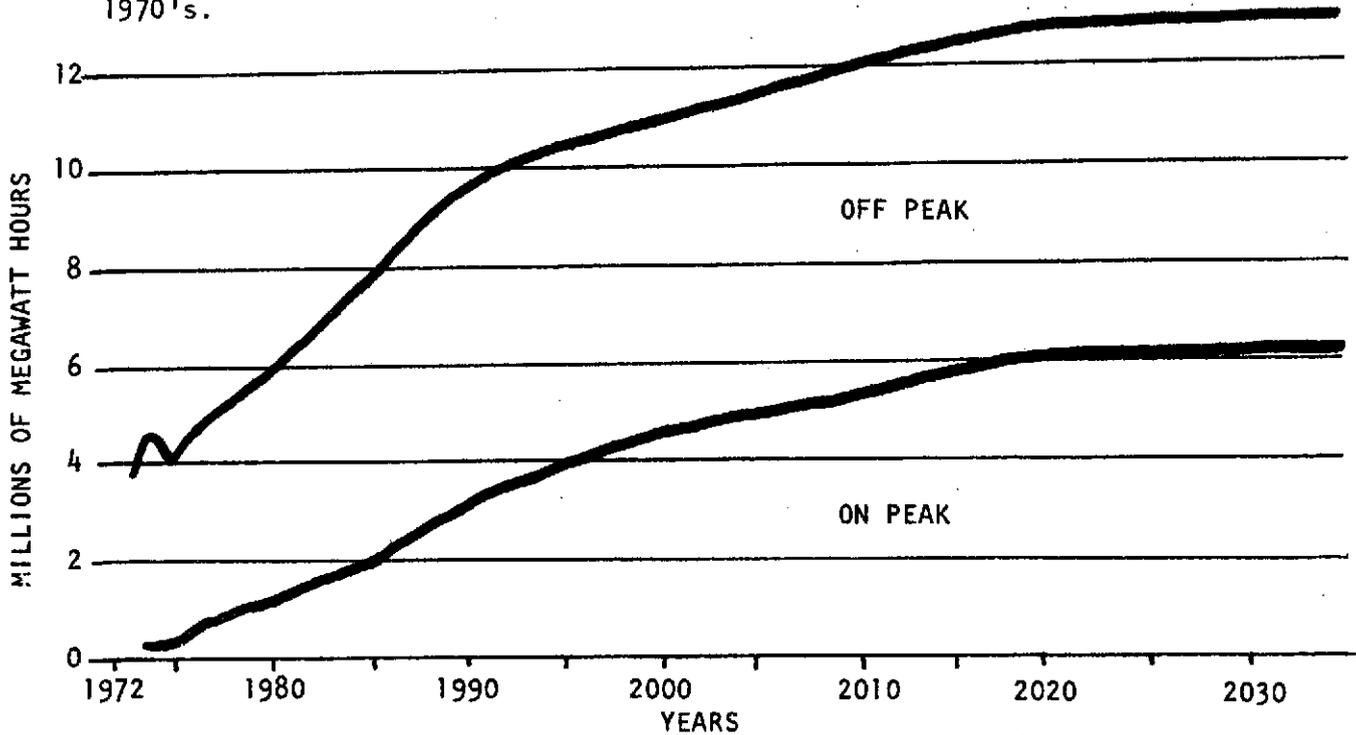
Figure 2.4 Projected Pumping Energy Requirements Associated With The California Water Project.

The charges for energy required for pumping are partially offset by revenue from hydro-electric power generation. Part of the hydro-electric power is generated by the Edward Hyatt and Thermalito Power Plants at Oroville, and part is generated by the California Aqueduct Power Plants. It is estimated that the energy generated by the California Aqueduct Power Plants will range from .9 million megawatt hours in 1974 to 1.5 million megawatt hours in 1985. Still, by 1985, the net energy requirement for pumping (above that which can be generated by the system) will be 5.7 million megawatt hours.

The energy generated by the California Water Project at the Edward Hyatt and Thermalito Power Plants, called Oroville-Thermalito Power, has been contracted for delivery, as stated in the following quote from the California Department of Water Resources:

> "The Oroville-Thermalito Power Sale Contract is in force until the year 2018. The Companies (Pacific Gas and Electric Company, Southern California Edison Company, and San Diego Gas and Electric Company) are obligated to pay approximately $8.1 million semiannually to the Department until contract termination. These firm payments are based on an estimated annual net energy generation of 2.1 billion-kilowatt-hours. The contract provides for an energy adjustment account which can be periodically cleared through supplemental payments by the Companies or through payments by the Department in the event actual annual net energy generation is more or less than 2.1 billion kilowatt-hours, respectively."

Positive or negative yearly balances are paid at a rate of $0.00259 per kilowatt hour or carried forward in an energy account. In 1972 the net total energy generated by the Oroville-Thermalito Plants was 1.6 million megawatt hours.

This energy was on peak energy and, thus, most valuable to the power companies. By the Oroville-Thermalito Power sale contract, the Department of Water Resources has contracted the power generating capacity of the power plants, rather than the energy actually generated. Thus, the economic benefit to the State of increased energy generation is comparatively small under present conditions. Still, the benefits to the power companies and to society are significant. Additional work is needed to elucidate the relation of the schedule of water release as determined by the various constraints on the system, to the change in energy generation and its economic worth.

Documents Consulted

1. The California State Water Project in 1973.
   Department of Water Resources, Bulletin No. 132-73.

2. The California State Water Project Summary.
   Bulletins No. 132-71, No. 132-70.

3. Oroville-Thermalito Power Sale Contract.
   DWR Contract No. 860502.

4. Plans of Operations for 1973-74. Internal Memorandum of the
   Resources Agency.

5. Report on Reservoir Regulation for Flood Control, Oroville
   Dan and Reservoir (August 1970). Department of the Army,
   Sacramento District, Corps of Engineers.

4. Water Quality Control

The management of the California Water Project is greatly affected by water quality considerations in that allowance must be made for release of enough water to maintain certain flow rates through the Sacramento-San Joaquin Delta to San Francisco Bay. These minimum flow rates are necessary to prevent salt water intrusion into the Delta and to provide "flushing" action through the Delta and Bay system to prevent water pollution and destruction of fish and wildlife habitat in the area. The principal document dealing with standards which must be met in the Delta is Decision 1379 of the State Water Resources Control Board which sets strong interim criteria to be met by State and Federal projects diverting water from the Delta.

At the present time there is considerable disagreement among the experts as to what minimum flows are actually necessary to prevent environmental degradation, what steps need to be taken to assure compliance with water quality standards; and whether the steps required by the Water Resources Control Board are reasonable (it is felt by some that the requirements imposed on the California Water Project go beyond the prevention of additional problems and actually require the amelioration of pre-existing problems.) At any rate, it is clear that as water shipments south from the Delta increase it will become increasingly difficult for the Water Project to both satisfy its contracts for water deliveries and comply with the requirements for minimum flows in the Delta imposed by the Water Resources Control Board. Thus the amount of water available from the supply area will become more critical, necessitating more intensive management of both the watershed areas and the reservoirs and other facilities.

5. Recreation and Fish and Wildlife Enhancement

Total expenditures of $40 million for recreation and fish and wildlife enhancement had been approved as of 1972, for land acquisition and for multipurpose construction costs allocated to that purpose at and about the major water storage lakes and reservoirs in Northern California and in the San Joaquin Valley. The Department of Water Resources is reimbursed for such expenditures by the California Legislature under a continuing $5 million annual appropriation. No charges are made to water users. Requirements for recreation and fish and wildlife management set some apparently minor constraints in water flows and water releases at some times of the year, as discussed elsewhere in this report.

6. Drainage

The Department of Water Resources has planned future construction of drainage faciliites in the San Joaquin Valley for disposal and reclamation of agricultural waste water accumulating in the valley. It is expected that water quality control problems related to the operation of such a drain, will have an effect on the overall operation of the California Water Project.

III. CURRENT OPERATION OF THE OROVILLE FACILITY

At the present time, the primary constraint imposed on the Oroville Reservoir facility is that pertaining to flood control. During the winter months a certain storage capacity must be maintained to provide a margin of safety in the event of high runoff. There is not, however, any significant constraint imposed for water supply purposes, due to the staged schedule of water deliveries by the California Water Project. While eventually over 3 million acre feet per year will be required by users in the San Joaquin Valley and the Los Angeles area, at the present time only about 1 million acre feet are being delivered. Thus demand pressures at the present time are not great and there is no problem in supplying enough water to fulfill current water and power contracts. By the mid 1980's, however, the amount of water available at any given time will become much more critical and a greater emphasis will probably be placed on water conservation practices than at present. Even before then, efforts to solve the state's energy crisis may place increased emphasis on the possibility of producing more hydroelectric power from the Oroville Dam facility.

A. General Operation of the Flood Control Function at Oroville Reservoir

Water releases from Oroville Dam to achieve flood control are based on an analysis of present and projected reservoir inflow, reservoir storage capacity, and constraints on outflow. Most of the investigation of downstream channel capacities, eventual reservoir storage, and probability of inflows of given size was carried out by the Army Corps of Engineers and the California State Department of Water Resources in the 1950's.

In the interest of flood control a monetary contribution by the Federal Government toward the construction cost of Oroville Dam and Reservoir was authorized by the Flood Control Act of 1958. On January 10, 1962, the President approved an allocation representing 22 percent of the cost of constructing the dam and reservoir, exclusive of power and recreational facilities. This allocation was based on an analysis of potential flood control benefits downstream from the dam site. The State of California accepted this allocation by approval of a contract with the United States on March 8, 1962. Under the terms of this contract, the State agreed to provide flood control in accordance with flood storage volume and safe outflow release schedules determined in the 1950's and updated with actual construction of the dam.

By contractual agreement (Department of the Army, 1970) between the State of California and the U.S. Army Corps of Engineers, Oroville Reservoir must provide a maximum of 750,000 acre-feet of flood control space for downstream flood protection. This protection includes the cities of Oroville, Marysville, Yuba City, Gridley, and several unincorporated communities. In addition, 283,000 acres of rural land, much intensively developed to fruit, nut, and row crop production, are protected along with utility lines, major highways, and important railroad routes.

Before construction of the Oroville Reservoir, damages from a single flood along the Feather River in the lowlands downstream from the dam site went as high as $82 million dollars (during December, 1955).

Flood protection is provided up to the magnitude of the standard project flood, which has been calculated for the dam site as an inflow of 440,000 cubic feet per second (cfs). This value is approximately 1.8 times the largest peak flow ever determined for that location. Permissible reservoir releases under non-emergency conditions should not exceed 150,000 cfs nor should flows surpass 180,000 cfs and 300,000 cfs above and below the downstream mouth of the neighboring Yuba River, respectively. Only about 36 percent of the Yuba drainage is presently controlled, so releases from the Oroville Reservoir must be adjusted accordingly. These maximum release volumes are small enough to be safely accommodated by downstream channel capacities in all but one minor unleveed situation.

Releases from Oroville Reservoir are not increased by more than 10,000 cfs nor decreased by more than 5,000 cfs in any 2-hour period. These release change limits prevent damage to structures or boating traffic on or near the river that might result from sudden changes in water level.

Other release criteria are met as flood control space permits. These water requirements consist of regional irrigation and power demands, general state water project needs, and downstream fishery requirements as established by the California State Department of Fish and Game and the U.S. Fish and Wildlife Service. Reserved unfilled flood control space is basically a function of a basin wetness index and the potential for a storm of a standardized magnitude. Thus as the dry summer months approach, flood storage space will drop to a negligible amount and the water storage space will drop to a negligible amount and the water storage available for other uses will be at a maximum.

Further information on flood control measures associated with the Oroville Reservoir will be found in a document entitled "Oroville Dam and Reservoir, Feather River, California; Report on reseroir regulation for flood control" which was published in 1970 by the Department of the Army, Sacramento District, Corps of Engineers.

B. Factors Governing Flood Storage Volume

Reserved flood storage volume at Oroville reservoir is a function of the potential for a standard project* storm and a calculated watershed ground wetness index. The potential for a standard project storm is based on a seasonal precipitation distribution analysis for the Feather

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*The term "project", as here used, pertains to the Oroville Dam project area, i.e. the Feather River drainage area.

River area. The parameter of interest in this case is 3-day precipitation exceedence once in 10 years. The result of this investigation indicates that the project basin could experience full storm potential for an average 3-day storm precipitation of 9.3 inches as early as 15 October and as late as 1 April. These same dates are used to indicate the period of full potential for the standard project rain storm. This storm is defined as a period of 96-hour duration in which 14.3 inches of precipitation on wet ground are deposited on thedrainage basin above Oroville Reservoir. This standard project storm gives rise to a standard project flood at Oroville Dam. This hypothetical flood has a peak flow of 440,000 cubic feet per second (cfs), a 72-hour volume of 1,520,000 acre-feet, and the potential to inundate approximately 292,000 acres of downstream lowland.

The same criteria showed that the Feather River watershed could have 80 percent of its standard project storm potential as early as 2 October and as late as 27 April. At least a 60 percent change of the full project storm potential was indicated to occur between 18 September and 23 May.

Standard project protection, then, requires that sufficient reservoir storage space be available on these dates to control a standard project flood resulting from these various percentages of the potential for a standard project storm, given a particular basin ground wetness index. The ground wetness index is calculated from a weighted measure of accumulated basin mean precipitation. It is designed to directly relate flood potential to the wetness of the drainage basin. The wetness index in present use allows a daily reduction in the weight given to previously occurring precipitation and is computed as follows:

$$Par = (0.97)(Par') + Precip$$

where

Par   = ground wetness index for the present day's operation

Par'   = previous day's index

Precip = precipitation occurring since Par' was computed.

Thus under wet ground conditions (wetness index = 11.0), control of the full standard project storm and consequent flood requires 750,000 acre-feet of unfilled reservoir flood control space (volume). However, under dry ground conditions (wetness index = 3.5), only 375,000 acre-feet unfilled reservoir volume is needed to control the full project storm between 15 October and 1 April. Unfilled reservoir flood control volumes have also been computed for wetness indexes between 11.0 and 3.5.

In order to have the required flood control space by 15 October, a contingency reservoir water level drawdown rate of 25,000 acre-feet

per day has been adopted. This drawdown procedure of course is only used if the reservoir water storage leaves an unfilled volume smaller than the required flood control space. The filling rate after 31 March has been set at 10,000 acre-feet per day. Both the drawdown and filling rates are consistent with project water release restrictions.

Required flood control volumes for seasonal periods susceptible to 80 and 60 percent of the full project storm have also been determined for the range of appropriate wetness indexes. Associated drawdown and filling rates have been calculated. Based on storage volumes necessary to control various percentages of full storms under varying ground wetness indexes, an overall schedule of required unfilled flood control volume storage at Oroville Reservoir and associated drawdown and fill rates has been given. This schedule is shown in Figure 2.5.

In the case where inflow and flood control storage are decreasing and no storms are forecasted, releases may be decreased to the greater of (1) the rate which will maintain the currently required unfilled flood storage volume or (2) the rate required by other uses of the reservoir. Hence the flood storage space may be slightly encroached upon to provide, for example, extra water for future power generation. The maximum safe total outflow reduction can be determined according to the amount of flood control space encroached upon and the magnitude of potential floods. (As previously stated, the rate of release reduction is limited to 5,000 cfs in a two hour period).

C. Minimum Release Requirements

In order to fully, but safely, utilize downstream channel capacities it was determined that a release capacity from Oroville Reservoir of 150,000 cfs is desirable throughout the unfilled flood control volume range and under all possible flood conditions. However, it was also found that safe, more cost efficient operation of the reservoir could result with lower release capacity in the lower elevation range of flood control space. It was therefore mutually agreed between the State of California and the United States that release capacity would be 150,000 cfs in the upper half volume of the required flood control space and a lesser amount (minimum 85,000 cfs) in the lower half. These rates allow a safe release routing schedule for control of the standard project flood.

D. Flood Control Release Constraints

Analysis of downstream normal channel capacity, levee capacity, and floodway capacity has yielded the following constraints on flow. On the Feather River above the Yuba River junction (approximately 30 miles downstream from the dam site) the flow may not exceed 180,000 cfs. The flow limit below the Yuba junction has been set at 300,000 cfs and below the Bear River junction (approximately 45 miles downstream from Oroville Dam) at 320,000 cfs. It should be noted that only about 36 percent of the Yuba drainage outflow is presently controlled. Releases from Oroville Reservoir must therefore be based in part on stream gage measurements or forecasts of the Yuba River flow rate.
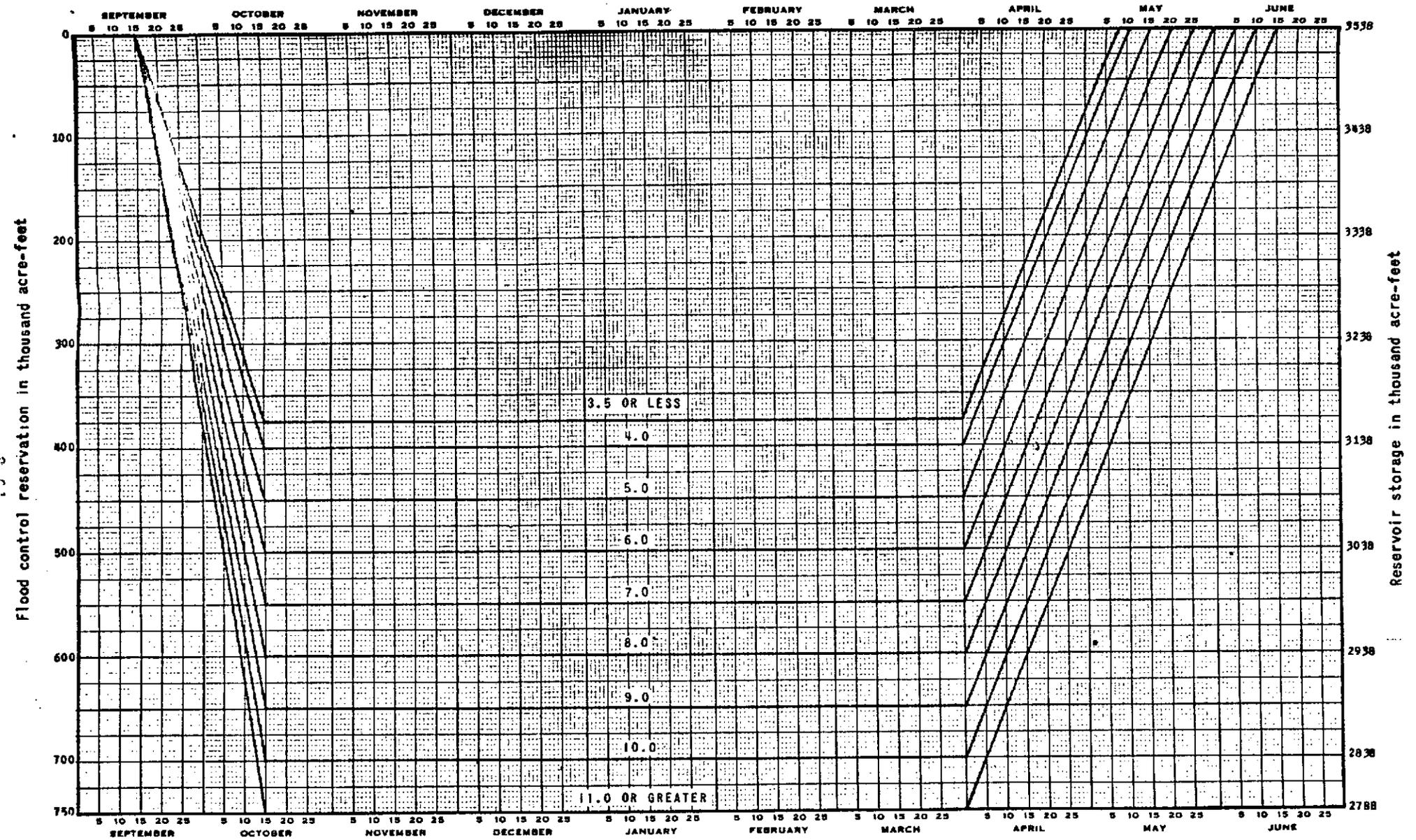
Figure 2.5 Schedule of Required Unfilled Flood Control Volume and Associated Drawdown and Fill Rates by Ground Wetness Index for Oroville Reservoir.

From Department of the Army (1970), Chart A-1 .

ACTUAL OR FORECAST INFLOW (WHICHEVER IS GREATER)	FLOOD CONTROL SPACE USED	REQUIRED RELEASES
c.f.s.	ac-ft	c.f.s.
0 - 15,000	0 - 5,000	Power Demand
0 - 15,000	Greater Than 5,000	Inflow
15,000 - 30,000	0 - 30,000	Lesser of 15,000 or maximum inflow
0 - 30,000	Greater Than 30,000	Maximum inflow for flood
30,000 - 120,000	- - - - - - - -	Lesser of maximum inflow or 60,000 c.f.s.
120,000 - 175,000	- - - - - - - -	Lesser of maximum inflow or 100,000 c.f.s.
Greater Than - 175,000	- - - - - - - -	Lesser of maximum inflow or 150,000 c.f.s.

Figure 2.6. Release Schedule for Oroville Reservoir Under Normal Conditions. From Department of the Army (1970), Chart A-1 .

The above flow rate constraints imply a maximum safe release at the Oroville Dam site of 150,000 cfs. No significant downstream flooding as a result of Feather River releases should occur under most conditions with this dam site rate limit. Minor flooding and damage, however, begin to occur at a flow of about 80,000 cfs to a small strip of agricultural land several miles below the reservoir.

Maximum release change limits have also been set for Oroville Reservoir, as previously stated. Such change limits are designed to prevent damage to structures or boating traffic on or near the river that might result from sudden changes in water level.

E. Overall Release Schedule Under Normal Conditions

The overall release schedule for Oroville Reservoir under normal conditions is given in Figure 2.6. All water use demands must be met within this schedule. At the higher inflow values, release criteria for flood control are of primary importance and release criteria for other water uses must take lower priority. These other water requirements include regional irrigation and power demands, general state water project needs, and downstream fishery requirements as established by the California State Department of Fish and Game and the U.S. Fish and Wildlife Service.

The actual inflow indicated in the left-hand column of the Release Schedule is that water volume actually gaged to have entered the reservoir. The forecast inflow of the same column is obtained from a Joint Federal-State (California) River Forecast Center streamflow simulation model. Expected water flow forecasts are becoming extremely important in flood control operations. The River Forecast Center hydrologic model is presently being used to make such forecasts on a six hour, twelve hour, twenty-four hour, and weekly basis. The predictive model employed by the River Forecase Center will be described in a later section of this Chapter.

F. Release for the Abnormal Flood Situation

A probable maximum flood for the watershed draining to Oroville Reservoir has been calculated using the probable maximum storm precipitation, as determined by the Hydrometeorological Section of the U.S. Weather Bureau, and the wettest ground conditions consistent with meteorological conditions necessary to produce the probable maximum precipitation. The maximum storm for the Feather River basin has been defined as a 72-hour period in which an average 21.1 inches of precipitation is deposited on the watershed. The resulting maximum rain flood, for which the spillway at Oroville Dam has been designed, has a peak flow of 720,000 cfs and a 72-hour runoff value of 2,510,000 acre-feet. It should be noted that this maximum peak flow rate is approximately 1.64 times the peak flow of the standard project flood and, as previously stated, the standard project flood flow peak is approximately 1.8 times the highest recorded storm runoff rate (250,000 cfs) ever recorded. Approximately the same relationships

hold for potential maximum, standard project, and historical maximum flood 72-hour runoff water volumes.

When the rate of rise of the Oroville Reservoir for a given elevation of the reservoir indicates a necessary exceedence of the normal maximum release capacity of 150,000 cfs, then use of the spillway is initiated. The spillway outflow rate is increased each hour, (at a rate not to exceed the 5,000 cfs limit) so that reservoir inflow is eventually matched by reservoir outflow. After the reservoir water level starts to fall, spillway gate openings are maintained until the inflow again reaches 150,000 cfs. At this point normal release scheduling is reinitiated.

In relating the foregoing to possible benefits to be derived through remote sensing, one consideration seems paramount. At the time when a major storm seems imminent, the very large "safety factor" which must be employed (through drawdown at the Oroville Reservoir) results primarily from very large uncertainties as to the maximum strength which that storm might achieve. Secondarily it results from similar uncertainties as to the "wetness factor" that prevails at that particular time, area-by-area, throughout the watershed. Just as some of our other research has indicated that a combination of meterological satellite data and ERTS data can permit the best crop forecast to be made, so it would seem that a similar combination would permit the best flood forecast to be made, and with equally dramatic cost effectiveness. We hope to perform research relative to this important possibility in the very near future.

IV. POTENTIAL VALUE OF REMOTE SENSING INFORMATION IN ECONOMIC OPERATIONS IN THE SUPPLY AREA

A. Models for Estimating Water Yield

1. Approach

Potential applications for remote sensing techniques in water supply estimation are presently being considered under two major contexts. The first involves a direct remote sensing input into present "state-of-the-art" streamflow prediction models. Relatively sophisticated water supply simulation systems are being developed and are presently being implemented for operational runoff forecasting by the State of California Department of Water Resources in conjunction with the National Weather Service. Areas of application for these new models include the Feather River watershed, primary test area for the water supply aspects of this study. Because of the fact that significant hardware and software systems already have been developed for the state's streamflow prediction models, proposals for present remote sensing applications are necessarily limited to more accurate definitions of model input parameters. Moreover, these remote sensing applications will likely be limited to those that are presently of an operational or nearly operational nature. Relative cost-efficiency comparisons for this situation would then be related to improved accuracies in present model predictions resulting from remote sensing inputs.

The second context involves future-period applications. From the standpoint of time required for research and testing, hardware development, and implementation, it is useful to divide the second context into two parts: the intermediate run (3 to 6 years) and the long run (after this first period). In these time frames, the models themselves might be modified or expanded to make optimal use of remote sensing capabilities. The intermediate period could involve modifications to make more effective use of present remote sensing capabilities and also to incorporate data flow capabilities from operational earth resource satellite and weather satellite systems. The long-run time frame would thus be used for bringing about the most intensive implementation of present and future remote sensing capabilities.

2. State Water Supply Modeling Responsibilities

Within the state of California, prediction of streamflow or runoff (i.e., water supply through time) is officially the responsibility of the Joint Federal-State River Forecast Center and the California Cooperative Snow Surveys. Both of these organizations are headquartered in the Resources Building, Sacramento, and both areincluded in The Resources Agency, Department of Water Resources (DWR), Flood Forecasting and Control Branch.

The federal half of the River Forecast Center (RFC) consists of personnel from the National Weather Service, operating under the auspices of the National Oceanic and Atmospheric Administration (NOAA) of the Department of Commerce. The state half is staffed by the DWR Flood Forecasting Section. Both sets of personnel work side by side as a team in the River Forecast Center.

The California Cooperative Snow Surveys (CCSS) has been officially in existence since 1930. Its primary function is to predict water supply resulting from snow melt runoff from 30 basins located principally in the Klamath, Cascade, and Sierra Nevada mountain ranges. Bulletins published on the 10th of February, March, April and May describe snowpack conditions, reservoir water storage status, and current "water year" rainfall patterns and runoff distribution as of the first of the given month. Based on the current snowpack conditions, forecasts of water runoff are made for every remaining month through July, and then for August and September combined. These predictions are based on the assumption of average climatic conditions prevailing after publication. Each succeeding publication updates the previous one. At the end of the water year, which runs from October to September, a summary of actual runoff throughout that year is published and comparisons made with predictions.

Information on water yield provided by the Snow Surveys' publications is utilized by 50 cooperating agencies. These include 25 irrigation and water districts, along with major private organizations, public utilities, municipalities, and state and federal organizations.

The Joint Federal-State River Forecast Center has as its primary responsibility the issuing of six, twelve and twenty-four hour river state forecasts during rain floods and snow floods for watersheds throughout the state. A secondary function is to provide daily water inflow forecasts to State, Bureau of Reclamation, and Army Corps of Engineers personnel operating the Oroville, Shasta, and Folsom Reservoirs respectively. Estimates of water inflow to other reservoirs are made as necessary. This water supply information is utilized in determining water release rates from the reservoirs. On occasion, forecasts are made for river stages downstream from dam sites to provide information on the maximum allowable releases from reservoirs.

The River Forecast Center also publishes bulletins and its information users include many of the organizations receiving information from the California Cooperative Snow Surveys. Coordination between the River Forecast Center and the Snow Surveys involves prediction coordination during snow melt floods. Forecasts of water runoff during such periods significantly differing from each other indicate that a check of the data and respective water supply model application are in order. A check in water supply forecasting as it relates to snowmelt yield is therefore provided by these two organizations.

An alternative way to state the water yield modeling responsibilities of the RFC and CCSS is in terms of the time period for which predictions are made. The River Forecast Center is primarily involved in issuing six hour to several day forecasts. Its modeling function is therefore real-time or what may be termed "dynamic" water yield prediction. The Snow Survey's state-wide forecasts, however, deal basically with monthly mean runoff amounts and therefore are commonly known as "volumetric" water yield estimation. Dynamic estimation is most useful in providing data for day-to-day regulation of reservoir levels and for real-time flood forecasting. Volumetric runoff estimates allow longer term water management planning.

This distinction between dynamic and volumetric yield prediction is an important one from the standpoint of the application of remote sensing. The difference in time interval of yield estimation will affect the potential use of remotely sensed data in the respective predictive models.

3. The Types of Water Supply Prediction Models Used

Two basic approaches to water yield modeling are exhibited by the above organizations. The Joint Federal-State River Forecast Center (RFC) employs a technique known as system "synthesis." In this case the system is considered to be known in terms of a set of mathematical equations, the objective being to determine the characteristics of the output for a given class of input. Moreover, since most components of the current RFC model are strictly arithmetic transformations of data or variable values, their simulation system can be classified as largely "deterministic."

The California Cooperative Snow Surveys' (CCSS) approach may be classified as that of systems "analysis." Here watershed input data (e.g., precipitation, temperature, snow water content, snow depth) are related to watershed output (water runoff past a gaging station) by a response function that, in a statistical sense, best describes the input-output pair. The CCSS model does not explicitly describe subsystem processes with mathematical equations as in the RFC model. Instead, it treats the watershed as a "black box," choosing to derive water supply output through a single relationship or series of relationships relating watershed input directly to output. Since these relationships are determined by statistical line fitting techniques, a given amount of uncertainty, or alternatively a statement of confidence concerning numerical exactness, can be attached to a given output value. Thus the Snow Surveys' model may be said to be "stochastic" or "probabilistic."

The CCSS model discussed above is applied to all 30 basins of responsibility. The process involved is essentially of the human-desk calculator type. However, for two of the thirty basins in which the Snow Surveys issues water supply forecasts, a computer moderated hydrologic model is also used. Its approach is again that of systems analysis. While largely probabilistic, this second model utilized by CCSS is broken down into components, sometimes utilizing strictly arithmetic transformations, to estimate various runoff components adding to total water yield.

The only two models currently being used for estimating water supply on the Feather River Watershed are the River Forecast Center model and the first of the California Cooperative Snow Surveys models alluded to above. As the Feather River Watershed is the source for the California Water Project and is the Northern Test Area for our NASA sponsored integrated resource study, most of the discussion to follow will be addressed to these two currently used hydrologic models.

The RFC Model

The three basic inputs to the River Forecast Center hydrologic model (Burnash et al., 1973) are (1) effective basin (watershed) precipitation, (2) basin evapotranspiration, and (3) basin characteristics affecting streamflow. The model output is streamflow (volume per unit time) passing a given gaging station. The model itself defines the basin as a set of water storage bins whose effective moisture storage capacities are determined by inference from rainfall and discharge records, which hold water temporarily and then gradually recede as their contents are removed by percolation, evapotranspiration, and/or lateral drainage. Thus the model is intended to represent watershed hydrologic processes in a rational, physically realistic manner.

By adjusting input values slightly, and by modifying moisture storage capacities and intercompartment flow rates, a hydrologist can "tune" the model through a series of computer runs to give the most accurate prediction of annual, monthly, three day, and/or daily runoff values when compared

with observed flow rates. Final tuning is performed automatically by the use of an optimization (fitting) function. This function is dependent on the root mean square errors of predicted versus actual runoff values for daily and monthly values, and on a ratio of annual runoff errors to annual precipitation. The empirical optimization presently in use is:

$$OPTIM = DSE^3 \times MSE^{4/3} \times AF$$

where

$$DSE = \text{Daily Root Mean Square error in Cubic feet per}$$

$$\text{second (CFS) per square mile of watershed (SQMI)}$$

$$= (E[\hat{Y}_{\substack{predicted \\ runoff}} - Y_{\substack{observed \\ runoff}}]^2)^{1/2}$$

$$MSE = \text{Monthly Root Mean Square error}$$

$$\text{and } AF = 1 + \frac{\Sigma | \text{ Annual Runoff Errors}|}{\Sigma \text{ Annual Precipitation}}$$

The exponents 3 and 4/3 are derived from cumulated experience of hydrologists during watershed modeling.

The sensitivity or accuracy of the RFC hydrologic model can be expressed in terms of the value of OPTIM or in terms of the time based error functions that determine OPTIM's value. The choice of error function is dependent upon the time dimension for the objective of the given water supply estimation. For instance, if concern centers only on an accurate prediction of three day flood flows, then a three day mean square error function would be appropriate. The authors of the present RFC model feel that a continuous water yield forecasting task is best judged in terms of a fitting function dependent on the several time units involved, therefore OPTIM.

Once the RFC hydrologic model is completely tuned for a given watershed, indicating a minimization of the error function, the model is then considered an operational tool for water yield forecasting for that basin. Six hour, twelve hour, twenty-four hour, and weekly forecasts of water flow are typical model applications.

The basic conceptualization for the River Forecasting model is given in Figure 2.7. This figure shows the soil mantle as composed of two primary layers: the upper zone and the lower zone. Each zone is then divided into water storage compartments corresponding to actual hydrologic states within the soil. In both zones tension water is defined as that water which is closely bound to soil particles, while free water is not bound to soil particles and is thus able to move deeper and/or laterally within the soil mantle.

Figure 2.7. Base concept on which the River Forecasting Model is based. From Burnash et al. (1973).

In general, within a given zone, tension water storage compartments must be filled before free water storages may gain water. This is only approximately true in the lower zone where variations in soil and precipitation conditions may allow some water to enter the lower zone free water storage compartments before the lower zone tension water deficiencies are satisfied. In this model, only water running directly off the soil surface or emerging from free water storage can give rise to runoff components adding to total water yield from the watershed.

The rate of vertical drainage from upper zone free water storage to deeper soils, referred to as percolation, is determined by the water content of the upper zone free water storage compartment and the deficiency of lower zone moisture volumes. Horizontal flow, or interflow, occurs in the upper zone only where the rate of precipitation exceeds the rate at which water may percolate downward. When the precipitation rate exceeds the maximum interflow drainage capacity, excess precipitation will result in surface runoff. The soil surface in such a situation will then give rise to a runoff regime similar to permanently impervious surfaces (rock, lake surfaces) and may be termed a temporarily impervious surface.

The primary and supplementary free water storages give rise to drainage in the form of either baseflow or subsurface flow not appearing in stream channels. These conceptual storage bins fill simultaneously from percolated water and drain independently at different rates. This characteristic of differential drainage rate leads to what is called a "variable ground water recession", which in turn is a variable rate of decrease in water flow flowing at flood peak plotted on a hydrograph (flow rate versus time). Such variation in flow rate allows an empirical determination of the respective flow rates and storage capacities (integration of rate over time) for these lower zone free water storages.

Streamflow prediction is therefore the result of processing effective precipitation data through an algorithm describing water movement in the soil mantle. This algorithm gives rise to runoff estimates in five basic forms: (1) direct runoff from permanently impervious areas, (2) surface runoff due to precipitation occurring at a rate faster than percolation and interflow can take place when both upper zone storages are full, (3) interflow resulting from the lateral drainage of a temporary upper zone free water storage, (4) baseflow from lower zone supplementary free water storage, and (5) baseflow from lower zone primary free water storage. Together the estimates of these runoff components give rise to the predicted water yield at a given gaging station. The prediction assumes that no moisture escapes from the watershed through deep bedrock aquifers below the stream channel.

The basic components of the River Forecast Center computerized hydrologic model are given in Figure 2.8. Input parameters along with a listing of RFC model components necessary for water yield simulation are described in Table 2.1 in terms of their computer mnemonics. The method of derivation of the listed parameters is also given.
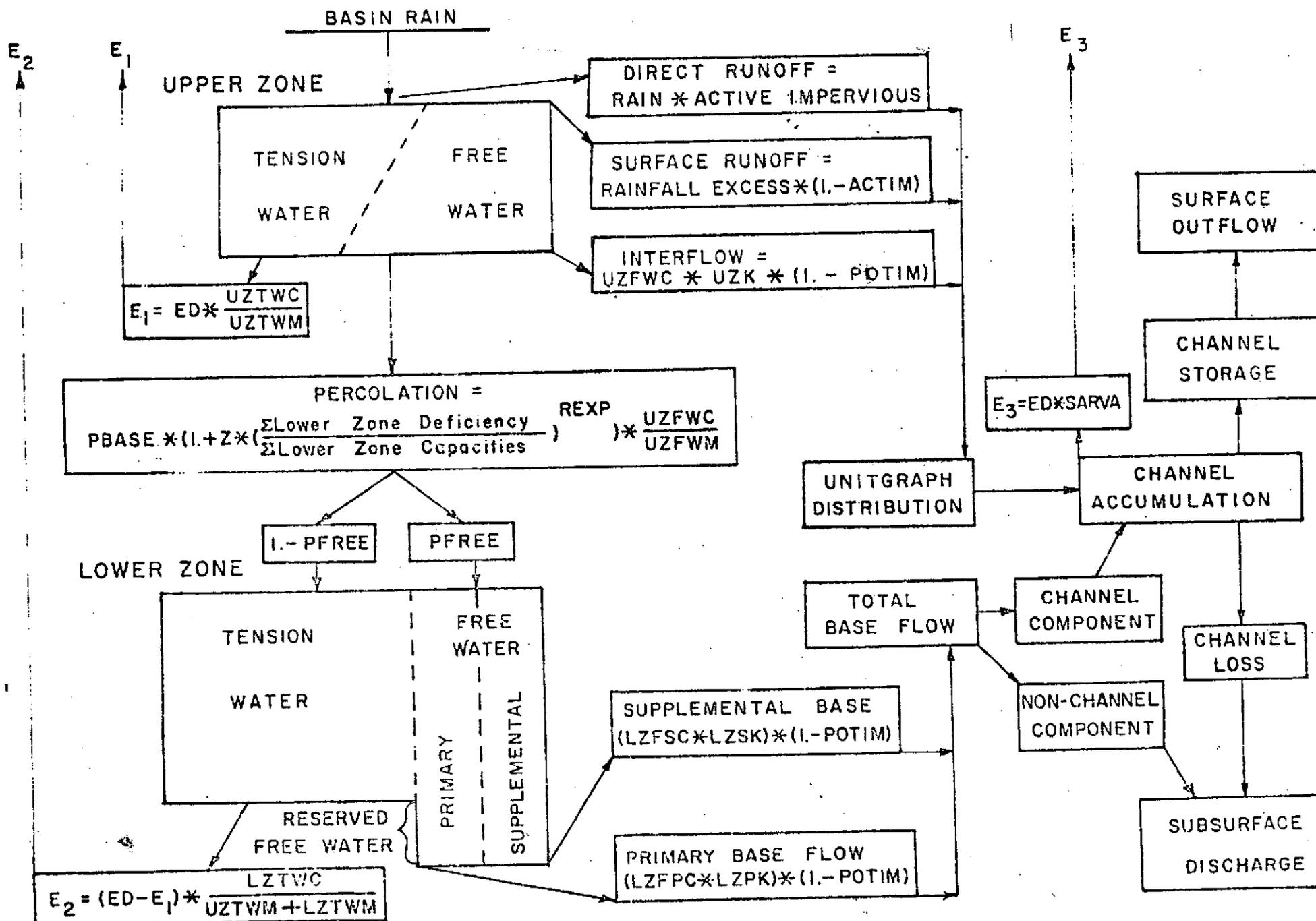
Figure 2.8. Components of a generalized hydrolic model. From Burnash et al. (1973).

Table 2.1. SIGNIFICANT PARAMETERS REQUIRED FOR WATER YIELD SIMULATION
UTILIZING THE JOINT FEDERAL-STATE RIVER FORECAST CENTER
HYDROLOGIC MODEL.

No.	Parameter	How Derived
1)	Weights applied to station rainfall values to determine basin mean rainfall, RAWT.	Set according to relative area closest to a given meteorological station and by the rainfall amount for a given station. The resulting basin weight for a given station is then established by optimization with respect to a given mean square error function or the fitting function OPTIM. Rainfall, or more accurately total precipitation, amounts for a given meteorological station are determined daily from historical records for model tuning. For a real-time situation, i.e. an application of the tuned model, precipitation amounts are taken from automatic[1] ground meteorological station readouts, or from phoned-in rain gauge

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[1]The California Department of Water Resources automatic ground
station (Barnes, 1973) system consists of a computer controlled network
of modular remote stations utilizing analog and digital sensors. In the
Feather River watershed there are presently six such stations making
real-time measurements of precipitation and optionally of temperature and
snow water content. Station power supply is provided by either AC com-
merical power or solar cells. A rechargeable 12 DC volt battery allows
operation of the station for about two weeks in the event of a power
failure. The stations transmit the data over VHF radio and state micro-
wave UHF communication channels to a Central Interrogation Station in
the Resources building at Sacramento.

The Central Interrogation Station consists of a control consol, a
Data General Corporation 1220 Computer, and two Teletype Corporation ASR
33 terminals. One Teletypewriter is located at the Federal-State River
Forecast Center. It may be used for remote station data printout, mod-
ification of computer software, or manual interrogation of remote station
sensors. Under normal operation the Nova 1220 Computer automatically
interrogates up to six groups of automatic stations at a given preselected
time interval from one minute to 24 hours.

Table 2.1 (continued)

No.	Parameter	How Derived

		measurements. Precipitation amounts for future periods are estimated from quantitative precipitation forecasts (QPE) made by meteorologists. These forecasts are derived with standard weather forecasting data and are specific to given reference locations. The resulting QPF's are then transformed by a predetermined algorithm to basin precipitation recording stations of interest.
2)	Monthly weights for matching evapotranspiration estimates or mean pan evaporation data to the basin's characteristic climate and plant cycles, PCTPN.	Derived from either (1) the monthly mid-point value taken from an average evapotranspiration demand curve for a similar watershed, or (2) daily computations of evapotranspiration, made from pan evaporation data by differentially weighting mid-month evaporation values. Between mid-month points weighting (dimensioning) is carried out by linear interpolation.
3)	Direct runoff and evaporation	
	a) Fraction of impervious basin contigous with stream channels, PCTIM.	Derived from hydrograph analysis (i.e., based on an analysis of the characteristics of flow volume past a gaging station with respect to time).
	b) The fraction of impervious area which appears as tension water requirements are met; i.e., active impervious ACTIM which is limited to a maximum value of ADIMP. The total of ADIMP and PCTIM is the potential impervious, i.e. POTIM.	Derived from hydrograph analysis.
	c) Fraction of the basin covered by streams, lakes, and riparian vegetation SARVA.	Derived from PCTIM or detailed maps.
	d) Evapotranspiration demand, ED.	Derived from (2).

Table 2.1 (continued)

No.	Parameter	How Derived

4) Upper zone tension water

   a) Maximum capacity in inches, UZTWM. — Derived from hydrograph analysis.

   b) Contents in inches, UZTWC. — Initially set at start of simulation. Adjusted later if necessary to conform to relationships discovered during simulation.

5) Upper zone free water

   a) Maximum capacity in inches, UZFWM — Established by optimization during simulation.

   b) Contents in inches, UZFWC. — Initially set at start of simulation. Adjusted later if necessary.

   c) Lateral drainage rate expressed as a fraction of contents per day, UZK. — Established by optimization during simulation.

6) The percolation rate from upper zone free water into the lower zone.

   a) The through-put rate during saturated conditions, PBASE. — Minimum value obtained through hydrograph analysis.

   b) The proportional increase in percolation from saturated to dry conditions, Z. — Established by optimization during simulation.

   c) An exponent determining the rate of change of the percolation rate with changing lower zone water contents, REXP. — Initially set at start of simulation. Final value established by optimization during simulation.

7) Lower zone tension water

   a) Maximum capacity in inches, LZTWM. — Established by optimization during simulation. Can potentially be related to wilting activity among deep rooted plants during long periods of drought.

   b) Contents in inches, LZTWC. — Initially set at start of simulation. Adjusted later if necessary.

Table 2.1   (continued)

No.	Parameter	How Derived

8) Lower zone free water

a) Supplemental free water
    storage.
    1) Maximum capacity in inches,   Derived by hydrograph analysis.
        LZFSM

    2) Contents in inches, LZFSC   Initially set at start of simula-
                                       tion. Adjusted later if necessary.

    3) Lateral draining rate ex-   Derived by hydrograph analysis.
        pressed as a fraction of
        contents per day, LZSK

b) Primary free water storage
    1) Maximum capacity in inches,   Derived by hydrograph analysis
        LZFPM

    2) Contents in inches, LZFPC   Initially set at start of simula-
                                       tion. Adjusted later if necessary.

    3) Lateral drainage rate ex-   Derived by hydrograph analysis.
        pressed as a fraction of
        contents per day, LZPK

c) Direct percolation to Lower   Initially set at start of simu-
    Zone Free Water, PFREE, the   lation.   Established by optimi-
    percentage of percolated   zation during simulation. May
    water which directly enters   also be established in some
    the lower free water aquifers   instances through hydrograph
    without a prior claim by   analysis.
    lower zone tension water
    deficiencies.

d) Ground water discharge not
    observable in the river
    channel
    1) Ratio of non-channel sub-   Established by optimization
        surface outflow to chan-   during simulation.
        nel baseflow, SIDE.

    2) Discharge required by   Initially set at start of simu-
        channel underflow, SSOUT   lation. Adjusted later as optim-
                                       ization requires.

e) Fraction of lower zone free   Initially set at the start of
    water incapable of resupplying   simulation.
    lower zone tension, RSERV

Table 2.1 (continued)

No.	Parameter	How Derived
9)	A non-dimensional unitgraph (here a time delay histogram) used for direct, surface and interflow runoff.	Initially set at the start of simulation.
10)	Channel storage characteristics to modify the timing of flow obtained from the normal unitgraph distribution.	Initially set at start of simulation. May be refined through optimization during simulation.

In the Feather River watershed not all precipitation occurs as rain. Throughout the October to April storm season snow is likely to fall in the middle to high elevation areas, thereby building a pre-spring pack often exceeding ten feet in some locations. In order to determine the effective precipitation input to the River Forecast Center's hydrologic model when precipitation occurs in both liquid and solid forms, the RFC has developed a snow melt submodel. This computerized simulation procedure calculates the amount of melt and determines what portion of the melt plus rain will be retained by the snow pack. The resulting pack water output is utilized on a daily basis as the effective precipitation input to the RFC water yield prediction model. Since remote sensing information could potentially be a very useful input into the River Forecast Center snow melt submodel, and since accurate determination of effective precipitation is especially critical to accurate water yield estimation by the RFC hydrologic model, a brief analysis of the melt submodel will not be given.

The snow melt (ablation) model (Burnash and Baird, 1973) consists of two major components. The first is a set of equations describing melt processes. The second takes the melt computed by the first component plus any liquid precipitation determined to have fallen and processes them through a snow pack algorithm. This second series of equations computes the proportion of the melt and rain which will be retained by the pack and therefore the amount to be released to the soil mantle. The pack algorithm also adjusts the density and depth of the snow pack, factors which affect water release.

Both components of the RFC snow ablation model employ the technique of system synthesis. Both are deterministic and the second, the pack algorithm, is a physically realistic conceptualization of actual snow pack processes. As in the case of the RFC hydrologic (streamflow) model, use of physically realistic change functions imposes a constraint on the set of possible model error sources. The human "tuner" may then direct his attention to the thereby limited set of possible input inaccuracies or inappropriate model relationships.

The first component of the RFC snow ablation model consists of three basic melt processes. These are 1) radiational melt resulting from the absorption of solar energy, 2) convection-condensation melt resulting from air with a specific temperature and moisture content moving over the pack, and 3) conduction melt resulting from precipitation which has a temperature in excess of freezing.

Radiation melt is calculated by use of the following equation:

$$RMELT = RADAT \times RATIO \times (1. - ABEDO) \times (CST + PACK \times ABSCF)$$

where:

> RMELT = daily radiational melt in inches

> RADAT = incoming radiation as determined from the solar constant and adjusted for latitude, day of year, and elevation of the area being modeled.

> RATIO = The fraction of incoming radiation which will penetrate the clouds. This value is estimated from the daily maximum-minimum temperature spread at the site, modeled as determined by lapsing the maximum-minimum spread from reference (commonly lower elevation) temperature recording stations if no local temperature station exists.

> ABEDO = albedo, i.e. the reflectivity of the snow surface determined by reference to published curves according to age of surface snow layer (time since last storm) and depth of snow (determined from on the ground snow course measurements during tuning of the model and from topographic and vegetation cover moderated transforms of this value to other areas in the watershed lacking ground data).

> CST = a coefficient modified according to aspect (from ground data or topographic data sheets) and used for converting absorbed radiation to melt in inches.

> PACK = water content of the pack as determined from snow course measurements (used as an indication of variable site shading and net long wave radiational loss); water content extrapolated as with snow depth for areas lacking ground truth.

> ABSCF = a CST adjustment factor designed to consider the change in site shading with increased water content (accounts for the effect of orientation changes induced by deep packs and the reduced shading which occurs as pack depth increases and large rocks and small trees are buried).

Convection condensation melt is expressed by the following relation:

$$CCMLT = ((TD - 32) \times .0104 + (TBAR - TD) \times .00305) \times WS \times ELTRM$$

where:

CCMLT = daily convection-condensation melt in inches.

TD = dew point estimate for the area modeled as lapsed from a reference temperature recording station if no local station exists.

TBAR = average resultant air temperature lapsed from reference recording stations if necessary.

WS = average daily wind movement in nautical miles at the pack surface presently determined via optimization processes.

ELTRM = a factor for adjusting the density of air relative to operational recording stations based on the elevation of the area to be modeled.

Conduction melt is calculated with the equation below:

$$M_P = .007 \, P_R (T_{WB} - 32)$$

where:

M_P = melt in inches due to rain.

P_R = rainfall in inches. The amount of precipitation at a modeled location is derived first by determining the relationship between reference recording precipitation stations and measured snow course water contents and then extrapolated by previously mentioned site-to-site water content transformations to areas without ground data. A precipitation relationship between areas having ground recording stations and ground dataless areas of the watershed is thus formulated. The precentage of precipitation that is liquid (i.e., rain) is calculated by multiplying the derived precipitation amount by a temperature dependent ratio of rain to snow (see Table 2.2).

T_{WB} = minimum resultant temperature (obtained by lapsing from recording station values) - 4° F.

Table 2.2. RELATIONSHIP BETWEEN TEMPERATURE AND PERCENTAGE OF PRECIPI-
TATION THAT IS IN THE FORM OF RAIN

Average Resultant Temperature (°F)	Percent Rain
<27°	0
27°	10
28°	20
29°	30
30°	40
31°	60
32°	80
>32°	100

The above three melt quantities are then sent through the second main component of the RFC snow ablation model. This is the algorithm which computes the amount of melt plus liquid precipitation which the pack will release and adjusts the structural makeup of the pack. Each snow pack adjustment will modify the ability of the pack to release water. A flow chart for this algorithm is given in Figure 2.9.

The Primary CCSS Model

The major inputs into the California Cooperative Snow Surveys' primary model (Howard, 1973) consist of (1) an April 1st snow pack index, (2) an October to March precipitation index, (3) an October to March run-off index, (4) the previous year's snow pack index, and (5) an April to June precipitation index. These inputs are used as independent variables in a regression equation to determine the output, April to July runoff expressed as a volume of water, for a given year. An example of such an equation is given for a particular Sierran watershed at the bottom of Figure 2.10. The coefficients for this regression were obtained through the usual Least Squares function fitting analysis.

Estimates of monthly runoff from February to March are also made, and published early in the season. These values are based on runoff, to time when the prediction is being made, plus historical average monthly runoffs to the month in question. In addition, the April to July runoff predicted by the given watershed runoff equation can be distributed on a monthly basis. This distribution is based on hydrographs (volume plotted versus time) for historical years of similar water volume.

It is important to note that CCSS water yield estimates are corrected for major impairments (e.g., reservoirs) upstream from flow gaging stations. The predicted water volumes thus represent unimpaired values, and hence indicate the water yield that would result if no artificial water delay mechanism existed in the watershed of interest.

Forecast confidence is expressed by CCSS in terms of runoff probability ranges. A given probability range is derived from historical runoff data for a particular watershed according to the month in which the April

$$DPTH = (PACK-SNOW)/DNSTY + SNOW/.25$$

RAIN > 0
yes   no

FCAP = DEPTH * .49
RNRET = (FCAP-PACK) * .55
(RAIN > RNRET)

yes   no

EFCRN = RAIN-RNRET   RNRET=RAIN
                         EFCRN=0

PACK=PACK+RNRET
DNSTY=PACK/DPTH
FCAP=PACK/DNSTY
CMPTN = (RAIN/(FCAP-PACK)) * .92

(CMPTN > 1)

yes   no

CMPTN = 1

DNSTY = DNSTY + (.49-DNSTY) * CMPTN
DPTH = PACK/DNSTY

FCAP = DPTH * .49
DNSTY = PACK/DPTH
PKRET = (FCAP-PACK) * .6
AVMLT = TTMLT - PKRET

AVMLT > 0
yes   no

                AVMLT = 0

TACK = PACK - AVMLT

TACK > 0
yes   no

DPCHG=TTMLT/DNSTY   AVMLT = PACK
PACK=TACK
DPTH=DPTH-DPCHG

DPTH > 0
yes   no

                AVMLT = AVMLT+PACK

PACK = 0
DPTH = 0
DNSTY = .25

DNSTY = PACK/DPTH

where:

AVMLT = Available melt (leaves pack)
CMPTN = Pack compaction term
DNSTY = Pack density
DPCHG = Pack depth change term
DPTH = Pack depth in inches
EFCRN = Effective rain
FCAP = Maximum moisture capacity of pack
PACK = Water content of pack in inches
RAIN = Liquid precip
RNRET = Rainfall retained by pack
SNOW = Water content of solid precip
TACK = Temporary water content
TTMLT = Total daily melt from all sources

Figure 2.9.   Model showing mechanics involved in determining snowpack.   From Burnash and Baird (1973).
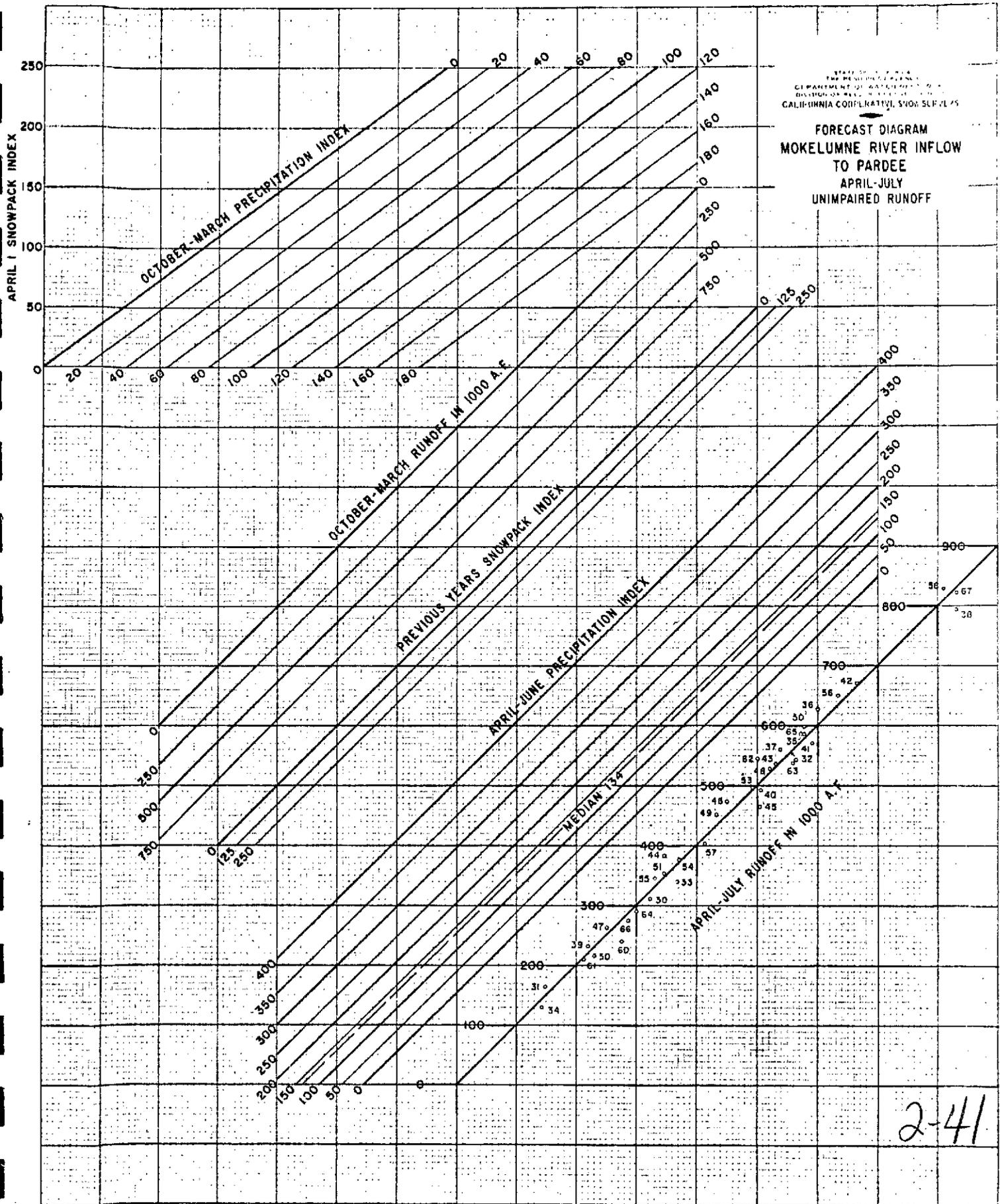
RUNOFF=(-0.2522)(OCT.-MAR. RO)+(0.2446)(PYS)+(2.7305)(SNOW)+(3.53II)(OCT.-MAR. PRE)+(I.2265)(A-J PRE)^2+(0.9944)(A-J PRE)$^{1/2}$- 282.0

Figure 2.10. Plot of regression equations used in forecasting river flow in the Sierra, as explained in the text

FORECAST COMPUTATION FORM

MOKELUMNE INFLOW TO PARDEE

APRIL - JULY UNIMPAIRED RUNOFF

19 _____

OCTOBER - MARCH PRECIPITATION

Precipitation Station (1)	Adjusted October - March Precipitation Normal (2)	October Precipitation (Inches) (3)	x Col. 3 1.0 (4)	November Precipitation (Inches) (5)	x Col. 5 1.0 (6)	December Precipitation (Inches) (7)	x Col. 7 1.0 (8)	January Precipitation (Inches) (9)	x Col. 9 1.0 (10)	Total Adjusted Precipitation (11)	Station Index Col. 11 x 100 ÷ Col. 2 (12)	February Precipitation (Inches) (13)	x Col. 13 1.0 (14)	Station Index Col. 14 x 100 ÷ Col. 2 (15)	March Precipitation (Inches) (16)	Station Index Col. 16 x 100 ÷ Col. 2 (17)
CALAVERAS BIG TREES 8928	38.04	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
SAN ANDREAS 2S. 7702	23.39	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
SALT SPRINGS 9105	37.93	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
TIGER CREEK 1277	45.05	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
TWIN LAKES 7689	35.61	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
		—		—		—		—				—			—	
		—		—		—		—				—			—	
		—		—		—		—				—			—	

Total
Basin Index: October - January   Total February   Total March

APRIL - JUNE PRECIPITATION

Precipitation Station (18)	Adjusted April - June Precipitation Normal (19)	April Precipitation (Inches) (20)	Station Index Col. 20 x 100 ÷ Col. 19 (21)	May Precipitation (Inches) (22)	0.8 x Col. 22 (23)	Station Index Col. 23 x 100 ÷ Col. 19 (24)	June Precipitation (Inches) (25)	0.8 x Col. 25 (26)	Station Index Col. 26 x 100 ÷ Col. 19 (27)
CALAVERAS B.T.	4.09								
SAN ANDREAS 2S.	2.49								
SALT SPRINGS	4.04								
TIGER CREEK	4.83								
TWIN LAKES	3.66								

Total
Basin Index: April   Total May   Total June

PRECIPITATION INDEXES

Indexes	February 1	March 1	April 1	May 1	June 1	July 1
October - January						
February	18					
March	16	16				
October - March						
April						
May				36		
June				7	7	
April - June	134	134	134			

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Figure 2.11.   Computation form used in forecasting river flow in the Sierra.

FORECAST COMPUTATION FORM 2-43

MOKELUMNE INFLOW TO PARDEE

APRIL - JULY UNIMPAIRED RUNOFF

Precipitation Correction - TWIN LAKES

SNOW PACK INDEX

Dates Measured	Snow Course Name (1)	Snow Course Number	Precipitation Adjustment Ratio (2)	Average April 1 Snow Course Water Content (3)	Feb 1 Date of Field Measurement (4)	Feb 1 Water Content of Field Measurement (inches) (5)	Feb 1 Intervening Precipitation Correction (inches) (6)	Feb 1 Col. 2 x Col. 6 (Note sign) (7)	Feb 1 Col. 5 + Col 7 (Note sign) (8)	Feb 1 Snow Course Index Col. 8 x 100 ÷ Col. 3 (9)	Mar 1 Date of Field Measurement (10)	Mar 1 Water Content of Field Measurement (inches) (11)	Mar 1 Intervening Precipitation Correction (inches) (12)	Mar 1 Col. 2 x Col. 12 (Note sign) (13)	Mar 1 Col. 11 + Col. 13 (Note sign) (14)	Mar 1 Snow Course Index Col. 14 x 100 ÷ Col. 3 (15)	Apr 1 Date of Field Measurement (16)	Apr 1 Water Content of Field Measurement (inches) (17)	Apr 1 Intervening Precipitation Correction (inches) (18)	Apr 1 Col. 2 x Col. 18 (Note sign) (19)	Apr 1 Col. 17 + Col. 19 (Note sign) (20)	Apr 1 Snow Course Index Col. 20 x 100 ÷ Col. 3 (21)
2,A,4,A	HIGHLAND MEADOW	323	1.5	48.1																		
2,3,4,5	U. CARSON PASS	106	1.1	34.6																		
A,A,4,5	BLUE LAKES	129	1.1	34.8																		
2,3,4,5	TWIN LAKES	107	1.0	30.0																		
2,3,4	TRAGEDY SPRINGS	130	1.4	43.3																		
2 4	WHEELER LAKE	131	1.7	51.6																		
2,3,4,5	LAKE ALPINE	141	1.3	40.6																		
2,A,4,5	PACIFIC VALLEY	132	1.2	36.2																		
2,3,4	CORRAL FLAT	133	1.2	38.8																		
2,3,4	SILVER LAKE	109	0.7	22.8																		
2,3,4,5	BEAR VALLEY NO.1	134	0.8*	25.4																		
2,3,4,5	BEAR VALLEY NO.2	339	0.9*	28.2																		
2,3,4,5	BIG MEADOW	146	0.7+	27.8																		
2,3,4	LUMBERYARD	135	1.0*	31.0																		
2,3,4,5	COTTAGE SPRINGS	147	0.4+	14.2																		

* TAHOE CITY
+ CALAVERAS BIG TREES

Total
February 1 Snow Pack Index

Average February - March Increment 30

April 1 Snow Pack Index
Estimated as of February 1

Total
March 1 Snow Pack Index

Average March Increment 11
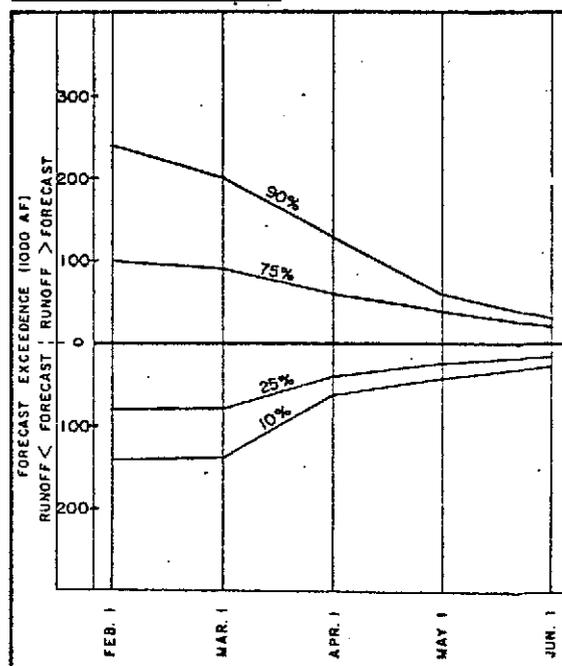
April 1 Snow Pack Index
Estimated as of March 1

Total
April 1 Snow Pack Index

OCTOBER - MARCH RUNOFF

PERIOD	FEBRUARY 1	MARCH 1	APRIL 1
October - January Runoff			
February Runoff	54		
March Runoff	73	73	
October - March Runoff			

FORECAST SUMMARY

Date of Forecast	April 1 Snow Pack Index	October - March Precipitation Index	Antecedent Conditions	April - June Precipitation Index	Miscellaneous	Median Forecast (1000 acre-feet)	Forecast Range (1000 acre-feet) There is a 10 % probability that forecast will Exceed	Not exceed
February 1								
March 1								
April 1								
May 1								
June 1								

FORECAST RANGE DIAGRAM

Figure 2.12.   Forecast range diagram (lower right) and associated computation forms used in forecasting river flow in the Sierra.

to July forecast is made. An example forecast computation form appears
in Figure 2.11 and of a forecast range diagram in the lower right-hand
corner of Figure 2.12. An 80 percent probability (using the runoff >
forecast 90 percent bound and the runoff < forecast 10 percent bound)
means that actual gaged runoff volume will fall within the stated limits
eight times out of tem.

Though it is not presently being done, the accuracy of the primary
CCSS hydrologic model could be expressed in terms of a root mean square
error function as with the RFC model. The accuracy of the CCSS model
over several years could then be defined as:

YRMSE = yearly root mean square error in cubic feet of water
          yield per April to July runoff period

$$= (E[Y_{predicted \atop runoff} - Y_{observed \atop runoff}]^2)^{1/2}.$$

Since the CCSS hydrologic model is probabilistic in nature, a
statement of confidence about predicted water yields can also be con-
structed. This statement consists of a claim that the actually <u>observed</u>
runoff amount will lie in a given value range, known as the confidence
interval, with a specified probability (commonly .90, .95, or .99).
The confidence interval is centered on the <u>predicted</u> value. This state-
ment may be alternatively described as a measure of how precisely the
yield estimate may be stated for a given level of confidence, that is
probability. The confidence interval, for a given level of confidence,
around a predicted value of runoff may be defined mathematically as:

$$CI = Y_{predicted \atop runoff} \pm t_{(d.f., 1-\alpha/2)} \left((V(Y_{predicted \atop runoff}))^{1/2} / n \right)$$

where:

   t   = a bell-shaped statistical distribution known as
          "Students t"; in terms of the present example it
          may be conceptualized as the difference between
          the predicted value and the eventual actually
          measured value divided by the standard deviation
          of the predicted value, for given d.f. and α.

   d.f = degrees of freedom = n - k - 1

   n   = number of observations on which the regression is
          based.

   k   = number of independent variables in the regression
          equation.

   α = the probability that $Y_{observed \atop runoff}$ will actually fall

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within the calculated confidence interval; this probability is alternatively known as the confidence level.

$$\overline{V(Y_{\text{predicted runoff}})} = \text{estimate of the variance of the predicted runoff.}$$

Since the size of the confidence interval about a given water yield estimate is one convenient statistical measure of the relative predictive value of that estimate, a convenient representation of the CI should be given. It is known as the confidence interval half-width. For standardization purposes it is necessary to express the confidence interval half-width as a percent of the estimate. Thus we have

$$\text{CI half-width} = 100 \cdot t_{(d.f., 1-\alpha/2)} \; \overline{V(Y_{\text{predicted runoff}})}^{1/2} \div Y_{\text{predicted runoff}}$$

as a measure of performance of the model.

The discussion now turns to a detailed analysis of the derivation of the five previously mentioned water yield prediction variables. The first was an April 1st snow pack index. This value is arrived at in the following manner. Several snow courses are laid out in the watershed of interest. A snow course is defined (Howard, 1973) to be a fixed line, usually situated in a relatively flat area, where the deposition of snow is more or less uniform and not subject to unusual drifting. Each course is generally 500 to 1000 feet long and is marked by signs. Snow courses are distributed throughout the basin in question so as to give a reasonable sampling of snow quantities present. In watersheds where water is used intensively there may be up to 20 or more snow courses, whereas in those where water use is not so critical the number will drop to as few as one. In the Feather River watershed there are nine snow courses.

Within each snow course, snow depth and water content are measured at a series of systematically located points. These are generally situated about 100 feet apart along a line following the long axis of the course. Measurements are always made within ± five to ten feet of the same spot for a given measurement point. Snow water contents can therefore be directly compared for succeeding measurement dates for given points and for given snow courses.

The measurement process at a given point in a snow course proceeds as follows. An aluminum sample tube, approximately 1.5 inches in diameter and up to 240 inches long, is inserted into the snow pack. When the bottom of the pack is reached, the snow depth is recorded and the tube, now containing a snow core, is then removed from the snow. Next the core length is measured to check for inconsistencies between depth and core lengths. The tube and its snow core are weighed and by subtraction of the initial weight of the empty tube the snow water equivalent (water

content), in inches of water, is determined directly from the weight measurement scale. The measured depth of snow and the water content may also be used to determine the snow density as a percent of liquid water density. Snow depth, water content, and (optionally) snow density point data are then averaged for the given snow course.

Much of the snow course measurement task is not performed by the staff of the California Cooperative Snow Surveys. Rather, personnel from cooperating agencies often make the appropriate measurements and then phone or telegram CCSS the data. Field data sheets are subsequently sent to CCSS.

According to California Cooperative Snow Surveys procedure, at least some snow courses in all monitored watersheds are nominally measured on the 1st of February, March and May. All snow courses in all monitored watersheds are sampled on the 1st of April.

Computations then proceed as given in the top table of Figure 2.12: If a given snow course (Col. 1) cannot be measured on the first of the month (Col. 4) its measured water content value (Col. 5) is adjusted to that baseline date by adding or subtracting precipitation (Col. 6, 7, 8) falling before or after the 1st respectively. The amount of this precipitation correction is determined by gages at recording meteorological stations (e.g., Twin Lakes) and then adjusted through historical relationships (Col. 2) to the given snow course location.

Once the water content (snow pack) indexes are determined for the 1st of February (Col. 9) and March (Col. 15) these values are then expressed in terms of an April 1st snow pack index. This transformation is accomplished by first calculating the average snow pack index for all snow courses in a given watershed (see bottom of Col. 9 or 15). Then, to the value thus obtained, is added a watershed snow water content value representing the average increment received from either Februrary 1st (see bottom of Col. 9) or March 1st (see bottom of Col. 15), as the case may be, to April 1st. The snow pack index thus derived represents the value of the first independent variable in the run-off prediction equation.

CCSS utilizes April 1st as a standard because they have found through comparison of the relative size of partial regression coefficients that this date is a major index of spring and summer runoff from Sierra watersheds. Moreover, it has been found that April 1st measurements historically reflect the magnitude of the snow pack at near maximum seasonal accumulation. Snowpack averages utilized by CCSS are based on the period 1931-1970.

The second independent variable in the primary CCSS hydrologic model is the October to March precipitation index. This value is determined in part for a given watershed as in the top table of Figure 2.11. In the case of a February 1st forecast of April to July runoff, total monthly precipitation received at each basin recording station (Col. 1) is noted for each month for October through January (Cols. 3, 5, 7, 9). If the hydrologist so chooses, he may differentially weight a given month's precipitation (Cols. 4, 6, 8, 10) according to the supposed effect which that month's precipitation has on basin wetness and the magnitude of the April to July water yield. In the example of Figure 2.11, all months are given the same weight.

Precipitation for each month, October through January, is then totaled for a given station (Col. 11). A station index, defined as the percent of average October - January precipitation represented by the given hydrologic year's October - January precipitation, is calculated in Column 12. These station indexes are next totaled and averaged to give an October to January index at the bottom of Column 12. This index is then entered in the second column (counting left to right) of the lower right-hand corner table of Figure 2.11. For a runoff forecast made February 1st, the October - January precipitation index is then added to historical average precipitation indexes for February and March. The resulting sum is the October to March precipitation index.

For an April to July runoff forecast made on March 1st, rainfall data are now available for February. Colums 13 and 15 in the top table of Figure 2.11 are then utilized to derive an average February precipitation index. This value is plugged into Column 3 of the lower

right-hand corner table of Figure 2.11. The addition of the calcu-
lated February index to the previously obtained October to January
index plus the historical average index for March gives an updated
October to March precipitation index. A similar approach for updat-
ing the October-March precipitation index for an April 1st forecast
date can be taken utilizing March precipitation data.

The third independent variable in the April To July runoff
prediction equation is the October to March runoff index. This value
is computed in the middle left-hand table of Figure 2.11. Forecasts
of April to July runoff made on February 1st utilize the sum of month-
ly runoffs from October to January as measured at a stream gaging
station near the watershed lower terminus. To these actually observed
values are added historical average values for February and March
(see Column 2, counting from left to right). The resultant sum repre-
sents a prediction of the October to March water yield volume as
estimated on February 1st.

An estimate of this third independent variable for runoff pre-
diction in the case of a March 1st forecast date continues as for a
February 1st date, except that actually observed runoff for February
is used instead of its average (see Col. 3). Estimation of April to
July runoff as of April 1st proceeds in a similar fashion (Col. 4)
with a substitution of actually measured March runoff.

The fourth independent variable in the April to July runoff
prediction equation is the previous year's snow pack index. This
value is an antecedent index representing the snow pack remaining at
the start of the hydrologic year in October. For many of the Cali-
fornia watersheds that are monitored, this index is often near zero.

The final predictor variable in the runoff estimation equation
consists of an April to June precipitation index. It is determined
in part by use of the lower left-hand table in Figure 2.11. For a
runoff forecast made on May 1st, April precipitation by station is
recorded in Column 19. A station index is then computed in Column
20, and these indexes are then averaged to form a basin April precip-
itation index. This value is then entered on the April line in the
fifth column (for a May 1st forecast date) in the Precipitation
Indexes table immediately to the right. Summing the entered value
with the already existing historical averages for May and June (36
and 7 respectively in this example), the April to June precipitation in-
dex is thus derived. A similar procedure, utilizing the two tables
at the bottom of Figure 2.11 can be used to derive this index for
June 1st and July 1st forecast dates. Note that for April to July
runoff predictions made prior to May 1st an average April to June
precipitation index is used. In the example given in Figure 2.11
this average index is 134.

The values of the five independent variables derived above are
then plugged into the right-hand side of the runoff prediction equa-
tion for the watershed of interest. The example used here is the

regression equation at the bottom of Figure 2.10. An alternative way to determine April to July runoff from the independent variables is given by the linear relationships in the body of Figure 2.10. In this representation, the slope of each line and the relative juxta-position of the lines are determined according to the relative value of the partial regression coefficients in the regression equation at the bottom of the figure.

To utilize Figure 2.10, one starts with the calculated April 1st snow pack index. From the point this value takes on the snow pack axis he proceeds horizontally to the diagonal line representing the calculated October to March precipitation index. A vertical line is dropped from this intersection to the October to March runoff line representing the calculated value. Next a horizontal line should be run to the appropriate value of the previous year's snow pack index and from there a vertical projection is required to the value determined for the April to June precipitation index. The last step is to run a horizontal line from the last index point to the April to July runoff line. The point on this runoff line that is intersected by the horizontal line is taken as the predicted value for April to July runoff for the given forecast. It will be noted, in the example given in Figure 2.11, that actual April to July runoff values observed in given years are plotted around the runoff line.

Finally, a forecast summary can be made which relies on all independent predictor variables except October to March runoff. The result of this summary is a median water yield forecast lying in an associated runoff value range within which the eventually observed runoff is said to fall with a given probability. This value range was described earlier in the discussion of CCSS runoff probability ranges.

The forecast summary is made by use of the Forecast Summary table and Forecast Range Diagram at the bottom of Figure 2.12. Values to be entered in Columns 2, 3, 4, and 5 (counting left to right) in the Forecast Summary are as previously determined. Their addition gives the median April to July runoff forecast which should agree approx-imately with that obtained in Figure 2.10. The forecast range for the ten percent exceedence level for a given forecast date is determined from historical relationships in the Forecast Range Diagram. The exceedence values so derived are then appropriately added or sub-tracted to the median forecast value to give the forecast range in the right-most two columns of the Forecast Summary table.

Personnel of the California Cooperative Snow Surveys analyze the watershed data in the manner outlined above and make basin-by-basin forecasts as soon as possible after the 1st of February, March, April, and May. These forecasts are published in the California Department of Water Resources Bulletin No. 120, Water Conditions in California, by the 10th of each forecast month.

The Modified (Dynamic) CCSS Model

The second hydrologic model (Hannaford et al., 1970) used by the
California Cooperative Snow Surveys is dynamic, that is it involves
real-time water yield forecasts, and is based on probabilistic rela-
tionships. This model was developed by a private firm in conjunction
with the CCSS and is presently utilized on two large southern Sierra
watersheds. It is not presently being applied in the state water
project source basin, the Feather River watershed. However, since
this second CCSS model is a presently operational water estimation
tool employed by the State of California, and since it could poten-
tially be applied to the Feather River area, a brief description of its
operation will now be given.

Input to the CCSS dynamic model consists firstly of an estimate of
average effective precipitation over the watershed. This value is
based on a probabilistic relationship derived from precipitation re-
cording station records and basin water yield. The second input is
a watershed temperature index derived from daily maximum and minimum
temperatures from reference recording stations. The temperature index
is adjusted to a mean basin elevation and then related to runoff via
historical records. A third model input consists of runoff as gaged
daily near the low elevation watershed terminus or just upstream from
major water impoundments. The final major input into the CCSS dynamic
model is the water content of the snow pack as determined from Snow
Surveys' snow courses. The accuracy of this determination is espec-
ially critical to the performance of the model.

The model output consists of a daily prediction of water yield,
that is discharge, throughout the hydrologic year. When past periods
are being modelled, data for precipitation, temperature, gaged flow,
and snow water content are as measured for those specified days as just
described. In this case, the calculated and observed water yields are
compared. For future periods, the data for the above four daily inputs
are taken from a historical hydrologic year exhibiting a climatic pat-
tern similar to the current hydrologic year to the time of the forecast.

The CCSS dynamic model is composed of five basic submodels. Each
submodel produces its own hydrolgraph (water yield versus time) and
the sum of these hydrographs over time gives rise to an estimate of
total water yield from the basin in question.

The first submodel consists of a determination of summer base
flow. This flow is defined as the minimum daily discharge expected
near the end of the water year after snow melt and recession flow
(stream flow arising from water emerging from temporary natural storage)
have been depleted. The second submodel is a derivation of the minimum
daily discharge during the winter known as winter base flow. Pre-
cipitation, snow melt, and temperature affect the size of this flow.
Computation of recession flow comprises the third submodel. This value
is defined as discharge arising from snow melt or precipitation which

Figure 2.13. The dynamic model of the California Cooperative Snow Survey
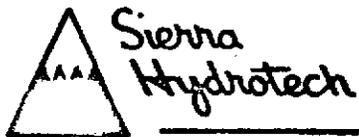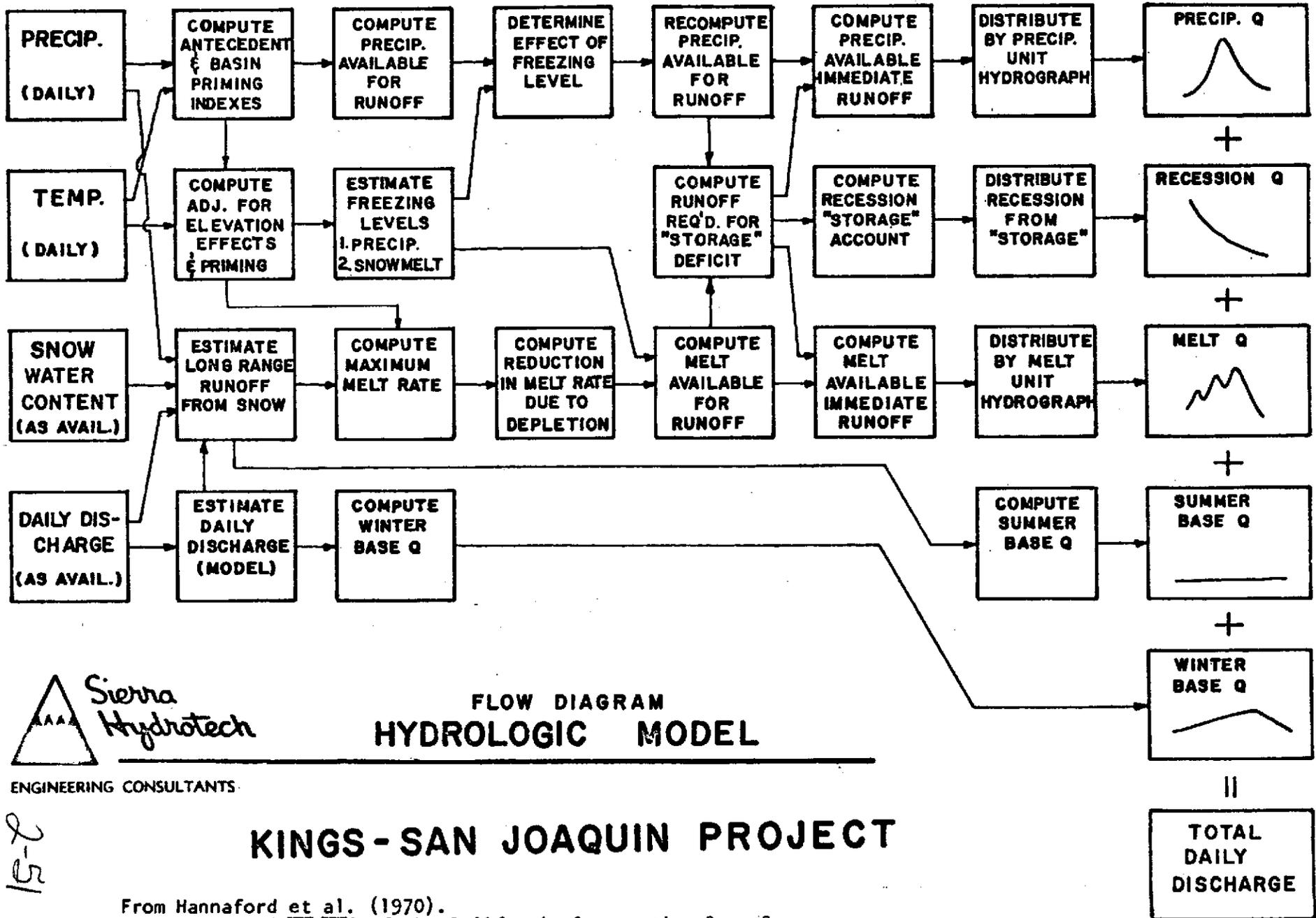
FLOW DIAGRAM
HYDROLOGIC MODEL

KINGS-SAN JOAQUIN PROJECT

From Hannaford et al. (1970).

passes through temporary natural storage in the watershed and runs off at a variable but derivable rate. This temporary storage consists of lakes, river channels, snow pack, and soil mantle zones such as conceptualized in the River Forecast Center hydrologic model. The effect of these storages is to delay runoff from precipitation and spread it out over a longer period of time. The fourth submodel is a determination of direct precipitation runoff resulting from rainfall over the watershed. This non-delayed form of runoff is a function of the overall basin wetness, the freezing level, and the volume of water in recession storage. Generally, as the volume in recession storage is increased, the rate of inflow into that storage is suppressed by a decrease in the infiltration rate. Therefore, the excess liquid precipitation must assume the form of increased direct runoff. The final submodel estimates snow melt. Maximum and minimum temperatures are used to index both the priming of the snow pack for melt and the rate of melt from the pack. These relationships are developed from historical temperature -- runoff data as indicated previously. The maximum potential and actual melt rates are determined from the amount of priming, the energy input into the pack, and the volume and area of the pack. The priming and energy components are indexed by temperature, and the pack volume and areal extent are estimated from snow course data.

The CCSS dynamic hydrologic model and the relationships between its submodels are shown in Figure 2.13.

4. Some Limitations of Current Water Yield Models

The RFC Model

The primary limitation affecting the River Forecast Center streamflow simulation model is limited data for input parameters and some model components. For example, mean effective precipitation is computed presently from a maximum of only five point recording station values. Evapotranspiration, an important loss mechanism for basin water, is not measured directly but only approximated from either a limited number of pan evaporation stations throughout the watershed or by using average evapotranspiration values from other basins. The fraction of the watershed covered by streams, lakes, and riparian vegetation is obtained by noting the difference between permanently impervious areas (found by hydrograph analysis) and paved surfaces draining directly into water bodies (as indicated on maps).

Use of limited data sets, as in the cases above, can lead to derivation of mean values for given model input parameters having relatively high coefficients of variation. Their use may also result in biased and inaccurate parameter estimates. Accuracy is defined here as the expected deviation of a sample mean from its true population value. In the present case, errors in parameter measurement and/or derivation, when associated with only a small number of data points,

tend to increase the chance that bias will occur. The coefficient of variation is defined as the ratio of the sample standard deviation to the estimated value of the mean. The standard deviation is a measure of the dispersion of sample values about their mean. The greater the dispersion, and therefore the the coefficient of variation, the less confident can we be that the mean will fall within given limits of its calculated value. Alternately stated, the greater the dispersion, the less precise the estimate.

Lack of precision and presence of bias can mislead optimization routines into settling on parameter values not representing the true state of the actual hydrologic system. The result may be to arrive at inappropriately "tuned" storage and flow rate settings for model components. The potential for making inaccurate forecasts of water yield is therefore increased.

The second significant limitation of the present RFC water yield model results from our inability to simulate runoff in separate subsections of the watershed of interest. This inability can be serious when the objective is to obtain accurate simulations under varying climatic and soil mantle regimes. As an example, effective precipitation as determined from the RFC snow ablation model must presently be spread equally over the watershed that is being modeled. In reality, however, the climatic regime from low to high elevation areas of a given basin will vary. While low to medium elevation areas of the Feather River watershed may be experiencing rapid melt with consequent soil storage compartment filling and discharge to streamflow during the early spring melt season, higher elevation packs, still under the influence of a wintery climatic regime, may be stable with little discharge from the underlying soil mantle. Obviously, discharge rates will be significantly different for different sections of the basin in this case. Even under the same melting regime, significant differences in soil mantle water storage abilities will give rise to significantly different water discharge hydrographs.

A second important advantage of dividing a watershed into subcompartments lies in the ability thus gained to assess the specific impact of given modifications of basin characteristics. For instance, removal of forest cover or soil litter cover, or modification of the permeability of the soil surface horizon as a result of a forest fire may alter an area's ability to discharge water. Other discharge modifications may result from timber harvest activity or from subdividing areas for home construction. To most accurately access the specific water yield impact of given natural or man-moderated activities in given areas, division of the watershed into subcompartments is potentially an effective device in hydrologic modeling.

Present River Forecast Center plans call for development of a basin compartmentalization option in the RFC water yield model. Such

watershed subdivision will put even greater demands for accuracy on the already limited data set. In terms of meteorologically-dependent RFC model inputs, it is probable that, with current low density climatic station networks, the estimated mean values for effective precipitation and evapotransporation will have higher coefficients of variation and higher potentials for bias then in the noncompartmentalized case. Either improved algorithms must be developed for extrapolating data from current stations to microsites lacking recording devices, or else new sources of data must be tapped. A combination of both solutions is likely the optimal path.

The CCSS Models

The limitations of the two California Cooperative Snow Surveys' water yield models are similar to those of the RFC model. Again the basic problem is limited data for input parameters. For both the primary (volumetric) and dynamic CCSS models, the density of precipitation recording stations throughout most monitored watersheds is low. In addition, many of these stations are concentrated at lower elevations below much of the snow pack region in most basins. Consequently, estimates of total precipitation received at various watershed locations based on adjusted station values are potentially subject to significant error.

The same situation exists for temperature estimation. Precise and accurate estimates of this parameter are important throughout the watershed in determining the rain-to-snow ratio and snow melt rates. Both of the CCSS water yield models could utilize improved estimates of snow areal extent throughout the hydrologic year. Such data would provide additional information on snow accumulation, melt rate, and antecedent indexes. Moreover, snow areal extent data, when combined with other remotely sensed ground characteristics, could be used to develop more specific relationships between snow behavior and vegetation, soil, geologic, and topographic features.

Each Snow Survey's model could potentially be applied to a compartmentalized watershed. In this case, as with the RFC model, the need is very great for more precise and accurate area-specific data than are presently available.

5. Proposed Future Studies Relative to the Forecasting of Water Supply

Studies with Respect to the RFC Hydrologic Model

The objective of the present NASA sponsored study with respect to the forecasting of water supply (i.e. water yield) by means of the RFC hydrologic model can be stated as follows. The objective is to determine whether remote sensing data can be cost-effectively integrated with data presently used in the RFC hydrologic model to produce potentially more precise and more accurate estimates of water yield. In efforts made to achieve this objective, the applicability to both

noncompartmentalized and compartmentalized water yield estimation should be examined. Special attention should be given to the unique capabilities of remote sensing for providing meteorological and basin characteristic descriptions for compartmentalized watersheds with minimum block sizes down to sub-square kilometer or even sub-hectare size.

The distinction previously made between dynamic and volumetric water yield models assumes importance at this point. The former indicated real-time simulation, while the latter implied long term yield estimation. Since the River Forecast Center hydrologic model is utilized presently in a primarily dynamic manner, applicable remote sensing techniques must meet the constraint of real-time usability. This constraint is reflected in the proposed avenues of investigation, as detailed in Table 2.3 for possible remote sensing applications in the RFC model.

Table 2.3. AVENUES OF INVESTIGATION FOR POSSIBLE REMOTE SENSING APPLICATIONS IN THE FEDERAL-STATE (CALIFORNIA) RIVER FORECASTING HYDROLOGIC MODEL

Remote Sensing Application to be Investigated	Potential Implementation Period
(1) Effective Precipitation	
(a) Estimation of mean total precipitation amount in specified area (total basin or subcompartment): application of meteorological satellite data applied in concert with real-time ground station data (radar, automatic basin meteorological stations) through appropriate sample design, hard and software integration.	Intermediate and particularly the Long Run.
(b) Estimation of surface temperature in specified area: application of meteorological satellite soundings (e.g., derived from the NOAA vertical temperature profile radiometer) calibrated through sample design to ground station measurements; use would be in the RFC show ablation model – specifically determination of the rain to snow ratio and as temperature input values for melt equations.	Intermediate and particularly the Long Run.

Table 2.3. (continued)

Remote Sensing Application to be Investigated	Potential Implementation Period
(c) Estimation of albedo in specified area: application of ERTS and meteorological satellite reflectivity data; use would be in snow ablation model melt equations.	Immediate, Intermediate
(d) Estimation of snow pack longwave radiation loss in specified area: application of meteorological satellite data; use would be in radiational melt equation of snow ablation model.	Intermediate
(e) Estimation of change in snow shading in specified area: application of ERTS and supporting aircraft sampling imagery; use would be in the snow ablation model radiational melt equation.	Immediate, Intermediate
(f) Estimation of cloud cover as a fraction of clear sky in specified area: application of meteorological satellite data along with possible limited use of ERTS data (for "past-tense" calibration of real-time cloud cover values); use would be in snow ablation model radiational melt equation.	Intermediate, Long Run
(g) Estimation of daily wind movement in nautical miles at the snow pack surface in specified area: application of meteorological satellite data; use would be in the convection-condensation snow melt equation of the snow ablation model.	Intermediate and particularly the Long Run.
(h) Estimation of surface pressure for given locations: application of meteorological satellite data; use would be in the convection-condensation snow melt equation in the snow ablation model.	Intermediate and particularly the Long Run.

Table 2.3. (continued)

Remote Sensing Application to be Investigated	Potential Implementation Period
(1) Determination of the areal extent of snow pack as a check on the operation of the snow ablation model pack algorithm as applied to a specified area; snow areal extent as determined from ERTS imagery (Lauer and Draeger, 1973).	Manual: Immediate Man-Machine Approach: Intermediate
(2) Estimation of potential evapotranspiration demand (ED) or of coefficients (PCTPN) to weight existing pan evaporation or evapotranspiration estimates in specified area: application of ERTS data (used to define ground cover type and physiological condition in accordance with usual sample designs) and meteorological satellite data (used to derive surface temperatures, pressures, wind speeds, radiation balance, water content).	Intermediate, Long Run.
(3) Estimation of impervious basin surface contiguous with stream channels (PCTIM): application of ERTS and supporting aircraft and ground data through appropriate sample designs.	Immediate
(4) Estimation of the fraction of the basin covered by streams, lakes, and riparian vegetation (SARVA): application of ERTS and supporting aircraft and ground data through appropriate sample designs.	Immediate
(5) Possible estimation of lower zone tension water maximum capacity (LZTWM): application of plant physiological state data from ERTS and supporting aircraft and ground data.	All periods.
(6) Possible estimation of stream channel storage capacity: application of aircraft imagery and supporting ground data.	All periods.

Studies With Respect to the CCSS Models

The objective of this NASA sponsored study with respect to CCSS water yield models can be stated in the same terms as for the RFC model. Future investigations as to the cost-effective application of remote sensing information and techniques would be concentrated, however, on the CCSS volumetric model. Applications to the Snow Surveys' dynamic model would be given only as they might arise while we were dealing with the other models.

Applications to the volumetric CCSS model would center on developing improved compartment-specific estimates of precipitation, form of precipitation, and areal extent of snow pack. Investigations would be made of melt and runoff rates resulting from given snow -- environment situations as remotely sensed. As an integral part of this investigation, methods would be sought to cost-effectively combine snow course measurement data and remote sensing information in efficient sampling designs. Proposed avenues of investigation for remote sensing application to long term volumetric water yield estimation are given in Table 2.4.

Table 2.4.   AVENUES OF INVESTIGATION FOR POSSIBLE REMOTE SENSING
APPLICATIONS IN THE CALIFORNIA COOPERATIVE SNOW SURVEYS'
VOLUMETRIC WATER YIELD MODEL.

Remote Sensing Application to be Investigated	Potential Implementation Period
(1) Estimation of mean total precipitation amount in specified area: application of meteorological satellite data applied in concert with ground station data records through appropriate sample design; use would be in CCSS precipitation indexes and possible snowmelt' rate and evaporative stress indexes (see 4 and 5 below).	Intermediate, Long Run
(2) Estimation of surface temperature in specified area: application of meteorological satellite soundings calibrated through sample design to ground station measurements; use would be in determination of a weighted rain to snow index and weighted melt rate and evaporative stress indexes (see 4 and 5 below) to be included in a CCSS watershed runoff regression equation. Weights would be based on the relative areal extent of a basin having given index values.	Intermediate, Long Run

Table 2.4. (continued)

Remote Sensing Application to be Investigated	Potential Implementation Period
(3) Estimation of the areal extent of snow pack in a specified area: application of ERTS and supporting aircraft imagery (Lauer and Draeger, 1973) to determine a snow extent index to be included in a given CCSS basin runoff regression equation.	Manual: Immediate Man—Machine Approach: Intermediate
(4) Estimation of a snow melt index for varying basin conditions: application of earth resource and meteorological satellite systems to an energy balance analysis of snow accumulation and melt under different vegetative soil, geologic, topographic, and climatic regimes.	Intermediate, Long Run
(5) Estimation of an evaporative stress index for varying basin conditions: application of ERTS data (used to define ground cover type and physiological condition) and meteorological satellite data (used to define surface climate) through appropriate sample designs to derive a weighted basin evaporation index. This index, as with the other proposed indexes, could then be utilized in CCSS runoff regression equations if its partial regression coefficient was found to be statistically significant.	Intermediate, Long Run

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B. Watershed Management Considerations

In addition to using remote-sensing derived information as an input to models for predicting runoff or water yield within the supply area, it seems likely that considerable potential exists for its use by those persons charged with the management of the upstream land areas, i.e., those involved in watershed management.

While the bulk of the effort during the past several months has centered around discussions with those directly involved in manipulation and planning of water facilities within the supply area, e.g., the Department of Water Resources, quite a bit is known about the activities and information needs of the primary land management and planning groups within the Feather River area, e.g. county planning agencies and the U. S. Forest Service, as a result of numerous contacts made over the past three years. It is planned that during the next several months, particular attention will be paid to isolating those information requirements which have a particular impact on the planning and conduct of watershed management activities, and on ways of estimating the economic importance of such information.

V. EVALUATION AND TESTING OF REMOTE SENSING TECHNIQUES

A. Report by Center for Remote Sensing Research (CRSR), Berkeley Campus

During the period covered by this report three studies were carried out by personnel of CRSR which have direct applicability to the water supply situation. These were: (1) the development of techniques for estimating areal extent of snow on ERTS-1 imagery; (2) vegetation/ terrain mapping using manual analysis techniques on ERTS and high- altitude aircraft imagery; and (3) the development of a multistage sampling scheme for performing resource inventories in wildland areas using ERTS data as a basic input.

Due to the necessity for concurrent work, the studies reported here have been carried out at the same time as the basic problem definition described in earlier sections has been progressing. While this might seem to be an illogical sequence, it can be justified on the basis that when the very specific parameters to be measured are defined, the remote sensing technology should be ready to be applied to them. Thus the studies reported here are quite flexible in that they can be easily modified to deal with specific parameters of interest to the water supply community if necessary.

1. Snow Survey Studies

Introduction

It has been recognized by many investigators that areal extent of snow could be a valuable parameter for improving the effectiveness of existing stream flow forecasting models (U.S. Army Corps of Engineers, 1956; Barnes, 1969; Banres and Bowley, 1969; Baker, 1971; Leaf and Haeffner, 1971; Tarble and Burnash, 1971). However, this parameter has rarely been used because it has been nearly impossible to econ- omically acquire such data for large areas at the accuracy required. However, it seemed probable to us that imagery obtained by the Earth Resources Technology Satellite (ERTS-1) (which is obtained over any particular location every 18 days, weather permitting), when used in conjunction with the appropriate supporting aerial photography could provide a means for obtaining accurate and efficient estimates of areal extent of snow cover during critical periods of the melt season.

Consequently, a study was carried out which resulted in the following: (1) sequential ERTS-1 imagery, U-2 high flight photography and ground data were used to develop a suitable reference document, in the form of an image interpretation key, which could effectively be used as training material for the determination of areal extent of snow in forested areas; (2) an efficient manual analysis technique was developed for estimating acreages of snow. This technique capital- izes on the human's ability to integrate information on the appearance of snow, as seen on satellite photos, with inforamtion obtained from

aerial photos regarding the type, density and distribution of the veg-
etation/terrain within which the snow occurs and which greatly in-
fluences the appearance of snow; and (3) within the Feather River
watershed in northern California an estimate of areal extent of snow
was made over a 2.1 million acre (850,000 ha) area using ERTS-1
imagery. The level of accuracy of the estimate was verified through
the use of sample vertical aerial photos, taken from a light air-
craft, showing in detail the actual snow cover conditions.

Procedures and Results

During the 1970-71 melt season, high flight aircraft obtained
small scale (1:100,000) 70 mm black-and-white photographs of a 170,000
acre (68,000 ha) test area within the Feather River watershed on five
different occasions. During the 1971-72 season, the NASA U-2 aircraft
stationed at the Ames Research Center, Mountain View, California flew
four missions, each of which covered the entire Feather River watershed.
In addition, during the 1972-73 melt season, ERTS-1 imagery was ac-
quired over the Feather River watershed every 18 days with clear
weather prevailing on April 4, April 22, May 10 and May 28. Conse-
quently, for three successive melt seasons, a sufficient amount of
imagery was available for study.

To correlate interpretations made of the appearance of snow as
seen on the small scale aerial or space imagery with ground conditions,
it was necessary to collect data on true snow cover conditions. During
the 1971-72 season, on three occasions coincident with U-2 overflights,
a field crew visited a series of plots established within the Spanish
Creek watershed. The field crews traveled by snowmobile and on snow-
shoes to each plot location. Data on extent and condition of snow,
including depth, were collected and recorded, consistent with California
Cooperative Snow Survey procedures.

Data collection on the ground, however, was very tedious and
time-consuming. Furthermore, only a few samples could be collected
before so much time had elapsed that further sampling became meaning-
less with respect to a specific high flight mission. Consequently,
the primary method employed for estimating true snow cover conditions
during the 1973 season was through the use of relatively large scale
vertical color aerial photographs (see Figure 2.14). Coincident with
each ERTS-1 overpass, our own personnel took as many as 150 35 mm
photos from a single-engine aircraft along preselected flight lines
which transected the entire watershed. These photos proved to be of
excellent quality, and the presence or absence of snow on the ground
was easily interpreted on them, even in areas where a dense forest
canopy obscured much of the snow. Supporting aircraft flights were
flown in 1972 on January 10, January 31, March 28, and May 2 and in
1973 on April 6, May 11, May 29, and June 4.

April 6, 1973   May 11, 1973   June 4, 1973

Figure 2.14.   These photos were taken over Bucks Lake, California from a single engine aircraft flying at 17,000 feet (5,180 m) above sea level, using a 35 mm camera with a 24 mm lens.   The original photos (in color) were used to make accurate estimates of actual snow conditions

Development of an Image Interpretation Key

A comprehensive image interpretation training and reference key
was prepared using 1971-72 melt season U-2 photography and ground data.
The key is for evaluating snow pack conditions as seen on small scale
synoptic view imagery. The primary value of the key is that it docu-
ments, in the form of word descriptions and photo illustrations, the
appearance of snow when influenced by a variety of vegetation/terrain
conditions. A selective type of key was prepared based on eight vege-
tation/terrain categories -- dense conifer forest, sparse conifer
forest, dry site hardwood forest, brushland, meadow or rangeland,
urban land, water or ice, and rock or bare ground. Within each cate-
gory, examples of different conditions of elevation, steepness of slope
and direction of slope (aspect) were chosen. For example, within dense
conifer forests, snowpack conditions are described for (1) high elevation
and steep north slopes, (2) high elevation and moderate north slopes,
(3) high elevation and gentle south slopes, (4) medium elevation and
flat areas, and (5) low elevation and steep north slopes. Each one
of these specific examples represents an entire page in the key and
consists of five illustrations -- one before the snow season, two at
the height of snow accumulation and two during the depletion period.
In the completed version of the key the eight vegetation/terrain type
categories are illustrated with a total of twenty-two specific examples.

Possibly the most important value of the image interpretation
key is that it allows the interpreter to become cognizant of the fact
that, for any given area, snow may be present on the ground but may
not be visible on U-2 or satellite imagery. This situation often oc-
curs within a dense coniferous forest in which a deep snowpack can be
completely obscured by the crown canopy. It has been emphasized in
the key, however, that the presence of snow in the dense forest usually
can be deduced by examining the appearance of adjacent vegetation/
terrain types. For example, if a dense stand of timber is surrounded
by meadows or brushlands, and snow can be detected within these ad-
jacent types, the interpreter can safely predict that the dense, heavily
shaded timbered area also contains snow.

Development of an Image Interpretation Technique

It was found in developing the interpretation key that four
environmental factors greatly influence the appearance of snow as seen
on aerial photographs, viz., elevation, slope, aspect and vegetation/
terrain type. For example, in certain areas a snow boundary may ap-
pear to follow a line of equal elevation but will drop down in elevation
considerably on north facing slopes. In addition, it was found that the
presence or absence of snow was (1) easily detectable in meadows and
bare areas, (2) sometimes, but not always, detectable in sparse con-
iferous forest, and (3) nearly impossible to detect in dense coniferous
forest. However, once an interpreter is properly trained to recognize
various combinations of environmental conditions, and is aware of the
relationships among these various conditions and the appearance of snow
associated with them, it was hypothesized that he could effectively detect

the presence or absence of snow at any location, even on very small scale imagery such as that obtained by ERTS-I.

Consequently, an interpretation technique was developed which allows a trained interpreter to accurately estimate areal extent of snow, is suitable for the interpretation of very large, complex forested regions on very small scale ERTS-type imagery, and is fast and inexpensive to implement. This technique capitalizes on the ability of the interpreter to integrate several kinds of information and quickly arrive at a decision. By examining two images simultaneously, one taken during a snow free period and the other during the melt season, an interpreter can concentrate on both the appearance of snow, and on the vegetation/terrain condition. Thus reliable estimates of areal extent of snow can be derived.

The procedure is simple and consists of the following steps:

1. Using a standard mirror stereoscope, the interpreter observes two images simultaneously -- one taken during the summer season showing vegetation density and terrain conditions, and one taken during the snow melt season showing snow conditions.

2. Through minor adjustments to the stereoscope and image viewing height, the two images are brought into common register, i.e., the images as seen by the interpreter appear to be superimposed on one another.

3. By winking the right or left eye, the interpreter can quickly examine the same area both with and without snow cover.

4. A grid of known dimensions is placed over the winter image and the total percent area within each grid cell that is covered by snow is estimated.

5. Each cell is coded as follows:

Code	Snow Cover Class
1	No snow present
2	0-20 percent of ground covered by snow
3	20-50 percent of ground covered by snow
4	50-98 percent of ground covered by snow
5	98-100 percent of ground covered by snow

6. Areal extent of snow is calculated for any given watershed by calculating the total acreage in each cover class (number of cells in each class x average number of acres per cell), and multiplying this gross acreage value in each class by the percentage midpoint of the respective class.

August 31, 1973   April 4, 1973

Figure 2.15. The photos above illustrate the two types of ERTS-1
imagery used to estimate areal extent of snow. The interpreter
views both the summer and winter image simultaneously and then makes
an estimate of percent snow cover on the winter image in each cell on
the grid. The interpreter is able to integrate information seen on
the summer image (relating to vegetation density and terrain type)
with information seen on the winter image pertaining to snow cover.
Bucks Lake, California appears near the center of each of these two
images, and also appears in each of the photos in Figure 2.14.

Testing the Intepretation Technique

The interpretation technique described above and the image interpretation key were used in an interpretation test applied to the Feather River watershed. Two color composite ERTS-1 images, one taken on August 31, 1972 and the other on April 4, 1973 (see Figure 2.15), were used, with a grid size of approximately 980 acres (392 ha) per cell. In addition, vertical 35 mm color aerial photos taken on April 6, 1973 were used to help train the interpreter (using 24 cells) and to evaluate the accuracy of the interpretation results (using 80 cells).

The interpreter spent 3 hours training himself to interpret the ERTS-1 data. Then in 9 hours he was able to classify the 2218 cells comprising the test area. By applying the appropriate weighting factors (i.e., using midpoints of the snow cover classes), the areal extent of snow for the 2,173,640 acre (880,000 ha) area was estimated to be 1,263,642 acres (512,000 ha). This estimate could have been easily broken down by any sub-units of the large test area that were desired.

To evaluate the accuracy associated with this estimate, the interpretation results for 80 of the cells were compared with estimates made on relatively large scale (1:45,000) color aerial photos. Based on previous comparisons which we had made between our interpretation of snow cover on large scale photos and our direct on-site snow surveys, these large scale estimates were felt to be very accurate, and truly indicative of the actual ground condition. Figure 2.16 shows the results of this comparison. It will be noted that only 13 cells out of 80 were incorrectly classified, resulting in an overall "correctness" of 83.7 percent, based on number of cells. Furthermore, 12 of the 13 cells were misclassified by only one class. In addition, when the areal extent of snow was calculated on the acreage basis, the image interpretation estimate of snow cover made using ERTS-1 imagery was 51,774 acres (20,961 ha), and the "correct" snow cover estimate made using the large scale 35 mm photos was 50,921 acres (20,615 ha), resulting in an overall "correctness" based on acreage of 98.4 percent.

Summary and Conclusions

Sequential aerial photography, Earth Resource Technology Satellite (ERTS-1) imagery and ground data were used to develop an image interpretation key to be used as an aid in training photo interpreters to estimate the areal extent of snow in forested areas, and as inputs to a rapid and relatively simple manual analysis technique for estimating acreages and extent of snow cover on satellite imagery. This technique is based on the interpreter's ability to integrate information on the appearance of snow, as seen on aerial or ERTS-1 imagery, with the type, density and distribution of the vegetation and characteristics of the terrain within which the snow occurs and which greatly

LARGE SCALE PHOTO DATA								
Snow Cover Classes						Total # Cells	Total Acreage	Total Acreage of Snow
1	2	3	4	5				
1	6	1				7	6,860	0
2		10		1		11	10,780	1,078
3		2	6	2		10	9,800	3,430
4			1	12		13	12,740	9,428
5				6		39	38,220	37,838
Total # Cells	6	13	7	21	33	80		51,774
Total Acreage	5,880	12,740	6,860	20,580	32,340		78,400	
Total Acreage of Snow	0	1,274	2,401	15,229	32,017	50,921		

Overall percent "correct" (based on cell count) = 83.7 percent
Overall percent "correct" (based on acreage count) = 98.4 percent

Figure 2.16. Results of the comparison between estimates of snow cover made on ERTS-1 imagery and those made on 1:45,000 vertical color aerial photos. Further tests are in progress to establish whether such favorable results represent a "random success". However, even less accuracy than that obtained in the present test would permit improvements to be made in currently operational snow survey procedures.

influence the appearnce of a snowpack as seen from above. By examining
two images simultaneously, one taken during a snow free period and the
other during the melt season, an interpreter can concentrate on both
the appearance of snow, and on the vegetation/terrain condition. Con-
sequently, reliable estimates of areal extent of snow in large complex
forested areas can be derived.

A test of the interpretation technique was conducted over a 2.1
million acre (850,000 ha) area in the Feather River watershed in
northern California. Using percent snow cover estimates made on
relatively large scale color aerial photographs of sample plots within
the test area and taken coincident with the ERTS overpass as a basis
for comparison, it was found that the interpretation of ERTS-1 imagery
yielded estimates of snow-covered acreage with a 98.4 percent accuracy.

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2. Vegetation/Terrain Type Mapping

Objectives

Nearly every land manager and resource specialist active within the Feather River watershed and contacted by our group expressed interest in obtaining regional statistics and maps on kind, amount and distribution of vegetation/terrain types occurring throughout the watershed. Moreover, it was generally understood among persons expressing this interest, that up-to-date vegetation/terrain information does not exist for this vast region because such information is nearly impossible to obtain using conventional mapping techniques. Several regional mapping projects, however, have been completed within the watershed, one done in 1967 by personnel of the California Department of Water Resources and another in 1970 by the California Comprehensive Framework Study Committee. Consequently, since the maps produced during these projects were available, an ideal opportunity presented itself whereby ERTS-1 imagery could be tested for purposes of mapping vegetation/terrain in terms of existing mapping objectives.

Attention, therefore, was focused on a single project -- that of the California Comprehensive Framework Study Committee. Interviews were held with Committee participants to obtain detailed information about the project. Specifically, information was gathered on mapping objectives, classificatioan scheme used, mapping techniques used, personnel requirements, and estimated project costs. The vegetation/terrain type map presented in Figure 2.17 illustrates the Feather River watershed; it is part of the Sacramento Subregion map which was prepared by the Framework Study Committee.
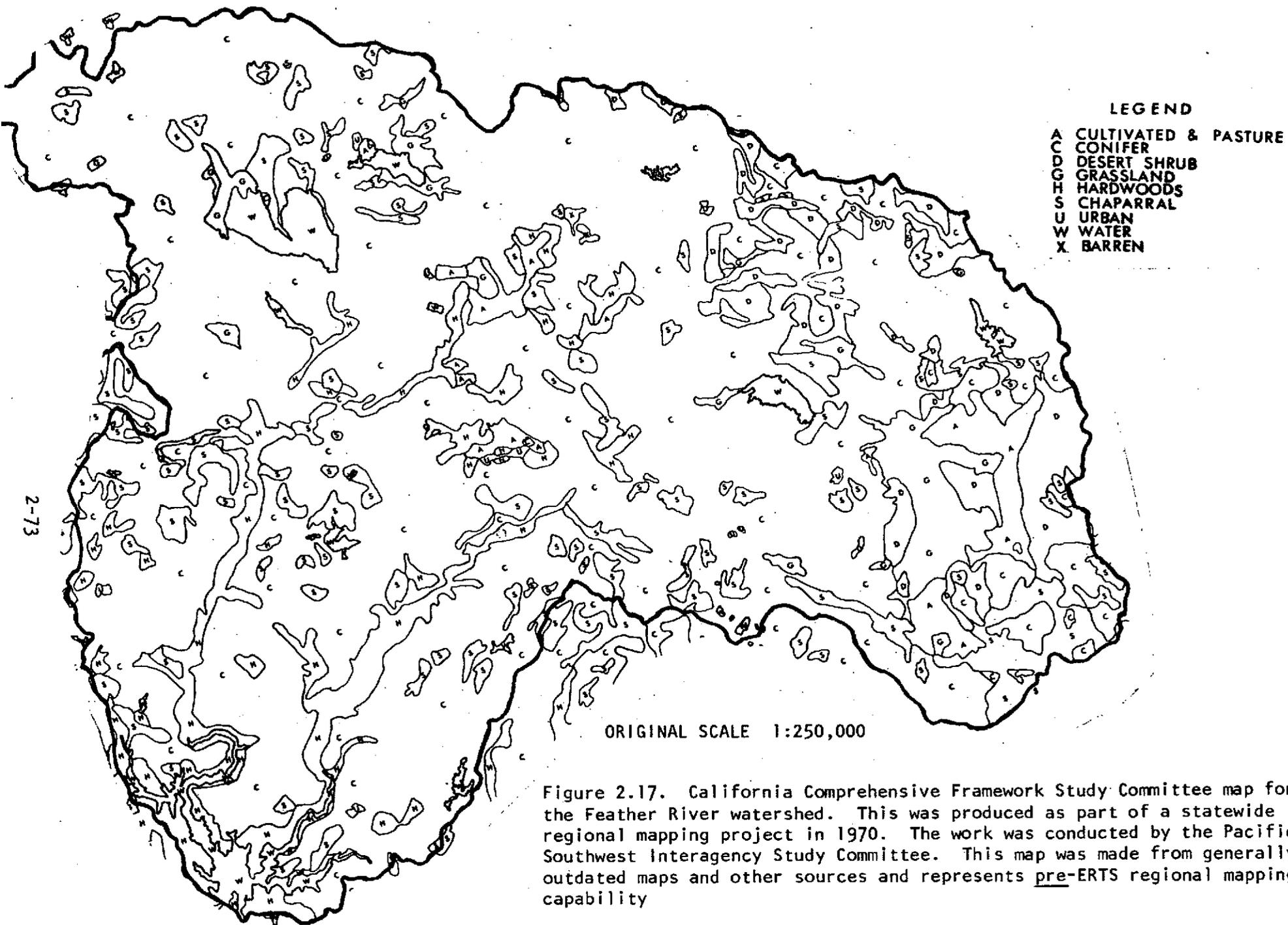
Thus, the objectives in our study were (1) to map with ERTS-1 imagery the resource complex within the entire Feather River watershed using the generalized Framwork Study mapping objectives as a guide. (2) to determine the level of accuracy associated with the generalized map made from ERTS-1 by comparing it with the map made from high altitude false-color infrared photography, (3) to determine the level of accuracy associated with the Framework Study map by comparing it with the map made from high altitude photography, (4) to map with ERTS-1 imagery the resource complex within the entire Feather River watershed, using detailed mapping objectives set at seeking the maximum amount of information about the region, (5) to determine the level of accuracy associated with the detailed map made from ERTS-1 imagery by comparing it with the map made from high altitude photography, and (6) to determine the timing and cost factors associated with preparing the generalized and the detailed maps made from the ERTS-1 imagery.

ERTS-1 Map Using Generalized (Framework Study) Classification Scheme

Regional mapping of the entire Feather River watershed from ERTS-1 color composites (bands 4-5-7) was done utilizing three dates of imagery in combination. The dates were July 26, 1972, August 13, 1972 and October 24, 1972. The August image was a precision processed image; thus, it provided an undistorted map base necessary for accurately locating highly identifable resources such as lakes and rangeland areas. A regional vegetation/terrain type map was produced by projecting and enlarging the ERTS-1 color composite transparencies to a scale of 1:250,000. The interpreter frequently interchanged the July and October images to take advantage of seasonal changes in reflectance occurring within certain vegetation types. The first map produced using this technique was made following the generalized classification scheme defined in the California Framework Study. The final ERTS-1 map product is illustrated in Figure 2.18.

Accuracy of Generalized Map

An evaluation of the level of accuracy associated with the generalized ERTS-1 map shown in Figure 2.18 is presented in Figure 2.19. The evaluation was done by comparing the ERTS-1 map with a map made from high flight photography. A grid of 474 points was constructed and placed over each of the maps with identical alignment. Thus the vegetation/terrain types within which the various points fell on each map were determined and tallied. The tallied results were summarized and are shown in Figure 2.19. These results indicate overall excellent agreement. Specifically, the average percent correct, (assuming that the higher flight map is "correct"), was 81 percent. The interpreter was able to proficiently map conifer forest, hardwood forest, grasslands, cultivated and pasture lands, desert shrub lands, water bodies and urban lands. The types that were most difficult to map were chaparral lands and barren lands.

LEGEND

A CULTIVATED & PASTURE
C CONIFER
D DESERT SHRUB
G GRASSLAND
H HARDWOODS
S CHAPARRAL
U URBAN
W WATER
X BARREN

ORIGINAL SCALE   1:250,000

Figure 2.17.   California Comprehensive Framework Study Committee map for the Feather River watershed.   This was produced as part of a statewide regional mapping project in 1970.   The work was conducted by the Pacific Southwest Interagency Study Committee.   This map was made from generally outdated maps and other sources and represents pre-ERTS regional mapping capability

LEGEND

A CULTIVATED & PASTURE
C CONIFER
D DESERT SHRUB
G GRASSLAND
H HARDWOODS
S CHAPARRAL
U URBAN
W WATER
X BARREN
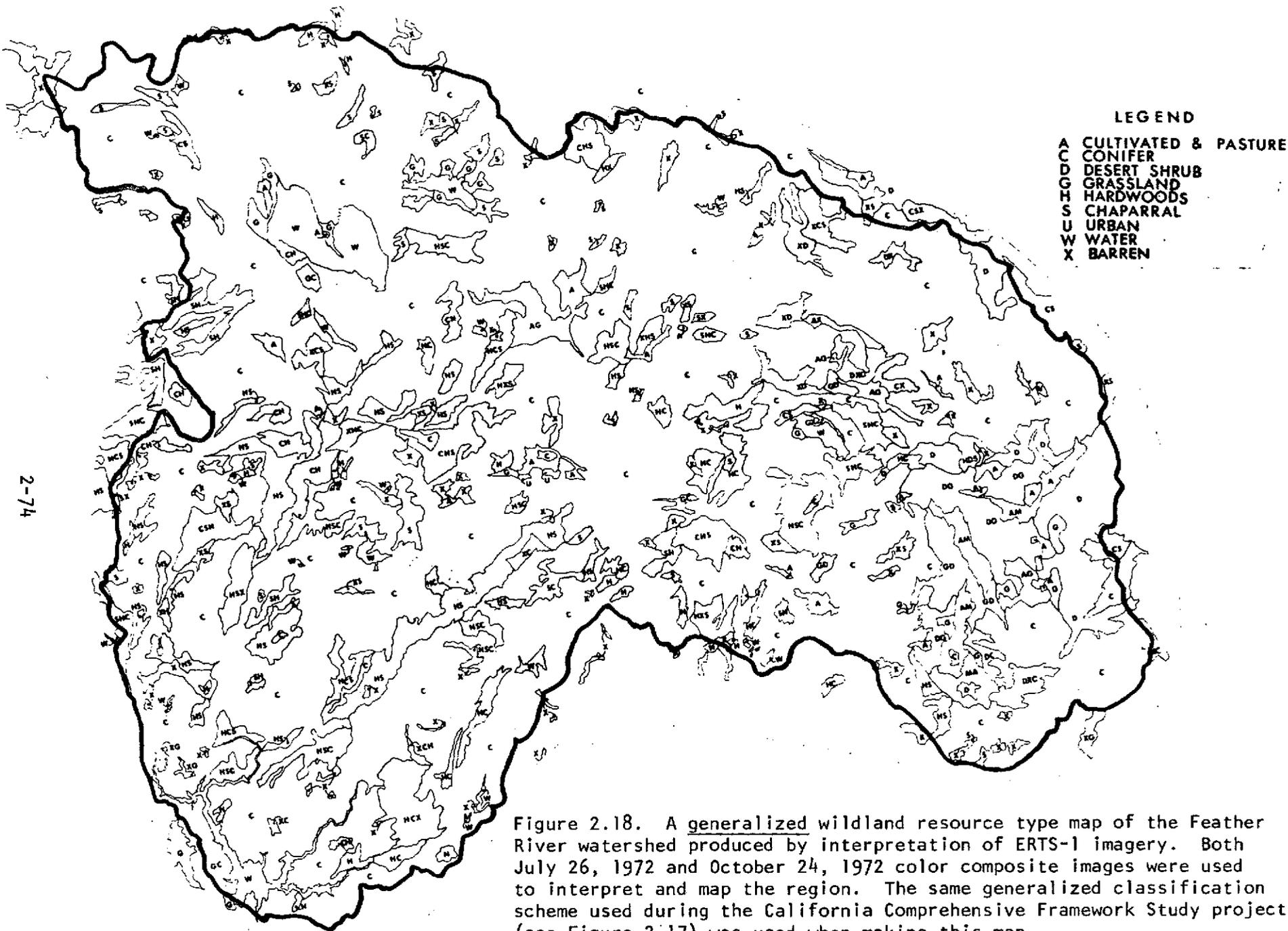
Figure 2.18. A generalized wildland resource type map of the Feather River watershed produced by interpretation of ERTS-1 imagery. Both July 26, 1972 and October 24, 1972 color composite images were used to interpret and map the region. The same generalized classification scheme used during the California Comprehensive Framework Study project (see Figure 2.17) was used when making this map.

| HIGH ALTITUDE GROUND COMPARATIVE MAP DATA | COMPREHENSIVE RESOURCES TYPE MAP FROM ERTS-1 IMAGERY ||||||||||||
INCLUSIVE RESOURCE TYPES	TOTAL PRESENT	TOTAL OMITTED	CONIFER (C)	CHAPARRAL (S)	HARDWOOD (H)	GRASSLAND (G)	CULTIVATED & PASTURE (A)	DESERT SHRUB (D)	BARREN (X)	WATER (W)	URBAN (U)	PERCENT OMISSION*	PERCENT CORRECT*
CONIFER (A, B, BB, C, E)	294	7	287	1	4	1			1			3	97
CHAPARRAL (K, J)	41	27	15	14	10		1		1			66	34
HARDWOOD (F, H, I)	37	7	5	2	30							19	81
GRASSLAND (G, S, R, N)	15	4	2		1	11		1				27	73
CULTIVATED & PASTURE (P, Q, R, M)	20	2	1				18	1				10	90
DESERT SHRUB (L, S)	19	1						18	1			5	95
BARREN (T, U, W, V)	34	14	10		1	1		2	20			41	59
WATER (X)	13	0								13		0	100
URBAN (U)	1	0									1	0	100
TOTALS	474	62											
TOTAL INDICATED**			320	17	46	13	19	22	23	13	1	474	
TOTAL COMMITTED			33	3	16	2	1	4	3	0	0	62	
PERCENT COMMISSION*			11	7	43	13	5	21	9	0	0		
PERCENT COMMISSION**			10	18	35	15	5	18	13	0	0		

*Based on the total number within the sample.
**Based on the total number indicated by the interpreter results

AVERAGE PERCENT CORRECT=81%

Figure 2.19. An evaluation of the ERTS-1 generalized resource type map (see Figure 2.18) is presented in the above table. Comparisons of the ERTS-1 map with the high flight map indicate excellent agreement. The percent correct results for the identification and mapping of conifer, hardwood, grassland, cultivated and pasture, desert shrub, water and urban types indicate high interpreter proficiency. Commission errors are low except for hardwood types. High omission errors for the chaparral type are associated with the frequent misinterpretation of chaparral as a hardwood or conifer type.

| | | COMPREHENSIVE FRAMEWORK STUDY COMMITTEE MAP BASE | | | | | | | | | | |
INCLUSIVE RESOURCE TYPES	TOTAL PRESENT	TOTAL OMITTED	CONIFER (C)	CHAPARRAL (S)	HARDWOOD (H)	GRASSLAND (G)	CULTIVATED & PASTURE (A)	DESERT SHRUB (D)	BARREN (X)	WATER (W)	URBAN (U)	PERCENT OMISSION*	PERCENT CORRECT*
CONIFER (A, B, BB, C, E)	293	5	288	2	3							2	90
CHAPARRAL (K, J)	49	18	10	31	8							37	63
HARDWOOD (F, H, I)	33	14	9	5	19							42	58
GRASSLAND (G, S, R, M)	22	7	2	2		15	2	1				32	68
CULTIVATED & PASTURE (P, Q, R, M)	15	4				4	11					27	73
DESERT SHRUB (L, S)	23	7				7		16				30	70
BARREN (T, U, W, V)	21	21	12	3	3			3	0			100	0
WATER (X)	17	1		1						16		6	94
URBAN (U)	1	0									1	0	100
TOTALS	474	77											
TOTAL INDICATED**			321	44	33	26	13	20	0	16	1	474	
TOTAL COMMITTED			33	13	14	11	2	4	0	0	0	77	
PERCENT COMMISSION*			11	27	42	50	13	17	0	0	0		
PERCENT COMMISSION**			10	29	42	42	15	20	0	0	0		

*Based on the total number within the sample.
**Based on the total number indicated by the interpreter results

AVERAGE PERCENT CORRECT=68%

HIGH ALTITUDE GROUND COMPARATIVE MAP DATA

Figure 2.20.   An evaluation of the Comprehensive Framework Study Committee Map Base (see Figure 2.17) is presented in the above table. Comparisons of the Framework Study map with the high flight map indicate good agreement.   The percent correct results for identification and mapping conifer, cultivated pasture, desert shrub, water, and urban resources indicate high interpreter proficiency. Commission errors are generally low except for hardwood and grassland types.   Furthermore the possiblity exists that some of the "errors" were made, not by the photo interpreter, but by the personnel who prepared the Framework Study map.
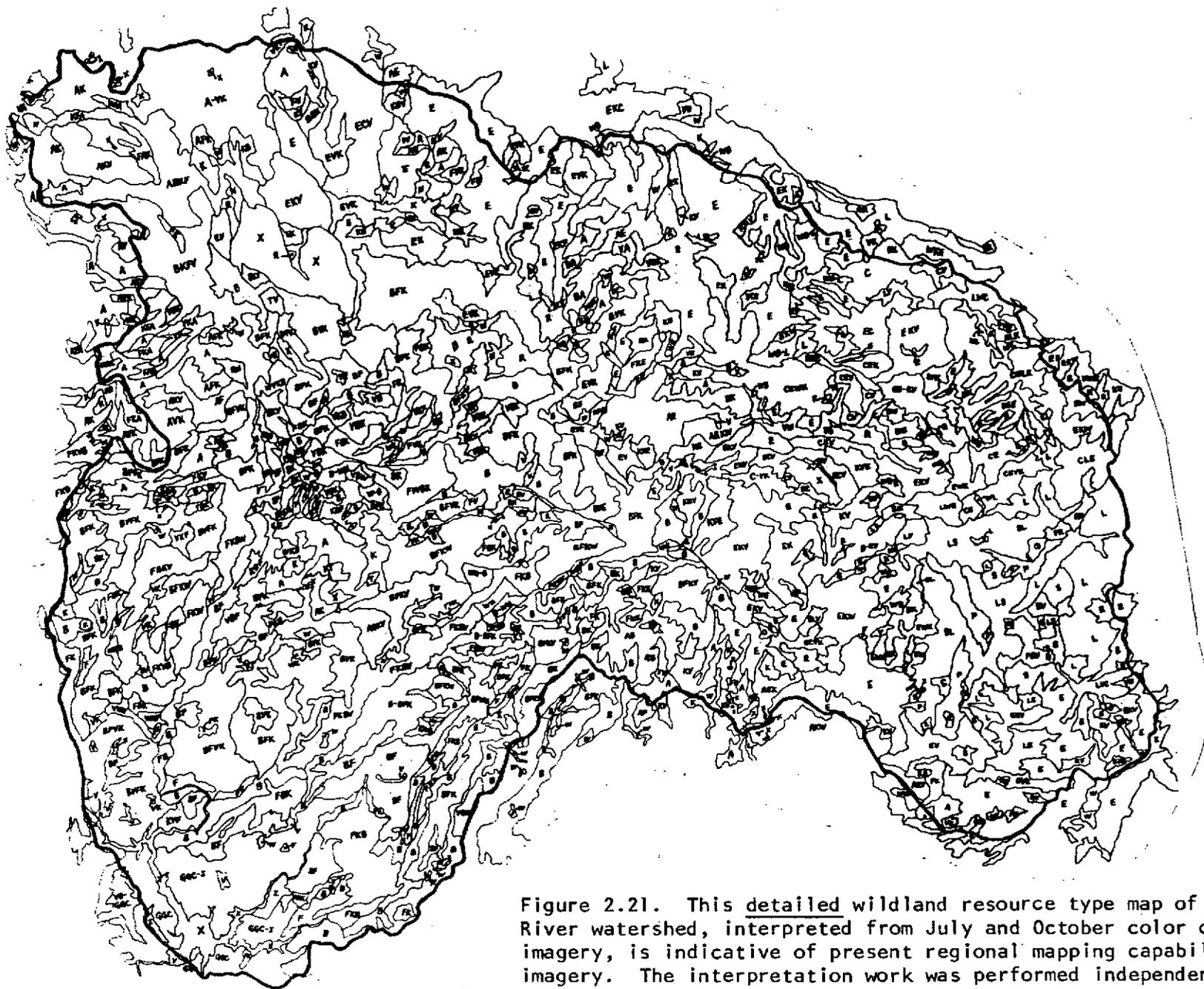
RESOURCE TYPE

A,O	FIR FOREST - MESIC MEADOW
B,BB	INTERMEDIATE MOUNTAIN MIXED CONIFER
C	EASTSIDE PINE - SCRUB FOREST
E	EASTSIDE TIMBERLAND CHAPARRAL COMPLEX
F	INTERMEDIATE MOUNTAIN XERIC HARDWOODS
G,GC	WESTSIDE FOOTHILL PINE - OAK WOODLAND - GRASS
I	WESTSIDE FOOTHILL MIXED HARDWOOD - CONIFER FOREST
J	WESTSIDE VALLEY FRONT CHAPARRAL
K	INTERMEDIATE MOUNTAIN CHAPARRAL
L	EASTSIDE VALLEY AND BASIN FRONT SAGEBRUSH SCRUB
N	INTERIOR VALLEY XERIC GRASSLAND
Q,R	CULTIVATED CROPLANDS AND MESIC RANGELAND
P	FRESHWATER MARSHLAND
S	XERIC EASTSIDE GRASSLAND - SCRUB RANGELAND
T	FOREST PLANTATION SITES
U	URBAN - RESIDENTIAL
V,W	EXPOSED SOIL AND ROCK (WG, WA, WP)
WB	EXPOSED BASALT BARRENS
WU	EXPOSED ULTRABASIC ROCK
X	STANDING WATER

Figure 2.21. This detailed wildland resource type map of the Feather River watershed, interpreted from July and October color composite ERTS-1 imagery, is indicative of present regional mapping capability from satellite imagery. The interpretation work was performed independently of other source information by a highly-skilled photo analyst.

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Accuracy of Framework Study Map

A similar point-by-point evaluation was made of the Framework Study Map shown in Figure 2.17 by comparing it with the high flight map. The tabulated results are illustrated in Figure 2.20 and show good overall agreement in that the average percent "correct" was 68 percent. Specifically, good agreement exists for conifer forest, grasslands, cultivated and pasture lands, desert shrub lands, water bodies and urban lands. However, poor agreement exists for chaparral lands, hardwood forest, and barren lands.

ERTS-1 Map Using Detailed Classification Scheme

Regional mapping was done of the entire Feather River watershed from ERTS-1 color composites (July 26, 1972, August 13, 1972 and October 24, 1972) with an objective of mapping vegetation/terrain types in maximum detail. The techniques used by the interpreter were similar to those used when preparing the generalized ERTS-1 map; however, a much more detailed classification scheme was employed in this case. Figure 2.21 illustrates the classification scheme used and the final map product derived from ERTS-1 imagery.

Accuracy of Detailed ERTS-1 Map

A point-by-point evaluation was made of the detailed ERTS-1 map shown in Figure 2.21 by comparing it with the high flight map. The summary results for 474 points are given in Figure 2.22. Note that the overall agreement between the two maps might still be called "good", (i.e., the average percent "correct" was 66 percent).

The results in Figure 2.22 indicate very high interpreter proficiency for identifying and mapping the eastside timberland-chaparral complex, eastside sagebrush scrub, forest plantation, urban-residential, and water resource types. Both the forest plantation and urban types, however, present tenuous data, since the total number of points present in each sample was small.

The high omission errors shown in Figure 2.22 are attributable to the relative scarcity of certain resource types. Moderately high proficiency was demonstrated in identifying and mapping fir forests, mixed conifer, hardwoods, pine-oak woodland, xeric grassland, grassland scrub rangeland, and exposed soil and rock. Commission errors were high for eastside pine scrub and marshland, indicating interpreter difficulty in identifying these types.

PRINCIPAL RESOURCE TYPE MAP FROM ERTS-1

HIGH ALTITUDE COMPARATIVE MAP DATA — RESOURCE TYPE	TOTAL PRESENT	TOTAL OMITTED	FIR FORESTS	MIXED CONIFER	EASTSIDE PINE-SCRUB	EASTSIDE TIMBERLAND-CHAPARRAL	XERIC HARDWOODS	PINE-OAK WOODLAND GRASS-CHAPARRAL	FOOTHILL MIXED HARDWOOD-CONIFER	FOOTHILL CHAPARRAL	MOUNTAIN CHAPARRAL	EASTSIDE SAGEBRUSH SCRUB	XERIC GRASSLAND	MARSHLAND	CULTIVATED CROPLANDS	MESIC RANGELAND	GRASSLAND SCRUB-RANGELAND	FOREST PLANTATION	URBAN-RESIDENTIAL	EXPOSED SOIL-ROCK	STANDING WATER	% OMISSION	% CORRECT*
FIR FORESTS	72	25	47	19		5	1															34	65
MIXED CONIFER	129	26	8	101		15	3				1									1		21	78
EASTSIDE PINE-SCRUB	12	4			8	3														1		33	66
EASTSIDE TIMBERLAND-CHAPARRAL	80	7	3		2	73					1									1		9	91
XERIC HARDWOODS	26	4			4		22															15	84
PINE-OAK WOODLAND GRASS-CHAPARRAL	8	2			1			6	1													25	75
FOOTHILL MIXED HARDWOOD-CONIFER	3	3			2			1	0													100	0
FOOTHILL CHAPARRAL	4	2			2					2												50	50
MOUNTAIN CHAPARRAL	28	18	1		4	2	5	6			10											64	35
EASTSIDE SAGEBRUSH SCRUB	13	0										13										0	100
XERIC GRASSLAND	8	3				1							5					2				37	62
MARSHLAND	2	1												1			1					50	50
CULTIVATED CROPLANDS	0	0													0							0	0
MESIC RANGELAND	14	6				1					1	1		3		8						42	57
GRASSLAND SCRUB-RANGELAND	16	4									4						12					25	75
FOREST PLANTATION	4	0																4				0	100
URBAN-RESIDENTIAL	1	0																	1			0	100
EXPOSED SOIL-ROCK	43	13			1	6	2	2	1		1									30		30	69
STANDING WATER	11	0																			11	0	100
TOTALS	474	120																					
TOTAL INDICATED			59	134	18	103	34	8	1	2	14	18	5	4	0	9	14	4	1	33	11	474	
TOTAL COMMITTED			12	33	10	32	12	2	1	0	4	5	0	3	0	1	2	0	0	3	0	120	
% COMMISSION*			17	26	83	40	46	25	33	0	14	38	0	150	0	7	12	0	0	6	0		
% COMMISSION**			20	25	55	30	35	25	100	0	28	27	0	75	0	11	14	0	0	9	0		

* BASED ON THE TOTAL NUMBER WITHIN THE SAMPLE
** BASED ON THE TOTAL NUMBER INDICATED BY THE INTERPRETER

AVERAGE PERCENT CORRECT = 66%

Figure 2.22. Comparative data between the principal resource type map interpreted from ERTS-1 imagery and the high altitude map base are expressed in this figure as percent omission errors. These results, based on 474 data points, distributed among nineteen principal resource types, indicate moderate to high interpreter proficiency in the identification of most types present. A complete discussion of these results appears in the text.

Timing and Cost Factors Associated with Preparing the Generalized and Detailed ERTS-1 Maps

Actual time and cost figures associated with producing the high flight map, the generalized ERTS-1 map (see Figure 2.19) and the detailed ERTS-1 map (see Figure 2.21) are presented in Table 2.5 . The most time-consuming phase of interpretation is the classification of wildlands from the imagery. The total time required to map the entire Feather River watershed varied from 11.5 hours for generalized mapping, and 17.5 hours for detailed mapping from the ERTS-1 imagery, to 182.0 hours for mapping from the high flight photos. Costs associated with these time figures are also presented in Table 2.5. These figures demonstrate cost ratios of 16:1 and 10:1, respectively, between high flight and ERTS-1, depending on the level of mapping detail required from the ERTS-1 images.

Conclusions

The Case Study presented above was designed to determine the practical usefulness of ERTS-1 imagery for vegetation/terrain mapping over vast, inaccesible wildland areas. The study has shown that ERTS-1 imagery is ideal for making generalized vegetation/terrain type maps, similar to the one made by the California Comprehensive Framework Study Committee. Specifically, the ERTS-1 map made for the entire 2-1/4 million acre Feather River watershed required only 11.5 hours of interpretation time. When the entire watershed was mapped in maximum detail with ERTS-1 imagery, the interpretation time required was 17.5 hours. To map the same area with high flight photos would cost at least ten times or sixteen times more, respectively, than with ERTS-1 imagery; however, a much greater amount of information would be derivable from the high flight photos. In addition, the generalized ERTS-1 map was certainly as good as, if not slightly better than, the Framework Study map in terms of level of accuracy.

The total estimated cost associated with preparing the Framework Study maps for the entire State of California (105 million acres) was approximately $12,000. This figure reflects only the man-hours associated with the task and does not include such items as supplies, travel expenses, overhead, etc. A similar projected cost for the making of a generalized vegetation/terrain type map for the entire State of California with the aid of ERTS-1 imagery would be approximately $4,000. Consequently, not only can a more timely and more accurate regional vegetation/terrain map be prepared from ERTS-1 imagery than from using conventional methods (i.e., Framework Study), but also the ERTS-1 map can be prepared for approximately one-third the cost.

Table 2.5. Actual Interpretation Time and Costs Associated with Mapping Vegetation/Terrain Types within the Feather River Watershed

	Mapping From High-Altitude Aircraft False-Color Infrared Photos	Mapping (Generalized) from ERTS-1 Color Composite Imagery	Mapping (Detailed) From ERTS-1 Color Composite Imagery
Delineation of Watershed Boundary	3.0 hours	0.5 hours	0.5 hours
Plotting Effective Areas	5.0 hours	0.0 hours	0.0 hours
Delination of Homogeneous Areas	48.0 hours	2.0 hours	4.0 hours
Photo Interpretation Training	6.0 hours	6.0 hours	6.0 hours
Resource Type Classification	120.0 hours	3.0 hours	7.0 hours
Total Interpretation Time Required	182.0 hours	11.5 hours	17.5 hours
Hourly Wage	$7.00/hour	$7.00/hour	$7.00/hour
Total Interpretation Costs (Time)	$1274.00	$80.50	$122.50
Total Cost/Acre	0.0566 ¢	0.00357 ¢	0.0054 ¢
Cost Ratio	16 ———————————┐		
	10 —————————————————————┘		

3. Multistage Sampling Study

As indicated in our discussion of the previously described
hydrologic models, there exists a need for both in place mapping and
a quantitative measure or estimate of the amount or magnitude of a
variety of environmental parameters characteristic of the watershed
areas. Thus it was felt important to develop techniques for producing
quantitative estimates of wildland resource parameters, using, where
possible, ERTS-1 data as an input.

In order to test the usefulness of ERTS-1 imagery for making
wildland resource inventories, a test was performed in which ERTS-1
imagery acted as the first stage of a multistage sampling design with
the objective of estimating the standing volume of merchantable timber
within the Quincy Ranger District (215,000 acres) of the Plumas National
Forest, within the Feather River test site.

The selection of timber volume as the parameter of interest for
this test was justified on several grounds. First, vegetation, in terms
of its amount, kind, and distribution is an important factor governing
the amount of water which will be supplied for downstream use by a
watershed which receives a certain amount of precipitation. Large
trees, for example, can intercept virtually all of the rain or snow
that falls in a light storm, so that little or no moisture reaches
the ground. Large trees also drain much water from the soil through
the process of transpiration. On the other hand, there is a special
kind of microclimate on the floor of a shady forest that slows the
rate of snow melt there. Furthermore, the presence of forest litter
and deep roots restricts the surface flow of water from a forest area
and increases the amount of deep percolation and eventual release of
water in the form of subsurface flow.

For all of these reasons, it would seem appropriate, within the
context of the present study of water supply, to investigate the feasi-
bility of mapping forest vegetation by means of remote sensing. If
such mapping would also produce an accurate inventory of the merchantable
timber, it would be doubly useful. Specifically it would facilitate
the work of both the resource managers who are concerned with the harvest
of timber and those who are concerned with the harvest of water from a
given watershed, and would serve to demonstrate to each such manager
that his success depended on the activities of the other.

Obviously, the sampling and data analysis procedures which were
developed for this test case can, in many cases, be readily adapted
for use in the inventory or measurement of many other parameters which
might constitute an input to hydrologic models, and hence the usefulness
of the techniques extends far beyond the specific case discussed here.

Secondary objectives of the inventory were: (1) to test the
operational efficiency of the sampling procedures of the multistage
sample design, (2) to test the effectiveness of the CALSCAN* classifier
on the ERTS-1 data, (3) to determine the value of ERTS-1 data and air-
craft data in reducing the sampling error, (4) to compare the costs of

this timber inventory with those for an equivalent inventory using conventional procedures, and (5) to determine whether information derived from such an inventory might provide meaningful input to a hydrologic model for the same area.

A three-stage sampling design was tested in which "timber volume" was the variable estimated. At each stage timber volume estimates were made from sampling units whose probabilities of selection of the sample were proportional to the corresponding predicted volumes, as interpreted from the next smaller scale imagery. Timber volume estimates were made from three stages: (1) the first stage involved automatic classification of the timberland on the ERTS-1 data tapes into four timber volume classes. Within the classified area, subsamples were selected (called primary sampling units or "PSU") from which a more refined estimate of timber volume could be made in the second stage; (2) the second stage involved the acquisition of low altitude photography of selected primary sampling units to select photo plots on which to make a second and more accurate timber volume estimate by comparison with photo-volume tables; (3) the third stage involved selecting individual trees within selected sample photo plots to make still more accurate timber volume estimates by photo measurement of all merchantable trees. Selected trees were then precisely measured (for volume) on the ground and these volume measurements in turn were expanded through the various stages of the sample design to estimate total timber volume over the national forest land within the Quincy Ranger District.

The statistical procedures for expanding the timber volume estimates though the various stages of the timber inventory are discussed later in this report. The procedures for selecting sampling sites and estimating timber volumes from ERTS-1 and aircraft imagery at each of the stages of the sample design are described in subsequent sections in order to demonstrate how the ERTS and supporting aircraft data were necessary components in performing the timber inventory.

Stage 1.   CALSCAN Classification of ERTS-1 Data and Primary
            Sample Unit Selection

ERTS-1 data tapes of the Quincy Ranger District, Plumas National Forest, were classified on the CRSR interactive human-computer system using a CALSCAN point-by-point classification routine. The coordinates of the Ranger District boundary and those of non-national forest land within the District were identified on the tapes so that only those picture elements associated with national forest land were classified and incorporated into the inventory. This procedure considerably reduced the costs of classification.

Classification was based on four timber volume classes, namely (1) non-forest; (2) forest sites containing less than 10,000 board feet per acre (bd ft/ac); (3) forest sites containing 10,000 to 20,000 bd ft/ac, and (4) forest sites containing more than 20,000 bd ft/ac. The

classifier was trained to recognize each of the four timber volume classes based upon photo interpreter selection of 33 training cells whose estimated range of timber volumes was based on photo interpretations of crown closure and average crown diameter. The training cells were selected from interpretation of high altitude color infrared photography (scale 1:120,000). Each of the training cells was located and digitized on the ERTS imagery. Point-by-point classification of all ERTS data points within the Quincy Ranger District proceeded by matching each data point (picture element) with the corresponding training cell. The results were grouped into the four timber volume classes. The accuracy achieved by automatic classification of ERTS tapes lends credence to the efficiency which can be gained in the timber inventory through analysis of ERTS data tapes in the initial stages of the sample design.

The classified ERTS data (CALSCAN classification) of the Quincy Ranger District were divided into rectangular sampling units (called primary sampling units). Each unit measured 1,325 feet wide by 1-1/2 miles long. The size of these sampling units was based upon (1) a practical area which could be photographed in a single flight line by a light aircraft using a 35 mm camera system, (2) the ability of the ground crew to complete the ground work for a flight line in one day and (3) the variation between SU's.

For each primary sampling unit, the following information was computed:

1. The number of points in each volume class (within the unit)

2. The weighted total volume for each volume class*

3. The sum of the weighted totals for all classes

4. A cumulative sum of the weighted totals

5. The mean volume for the sampling units

6. The variance of the sampling units

Based upon the information either estimated or computed for each primary sampling unit, four units were selected for further sampling in the timber inventory. The four units were selected with probability of selection proportional to their estimated volumes. The locations of the four selected PSU's were transferred from the ERTS classified

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* The weighted total volume was determined by multiplying the number of points in each volume class by the assigned weight for that class. The assigned weight is the volume estimate given by PI's. In this instance T1 (0-10,000 bd ft/ac) = 1, T2 (10,000-20,000 bd ft/ac) = 2, T3 (20,000 bd ft/ac and above) = 3, and all non-forest types were given a weight = 0.

Images to the color-infrared high altitude aerial photography (scale 1:120,000), to facilitate locating them accurately from the air when they were photographed from a lower altitude as part of the second stage of the timber inventory.

Stage II.   Volume Estimation on Low Altitude Photography

Two 35 mm cameras were used to obtain low altitude photography of the selected primary sampling units simultaneously at two different scales. A 24 mm focal length, wide-angle lens was used to acquire complete coverage of each sampling unit at an approximate scale of 1:7,500, and a 200 mm focal length was used to obtain large scale stereo triplets, scale approximately 1:1,000, from which to make precise photo estimates of timber volume. The camera with the telephoto (200 mm) lens was equipped with a motorized film drive which enabled each stero triplet to be taken within one second at five second intervals while the camera with the wide-angle lens was operated manually to obtain single frames at five second intervals. The photo coverage for each PSU consisted of ten stereo triplets and ten wide angle photographs.

The wide-angle photos of each primary sampling unit were mosaiced together to show its full area. The center of the middle photo for each stereo triplet was used as the plot center, and these centers were located and marked on the mosaic. The plot centers were also located on a topographic map and the elevation of each was determined, to facilitate calculation of photo scale.

The scale of each photo plot was determined from the relation $\text{photo scale} = \frac{\text{camera focal length}}{\text{flight altitude above terrain}}$. In determining flight altitude above terrain, the elevation of the plot (as read from the topographic map on which plot centers had been located) was subtracted from the flight altitude of the photographic aircraft above sea level (as read from the aircraft's altimeter at the time of photography). A 0.4-acre circular plot was then drawn about the photo plot center. The timber volume in each 0.4-acre photo plot was estimated by referring to photo-volume tables based upon interpretation of the plot's percent crown closure and measurement of average stand height using a parallax bar (Chapman, 1965)*. Within each primary sampling unit two out of the ten possible photo plots were chosen with probability of selection proportional to their estimated volumes.

Stage III.   Selection of Trees for Precise Ground Measurement
of Timber Volume

In the third stage, all trees of merchantable size within each selected photo plot were pin-pricked and numbered. For each of these trees, the average crown diameter was determined based on the longest and shortest dimensions of their crowns. After adjustments for scale,

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* Chapman, Roger C. 1965. Preliminary Aerial Photo Stand-Volume Tables for Some California Timber Types. Pacific Southwest Forest and Range Experiment Station Research Paper No. 93. 9 pp.

Figure 2.23. The top photo was taken with a 24 mm lens. The bottom photos illustrate the stereo triplet obtained by the telephoto lens at the same time. The inked circle on the bottom center photo delineates the scale-adjusted, 0.4 acre ground plot.

the average crown diameter value was cubed (raised to the third power) to be used as a relative measure of the merchantable volume of wood in the individual tree for the third stage volume estimation. Four trees were selected from the population of merchantable trees found within each photo plot, to be measured by a dendrometer on the ground. (Selection again was based upon probability proportional to the estimated volume of each tree).

A two-man crew was sent into the Quincy Ranger District with a Barr and Stroud optical dendrometer and measured the selected trees. The large scale (low altitude) photographs were used to locate the photo plot centers as well as the trees within the plots to be measured. In addition to the dendrometer measurements, an easily recognizable feature on the ground near the plot center was measured in order to get a more accurate estimation of the photo scale of the plot. The dendrometer measurements thus obtained were entered into a computer program that calculated merchantable stem volumes for the individual trees. These volumes were then expanded through each stage of the sample design to estimate total volume on the District, consistent with the statistical methods for variable probability sampling.

Results

The total volume of timber on the Quincy Ranger District of the Plumas National Forest was estimated to be 407 million cubic feet (approximately 2.44 billion board feet) based on eight selected photo plots located within four primary sampling units. The sampling error associated with this estimate was 8.2 percent, which falls well below the acceptable S.E. of 20 percent for the District. This indicates that the true volume of merchantable trees on the Quincy District will fall into the interval 352-462 million cubic feet with .80 probability.

There were only thirty-one trees total measured by an optical dendrometer on the ground at the eight plots (thirty-two trees should have been measured but one plot out of the eight contained only three merchantable trees which could be measured). The field work required one week's time by a two-man crew, and the total area of the ground plots measured was 3.2 acres, representing a sampling fraction of about 1/67,000 (.0015 percent).

Table 2.6 lists the costs of a timber inventory on 215,000 acres using the multistage sampling design just described as an operational system. The expected costs of making such an inventory on the Plumas National Forest, which has an area of 1,161,554 acres, would be approximately $15,000 and would take five months to complete. In contrast, the U.S. Forest Service recently made an inventory of somewhat lower probable accuracy on the Plumas National Forest at a total cost of $300,000 and took two years to complete it.

Conclusions

The preliminary results of the timber inventory of the Quincy Ranger District indicate that the procedures employed in the multi-stage sampling design are valid and substantially reduce both the costs and the amount of time required to perform a timber inventory of acceptable accuracy for a large area. This study demonstrates the value of ERTS-1 data for accurately correlating picture elements with timber volume estimates as a fundamental first step in selecting primary sampling units in the first stage of the inventory. The inventory procedures utilized here will be applied for the remaining districts of the Plumas National Forest in an effort to estimate the total timber volume on the forest. Based on the preliminary results it is felt that the sampling error will be well below the ten percent specified at the beginning of the study.

Table 2.6.   Cost Estimate -- Timber Inventory -- Based on 215,000 Acres, Quincy Ranger District

COMPUTER PROCESSING

CALSCAN TRAINING AND PHOTO INTERPRETATION	$120
CALSCAN CLASSIFICATION	210
STATISTICAL BREAK-UP	40
CALSCAN STATISTICS	12

$382

AERIAL PHOTOGRAPHY

AIRCRAFT AND CREW	$210
FILM AND PROCESSING	90

$300

SUPPLIES AND EXPENSES

TRAVEL	$350
MISCELLANEOUS	50

$400

Table 2.6. (continued)

PERSONNEL

    1 PROJECT SCIENTIST, 2 MOS. F.T.E. @ $1,100/MO. $2,200
    1 SOFTWARE CONSULTANT, ½ MO. F.T.E. @ $1,300/MO.   650
    1 STATISTICIAN, ½ MO. F.T.E. @ $1,100/MO.   550
    2 LAB ASSISTANTS, 1 MO. F.T.E. EACH @ $620/MO.   1,240

                              SALARY SUBTOTAL $4,640

    ASSOCIATED OVERHEAD @ 20% $968

                                                               $5,568

                                                 TOTAL $6,640

Statistical Methods Used

Timber volume predictions were made from three stages of the
timber inventory for the purpose of selecting sample plots whose
probability of selection would be proportional to the volume
predictions. Thus, variable probability sampling methods were used
to estimate the total volume in this timber inventory.

Three variables proportional to timber volume were used in
generating the selection probabilities: (1) "volume" estimates of the
ERTS picture elements based on the spectral signatures on four bands
and subsequent training and classification; (2) volume estimates of
plots on 1:1,000 scale color prints, based on photo-volume tables
(Chapman, 1965)* and (3) volume estimates on large scale photos, based
on crown diameters cubed.

When one uses a scheme where probability of selection is propor-
tional to the estimated volume, the effort is focused on the areas
of higher timber volume and thus adds to the overall cost-efficiency.
The ability to list the populations at each stage prompted the selec-
tion of list sampling as the variable probability sampling scheme.

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* Chapman, Roger C. 1965. Preliminary Aerial Photo Stand-Volume
Tables for Some California Timber Types. Pacific Southwest Forest
and Range Experiment Station Research Paper No. 93. 9 pp.

Method of Estimation

The method of estimation was based on "unequal expansion" as implied by the probability scheme discussed above. At each of the three stages, the probability-proportional-to-estimated-size (p_i) was obtained by listing the volume estimates of the sampling units (x_i), and dividing them by the total of volume estimates

$$(\sum_{i=1}^{n} x_i):$$

$$p_i = \frac{x_i}{\sum_{i=1}^{n} x_i}$$

A sample of a chosen size was then drawn by applying random integers from 1 to $\sum_{i=1}^{n} x_i$ and observing the probability interval and the corresponding sampling unit which contains the randomly selected integers.

In the first and second stages the timber volumes of the selected sampling units were estimated by subsequent sampling, whereas in the third stage the volume was carefully measured by a precision dendrometer. The entire three stage estimation procedure was as follows:

Stage I; A sample of n_h out of the N_h PSU's was drawn from stratum h with probability proportional to estimated size (ppes). The estimate of the total volume then became —

$$\hat{V} = \sum_{h=1}^{L} \frac{1}{n_h} \sum_{i=1}^{n_h} \frac{y_{hi}}{p_{hi}}$$

where: L = total number of strata

P_{hi} = selection probability of the ith PSU in the hth stratum

y_{hi} = total volume of the ith PSU in the hth stratum (remains to be estimated by subsequent stages).

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<u>Stage II</u>: To estimate the total volume (y_{hi}) of the $i^{\underline{th}}$ PSU, a sample of n_{hi} out of the N_{hi} secondary sampling units (.4 acre plots) was drawn with ppes. This gave:

$$\hat{y}_{hi} = \frac{1}{n_{hi}} \sum_{j=1}^{n_{hi}} \frac{y_{hij}}{p_{hij}}$$

However, in order to include area expansion from circular sample plots to the full PSU, and also to stratify the second stage plots into four volume strata, the estimator became:

$$\hat{y}_{hir} = \sum_{r=1}^{R} \frac{1}{p_{hir}} \frac{A_{hir}}{a_{hir}} \frac{1}{n_{hir}} \sum_{j=1}^{n_{hir}} \frac{\hat{y}_{hirj}}{p_{hirj}}$$

where: $r = 1,2,\ldots,R$ refers to the CALSCAN volume strata

p_{hir} = selection probability of the $r^{\underline{th}}$ volume stratum of the $i^{\underline{th}}$ PSU in the $h^{\underline{th}}$ stratum

A = area (indexes as above)

a = sampled area (indexes as above)

n = sample size (indexes as above)

p_{hirj} = selection probability of the $j^{\underline{th}}$ plot of the $r^{\underline{th}}$ volume stratum, of the $i^{\underline{th}}$ PSU in the $h^{\underline{th}}$ stratum

$\hat{y}_{hirj}$ = plot volume (to be estimated by stage III)

<u>Stage III</u>: To estimate the total volume of the jth plot, a sample of n_{hirj} out of the N_{hirj} tertiary sampling units (trees) was drawn with ppes. Then:

$$\hat{y}_{hirj} = \frac{1}{n_{hirj}} \sum_{k=1}^{n_{hirj}} \frac{y_{hirjk}}{P_{hirjk}}$$

where: P_{hirjk} = the selection probability of the kth sample tree of the jth plot of the rth volume stratum of the ith PSU of the hth stratum.

y_{hirjk} = the dendrometer-measured volume of the kth sample tree of the jth plot of the rth volume stratum of the ith PSU of the hth stratum.

Combining the various stages above, the entire estimator became:

$$\hat{V} = \sum_{h=1}^{L} \frac{1}{n_h} \sum_{i=1}^{n_h} \sum_{r=1}^{R} \frac{1}{P_{hir}} \frac{\hat{A}_{hir}}{a_{hir}} \frac{1}{n_{hir}} \sum_{j=1}^{n_{hir}} \frac{1}{P_{hirj}} \frac{1}{n_{hirj}} \sum_{k=1}^{n_{hirj}} \frac{y_{hirjk}}{P_{hirjk}}$$

Variance of the Estimator

In multistage sampling, when the number of first stage units is large, most of the variability in the population is due to the first stage. Therefore, it suffices to consider only the first stage values (here y_{hi}) to estimate the population variance and, consequently, the variance of the estimator (Durbin, 1953, p. 262; Kendall and Stuart, 1967, vol. 3, p. 200; Langley, 1971, p. 131).

Thus, for the first stage our stratified sampling estimator becomes (Cochran, 1963, p. 260):

$$\hat{V} = \sum_{h=1}^{L} \frac{1}{n_h} \sum_{i=1}^{n_h} \frac{y_{hi}}{P_{hi}}$$

Its variance is:

$$Var(\hat{V}) = \sum_{h=1}^{L} \frac{1}{n_h} \sum_{i=1}^{N_h} P_{hi} \left(\frac{y_{hi}}{P_{hi}} - V_h \right)^2$$

which has an unbiased estimator:

$$\hat{Var}\,(\hat{V}) = \sum_{h=1}^{L} \frac{1}{n_h\,(n_h - 1)} \sum_{i=1}^{n_h} \left(\frac{y_{hi}}{P_{hi}} - \hat{V}_h\right)^2$$

For proportional allocation, $n_h = n(N_h/N)$ and

$$Var\,(\hat{V}) = \sum_{h=1}^{L} \frac{N}{n\,N_h} \sum_{i=1}^{N_h} P_{hi} \left(\frac{y_{hi}}{P_{hi}} - V_h\right)^2$$

$$\hat{Var}\,(\hat{V}) = \sum_{h=1}^{L} \frac{N^2}{n\,N_h\,(nN_h - 1)} \sum_{i=1}^{n_h} \left(\frac{y_{hi}}{P_{hi}} - \hat{V}_h\right)^2$$

The last equation is an unbiased estimator of Var $(\hat{V})$ and can be used for the estimation of the sampling error of the inventory.

Sample Size

(a) From the usual confidence statement

$$P \left\{\hat{V} - t_{\alpha;\,n-1} \sqrt{Var(\hat{V})} < \mu \le \hat{V} + t_{\alpha;\,n-1} \sqrt{Var(\hat{V})} \right\} = 1 - \alpha$$

To obtain n for a fixed precision level (d), e.g. 5% of Y at 95% confidence level, proceed as follows:

Let $d = t \sqrt{Var(\hat{V})}$, i.e. half-width of conf. int., also called "allowable error"

$d^2 = t^2\, Var(\hat{V})$.

Since

$$Var(\hat{V}) = \frac{1}{n} \underbrace{\sum_{i}^{N} P_1 \left(\frac{y_1}{P_1} - V_h\right)^2}_{S^2}$$

Then

$$d^2 = \frac{t^2 s^2}{n}$$

And

$$n = \frac{t^2 s^2}{d^2} .$$

The value of S^2 was unknown in this application, and had to be

estimated. Recalling that the population consists of N primary sampling units as a result of the partitioning of the forest in ERTS image, the population variance S^2 is obtained by

$$S^2 = \frac{1}{N} \sum^{N} (y_i - \bar{y})^2$$

where y_i denotes the total volume of the $i\underline{th}$ PSU, and $\bar{y}$ their average.

The CALSCAN classification provided a means of estimating the value of y_i for each PSU, since each picture element had been assigned to a volume class. Thus the weighted sum of these gave the total volume of the PSU. More formally,
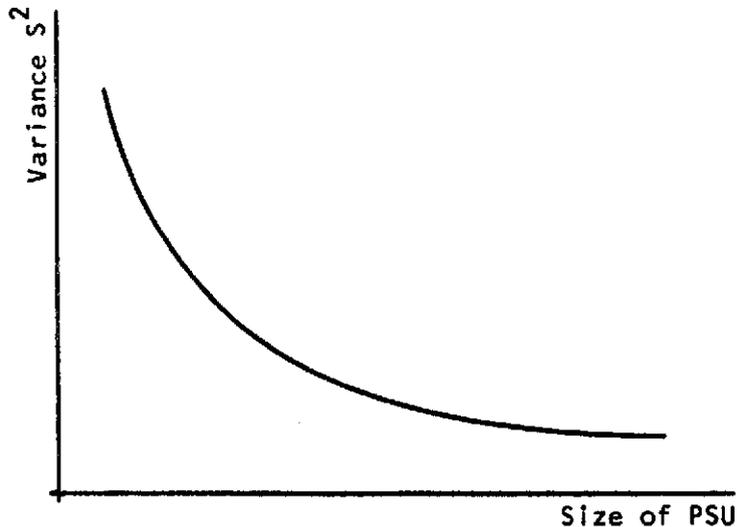
$$y_i = \sum^{n}_{l} \sum^{m}_{k} w \cdot c$$

where $k = 1, \ldots, m$ is no. of rows of picture elements in PSU

$l = 1, \ldots, n$ is no. of columns of picture elements in PSU

w = volume weight for c

c = CALSCAN class assigned to the $kl\underline{th}$ picture element

This approach also enabled a study of optimum size and shape of the PSU. Using the variance S^2 as a criterion and varying the size of the PSU, the following relationship was obtained:

Similarly, by varying the width and length for a fixed size of the PSU,

and observing the S^2, respectively, the optimal width/length ratio was found. The outcome of this particular study had to be qualified by practical considerations, e.g., those related to the procurement of the aerial photos of PSU's for subsequent sampling.

As a result, a rectangle of size (43 x 5) picture elements (1325' x 1.5 mi.) was selected to be used for each PSU in the survey.

Through use of the coefficient of variation (CV) and 95 percent level of confidence, the number of PSU's was found by,

$$ n = \frac{t^2 \cdot (CV)^2}{d^2} $$

Actually, for small sample sizes, the t-value changes with the n, and n has to be calculated by iterating with a few t-values.

Example, Plumas National Forest:

(1) Assume n = 13, then $t_{(n-1)}$ = 2.18 at 95% level.

Assume CV = .18

Let d = t $s_{\bar{x}}$ = .10 (allowable error, i.e. half width of conf. int.)

Then

$$ n = \frac{t^2(CV)^2}{d^2} = \frac{(2.18)^2 (0.18)^2}{(0.10)^2} = \frac{0.154}{0.01} = 15.4 \approx 16. $$

Second iteration: Assume n = 15, then $t_{(n-1)}$ = 2.13 at 95% level

$$ n = \frac{(2.13)^2(0.18)^2}{0.01} = \frac{0.147}{0.01} = 14.7 \sim 15. $$

(2) Assume n = 60, then $t_{(n-1)}$ = 2.00 at 95% level

Let d = t·$s_{\bar{x}}$ = .05, i.e. $s_{\bar{x}}$ = 2.5%

Then

$$ n = \frac{(4)\ (0.0324)}{0.0025} = \frac{0.1296}{0.0025} = 51.8 \approx 52. $$

B. Report by the Algazi Group, Davis Campus

During the period covered by the present report our group has made considerable progress on the handling and processing of digital remote sensing data, including that acquired by ERTS-1. A substantial amount of our time and effort has been devoted to responding to NASA's requests for both oral and written presentation on the results of these investigations. Such efforts were, in a sense, culminated in our presentation at the ERTS-1 symposium in Washington D. C. in November, 1973 of a paper entitled "Multispectral combination and display of ERTS-1 Data".

The progress which we have made in this general area during the present reporting period can be divided into the following broad categories: (1) minor hardware modifications and improvements in the digital image processing facility which is central to our work; (2) development of a systematic image enhancement procedure applicable to a variety of problems as well as to remote sensing; (3) preliminary work on the combining of multispectral data for the study of Earth Resources; (4) application of the procedures of (2) and (3) in enhancing ERTS-1 data and imagery of interest to several participants of our integrated study; and (5) articulation and investigation of some of the basic issues which underly the interactive processing of remote sensing data by digital computers.

Each of these categories will now be reported upon.

1. Modifications to the Digital Processing Facility

Two noteworthy changes have been made in our digital image processing facility: (a) a precision CRT has been employed in such a way as to allow us to generate color composites having better resolution (more than 512 x 512 pixels), improved color rendition, and improved color consistency. This system also makes possible the use of geometric correction algorithms within our facility. (b) A second digital tape drive has been added to our facility and will allow greatly improved capability in the handling of large quantities of data.

2. Development of a Systematic Image Enhancement Procedure

The procedure previously reported upon has been refined by more careful consideration of the rational choice of the color coordinates used for display. Work on this procedure is continuing and a paper relative to it is being prepared for publication.

3. Combination of Multispectral Data for the Study of Earth Resources

Some of our results to date under this heading have been presented in the paper, "Multispectral Combination and Display of ERTS-1 Data" at the

3rd ERTS-1 symposium. The scope of our work in this field is enlarging to include several important considerations. Specifically, because of the high correlation both spectrally and spatially in the ERTS-1 data it seems possible to achieve at the same time several of the following objectives:

(a) Improvement of the quality of the data by reduction of the noise due to errors and coarse quantization.

(b) Efficient representation of the data either for transmission (encoding) or for further processing. It appears probable that this capability can be achieved without any loss in, and possibly with a net improvement of, data quality.

(c) Presentation of the information provided by sensors in a more interpretable form. This is related to our work in image enhancement.

(d) Significant increase in the speed of processing for enhancement or classification. This capability depends upon the choice of linear combinations with fast algorithms.

4. Application of These Newly Developed Procedures to Problems Which are of Interest to Participants in our Integrated Study

We have followed our previous contact with users of data, both within and outside the University. We have conducted and are continuing to conduct work on the following application areas.

(a) Delineation and mapping of snow cover. Some preliminary work has been done and we are quite encouraged both by our results and those obtained by Dr. Martin Taylor of the Canadian Center for Remtoe Sensing Research on the use of image enhancement for this problem.

(b) Mapping and enhancement of salt affected soils. This work, carried out by a Ph.D. student, Mr. Samulon, is nearing completion and will be reported later on. It deals with a significant problem related to irrigation and, to our knowledge, no other work relative to this problem using digital processing techniques is being pursued elsewhere.

5. Basic Issues in the Processing of Remote Sensing Data for Application

From more than one year of experience which we have had with ERTS-1 data, and in view of the results of a large number of other ERTS-1 investigators, it appears worthwhile to take stock of the digital technology and algorithms now available.

We plan to examine and incorporate into our software packages some of the algorithms developed elsewhere which seem most useful to our continuing work.

(a) Geometric correction — Various algorithms will allow us to generate images with one of several possible levels of geometric accuracy.

(b) Radiometric correction = Some results have been reported on correction of radiometric values for atmospheric effects, sun angle, and sensor altitude. We plan to assess the significance of these results. Principally some correction for atmospheric effects seems needed in applying remote sensing data to water quality monitoring.

(c) Preprocessing and interactive processing of remote sensing data to increase efficiency and interpretability. Some of this work falls along the lines described earlier, since it requires linear combinations. An alternate procedure will continue processing by image enhancement with subsequent classification, but this method is generally more involved and more costly.

(d) Generally we recognize the need to try to incorporate all available data, including ground truth in the form of radiometric values, atmospheric modeling, sun angle correction, and sensor characteristics into a unified discussion of the radiometric value recorded by a satellite. We plan to survey the literature in one field of application, water quality monitoring, and try to incorporate findings into algorithms.

(e) Subpixel processing: In some applications, notably the quantitative determination of water surfaces, it is desirable to incorporate subpixel information. Some results have been reported. We have had previous experience ourselves, acquired in a different context. Here again we plan an incorporation of existing algorithms and a determination of the potential worth and computational complexity of such techniques.

VI. SOCIO-ECONOMIC AND POLITICAL CONSIDERATIONS

During the period covered by this report, research activities of
the Social Sciences Group on the Berkeley campus have been devoted to
the gathering of information consonant with the revised proposal for
this integrated study, dated September 30, 1973. As the following
pages will indicate, in one phase of these activities we have been
exploring the social, political and economic aspects related to water
supply in the state of California, with particular reference to the
California Water Project. More specifically, this section discusses
the social environment of the management of the supply of water,
including the various perspectives that influence and are influenced
by the decisions made.

The water resource is part of a matrix of vital resources in the
State; its management takes place in a social mileu, in which histor-
ical background, legal constraints, regulations and commitments, economic
considerations, and cultural practices all play determinative roles.
During the months just past, the Integrated Study of Earth Resources
has conducted research on the decision-making processes pertaining
to water. Effort has been directed to ascertaining who are the decision
makers, what are their areas of responsibility, what kinds of informa-
tion do they need, who are their publics, what are the objectives, how
are these identified, and how do officials go about achieving them.
Ultimately, we hope to come up with definitive answers as to how remote
sensing and aerial technology can be utilized to improve the management
of water resources.

In order to achieve this purpose, the various specialists partici-
pating in the Project have studied crucial aspects of California water,
each specialist bringing to bear his particular kind of competence but
always working in concert with the others on what have been singled
out as the matters of greatest importance. For example, with respect
to supply, the hydrologists have concentrated their efforts on exist-
ing projects and management policies so as to learn what kinds of infor-
mation are needed by the responsible agencies. They are interested in
learning about the amount, timing, and format of the information, who
uses it and how it is put to use -- all with respect to the planning
and carrying forward of operations of the California State Water Project.

The California State Water Project is both the end-product of and
a link in a long chain of historical events, technological developments,
political and bureaucratic arrangements, legal tangles, and economic
projections, which have had bearing on decisions amde long ago and
which are now being implemented. Several years into its second decade,
the California State Water Project has completed a number of the goals
set for it. The Commissioner's Annual Progress Review lists some of
them: conservation and delivery of water from Plumas County to Los
Angeles County; water service in the San Francisco Bay Area; provision
of facilities for family recreation and sport fishing in northern,

central, and southern California; smog-free generation of electric power; maintenance of flood control and of water quality control. These items, although covering a broad range of activity, only begin to suggest the degree of involvement of water with the total social, political, and economic pattern of life in California.

A. Information Needed for Use in Water Supply Models

It becomes clear that to meet the enormous responsibility implicit in their mandate, managers of California's water resource must provide intelligent planning. This requires reliable models. And such models depend on information. For the hydrologists who are gathering data and devising new techniques for handling them, one area of research is in water supply conditions, which include sources. They measure precipitation and gauge the effects of such vagaries of the weather as protracted periods of heat, snowpack, rainfall, state of the watersheds feeding the major streams, etc. The way in which severe drought in southern California can affect water supplies is a case in point. The General Manager of the Metropolitan Water District of southern California expressed the belief that, but for the initial service of the State Water Project, his District would have been "very hard pressed to provide sufficient water at least for agricultural use in the Metropolitan Water District this year -- principally in Orange, Riverside, and San Diego Counties".*

Of similar importance in the development of a hydrologic model is the existence of ground water, many studies having already been made in the known basins throughout the State. The management of ground water is a key factor in the coastal water basins in particular because of the possibility of sea water intrusion. Desalinization as a technological means of coping with salinity is steadily advancing and may eventually become a key factor in the future development of California's water resources and a prime element in water supply considerations.

B. Some Social Factors Bearing on Water Supply

It is evident that information on all the above-mentioned matters relating to supply is central to the management of water, and researchers from the broad spectrum of disciplines associated with the University of California's Integrated Project have devoted their energies to identifying the kinds of information needed, the jurisdictional and institutional arrangements that now exist (or might be necessary) for its utilizayion, and the social factors bearing on water supply. Noteworthy in this respect is the observation that for almost all of the items listed as important achievements in the Commissioner's Report and for every one of those included by the Department of Water Resources in its decennial report, Water for California, The California Water Plan

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*The California State Water Project Summary, Bulletin No. 132-73, Appendix C, November, 1973, p. 14.

Outlook in 1970, (Bulletin No. 160-70, December, 1970), there are clearly discernible social correlates which, in many instances, may be or could become strongly determinative.

Here, then, is one of the important points of conjuncture between the physical and the social scientists in the Integrated Project. Supply cannot be construed only in terms of measurements of acre feet but, instead, must be considered in a framework that includes places, people, occupations, and life styles. It was mainly in response to those social exigencies that the California State Water Project was initiated, and it is in these terms that implementation and further developments must rightfully and meaningfully be considered.

C. Controversial Issued Related to Water Supply

As anyone engaged in research of almost any aspect of California water soon learns, controversy has accompanied just about every plan made and every step taken. This situation prevails to this day, and all the more so as rapid changes in technology, public attitudes, and life styles have added new dimensions to water as a resource. Even in the days of the Conquistadores, water was no simple matter; much blood was spilled over the rights to it. The history of the California State Water Project is a chronicle of battles, both political and legal. Many of them are still being fought in the courts and outside, too. And, as will become evident when we set forth some of the issues under contention, there appears to be no "right" and no "wrong". In fact, it is rather difficult, even with respect to such superficially mundane matters as supply, to screen out the almost built-in advocacy positions.

To present the official point of view as it appears in reports of the Commissioner would in itself represent a kind of taking sides, for it would imply that either this was the right way to proceed or that there was no respectable alternative. What becomes very apparent in our research is that there do persist serious disagreements, some of which are still under litigation, that the discerning voices are not at all limited to "eco-freaks" but emanate, in fact, from duly-accredited jurisdictions within the "water Establishment" itself, and that there are still many unresolved issues. Acknowledgement of the existence of controversy is a necessary ingredient of this report of our research findings, for to do otherwise, i.e., to accept official statement as undisputed givens would be to ignore the reality of the social environment. It is on the assumption that decisions must be made and that more timely, more complete, and perhaps more cost-efficient information may help make wiser decisions that we shall continue to maintain a neutral posture with respect to the issued being argued.

With respect to supply, for example, the Department of Water Resources, states that surface water resources are ample to meet foreseeable statewide needs on an overall basis, but that they are "maldistributed geographically with respect to areas of need",* with

*Water for California, The California Water Plan Outlook in 1970, op cit, p. 63.

75 percent of the water resources located north of the Sacramento-San Joaquin Delta, while 75 percent of the requirements occur south of the Delta. The California State Water Project, of which the Feather River Project is the first step, was conceived to conserve surplus water supplies in the northern portion of the State and convey them to areas of deficiency in central and southern California. It is intended for interseasonal as well as geographical transfer. Water is conserved in the winter and early spring and used in the summer and fall when rain is scarce in California. Little would be accomplished in reviewing here the enormous, bitter, and enduring criticism generated by the California Water Plan. For purposes of this report, and to illustrate the point, made earlier, that almost all of the important achievements included by the Commissioner in the decennial report had clearly evident social aspects, it would be useful to examine several of them.

1. Increased Availability of Water -- A Blessing or a Curse?

One major accomplishment of the State Water Project was: "It is conserving and delivering water from Plumas County to Los Angeles County for Californians' use in their homes, farms, and factories". This, according to the geographers in the Integrated Study, may be a mixed blessing. Their studies of expanding urbanization indicate that availability of water is a prime factor in the intrusion of man into the desert, often with irreversible ecological results. Moreover, the growth and spread of populatin in the Los Angeles area have served as so unfavorable an example to other parts of California that voters in Marin County recently used limitation of water as an instrument to discourage regional development. They overwhelmingly defeated a bond issue proposed for the Water District. The implications were clear: water planning could be made tantamount to growth control; and Utility Districts are becoming the key target. When a bond issue is turned down, it is really a public expression of a moratorium on growth.* Their position is epitomized by the statement quoted in the National Water Commission's report** and attributed to the governor of one of the western states: "Visit us but don't stay!".

2. The Question of Preferential Water Rates for Farmers

With water for domestic consumption commanding a much higher price than is paid by agricultural users, there are unmistakable economic forces at work influencing policy with respect to supply. Metropolitan and industrial use of water are growing steadily, and not

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*This is a trend just beginning to surface, and one that must be taken into serious account in decisions about water resources. "Land Use and Utility Districts" has been the theme for several conferences in California and is beginning to appear as a more and more frequent agenda item in the meetings of official bodies.
**Water Policies for the Future, Final Report to the President and to the Congress of the United States by the National Water Commission, Washington, D. C. June, 1973, p. 1.

only do they pay two to three times as much for water, but they also
are gaining representation as reapportionment reflects the shifting
urban-rural ratio. In the current calculus, cities may appear to be
more cost-effective; the question then to be faced will be "who will
provide the food?". Right now, this matter has become a crucial issue
in Alameda County, where proposed legislation could force farmers to
pay at least 80 percent of the price paid by industrial, commercial,
and residentail users. This would nearly double the amount that farmers
now pay for the water they pump out of their land to water crops. The
spokesman for industry is vice president of a sand-and-gravel firm.
He voices the classic argument of those who have objected against
"bargain water rates" for farmers. "The price of water has increased
for us, but farmers haven't had to share in that increase. Why should
our business subsidize theirs?". Action on the bill will occur in
January, 1974. What happens then is crucial for the farmers of southern
Alameda County, once the largest producer of high quality cauliflower
and still one of the great flower-growing regions of the state. That
water management policy could precipitate a headlong collision between
farmers and the bulldozers of the subdividers and developers is an
eventuality not mentioned in the official records, although it is
suggested in a publication of the U.S. Geological Survey.*

3. The Question of Recreational Benefits

Another accomplishment of the State Water Project may be noted,
viz, "It is providing family recreation and sport fishing in northern,
central, and southern California". The 1970 amendment to the Davis-
Dolwig Act provides for a total of $60 million in general obligation
bonds "to finance the design and construction of recreation, fish, and
wildlife enhancement for the State Water Project -- $54 million to be
allocated to the Department of Parks and Recreation and $6 million to
be allocated to the Department of Fish and Game and the Wildlife Con-
servation Board."**   What kind of "family recreation" this investment
will buy is elucidated in the Department of Water Resources Bulletin
No. 132-73, The California State Water Project in 1972 (p. 53):

> At Lake Oroville, concessions by the Southern Cal-
> ifornia Financial Corporation, under contract with
> the Department of Parks and Recreation, will be opened
> to the public during the early spring of 1972 (pri-
> marily at Bidwell Canyon. The development will
> feature:

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*William J. Schneider, David A. Rickert, and Andrew M. Spieker, Role of
Water in Urban Planning and Management, U.S. Dept. of the Interior,
Geological Survey Circular 601-H, Washington, D. C., 1973.
**Outlook op cit, p. 53.

- A kiosk (pay station).

- Six boat-launching lanes, with parking for more than 250 cars.

- A marina, with 200 parking spaces and 100 boat slips.

- Seven boat storage buildings.

- Two fish cleaning facilities.

- Eighty-two trailer hookups.

- Camper store and snack bar.

- Three restroom buildings.

Table 2.7 which is extracted from the report, reflects the way in which "recreation" is calculated:

TABLE 2.7
CHRONOLOGICAL ACCOUNTING OF THE INTENSITY OF
RECREATIONAL USE IN FOUR MAJOR AREAS OF THE
FEATHER RIVER BASIN AND ITS IMMEDIATE ENVIRONS

Calendar Year	(In recreation days)				
	Frenchman Lake	Antelope Lake	Lake Davis	Oroville-Thermalito	Total
1962	30,000	---	---	---	30,000
1963	105,000	---	---	---	105,000
1964	320,000	11,600	---	---	331,600
1965	474,000	25,800	---	---	499,800
1966	360,000	105,000	---	---	465,000
1967	306,900	95,100	---	---	402,000
1968	312,000	54,300	210,000	288,000	864,300
1969	394,500	99,300	439,300	516,400	1,449,500
1970	396,800	76,400	419,700	483,400	1,376,300
1971	344,400	71,400	549,800	546,900	1,512,500
Total thru 1971	3,043,600	538,900	1,618,800	1,834,700	7,036,000

(Source: Water Resources Bulletin No. 132-72, June 1972, p. 52.)

The reasoning applied to evaluation of the net benefits from flat water recreation development goes like this:

> The evaluation of a project for recreational bene-
> fits is usually made in terms of visitor-days of
> use converted to and expressed as a monetary value.
> The net number of visitor days of use of a project

is determined by deducting the number of visitor-
days of use expected without the project and without
additional recreational facilities, from the number
of visitor-days of use anticipated with the project.
The net economic worth or benefit of recreation use
is derived by multiplying visitor-days of use by the
assigned value of a visitor day of use.[*]

Using "recreation days" as a basis for computing benefits is,
however, not a universally accepted notion. A review of the literature[**]
reveals large areas of disagreement among economists and between econ-
omists and resource planners on how benefits of recreational services
can be assessed. Since they fall into the category of "nonmarket,
intangible, or incommensurable", they elude the usual monetary measures.[***]
Such gross-use estimates do not reveal who receives the direct recreational
benefits of the facilities. Howard E. Ball, in a critique of the user-
day concept of measurement[****] underscores the fact that there is no
zero-cost public outdoor recreation, that taxpayers always have to
pay. He points out, moreover, that to be a "beneficiary" you have to
want the particular kind of outdoor recreation and must have "the
psychosomatic and financial wherewithal to go get it. It would not
come to you, except vicariously".

No allowance is made in the recreation-day benefit calculations
for social costs, such as road traffic to the sites, environment dam-
age wrought by intensive usage, etc. Nor is there recognition of prior
or substitute recreational uses of the area without development. For
example, the point has been made[*****] that the substitution of slack
water recreation does not necessarily compensate for the loss of the
many recreational services of a free-flowing stream-white water canoe-
ing, float-trip boating, fishing from the bank, wading, and the like.

[*]California Department of Water Resources, Oroville Reservoir, Thermalito
Forebay, Thermalito Afterbay, Bulletin No. 117-6, Sacramento, 1966, p. 13.
[**]Lionel J. Lerner, "Quantitative Indices of Recreational Values", Water
Resources and Economic Development of the West: Economics in Outdoor
Recreational Policy, Report No. 11, Conference Proceedings of the Committee
on the Economics of Water Resource Development, Western Agricultural
Economics Research Council jointly with the Western Farm Economics
Association "Reno, University of Nevada, 1962, pp. 55-80.
Marion Clawson and Jack L. Knetsch, Economics of Outdoor Recreation,
Resources for the Future, Ind., Baltimore, The Johns Hopkins Press, 1966.
Ruth P. Mack and Sumner Myers, "Outdoor Recreation", in Measuring Benefits
of Government Investments, Ed., Robert Dorfman, Washington, D. C., The
Brookings Institution, 1965, pp. 71-101.
[***]Frank H. Bollman, "On the Demand for Water in its Natural Environment",
in California Water, ed., David Seckler, Berkeley, University of California,
Press, 1971, pp. 84-108.
[****]Robert Dorfman, ed., Measuring Benefits of Government Investments,
op cit, p. 105.
[*****]Bollman, op cit, p. 95.

The same difficulties of assigning values of costs and benefits arise in connection with the controversy over the preservation of "wild rivers" in their pristine state. The battle lines are drawn between conservationists and developers and many are the legal suits. The value-preference structure of one set of advocates as against others is imposed on the total population. In the allocation of recreation resources in general, there are the "recreation Brahmins who commune with the far wilderness as against the peons and untouchables who pant for the hot sands and hot dogs of public beaches."**

4. Should the Peripheral Canal Be Built?

Perhaps nowhere in the entire spectrum of California water is there so much divergence of position between the Commission and other sectors of the "water establishment" (and certain public groups as well) as on the issue of the Peripheral Canal. Controversial and fraught with political overtones, special interest pressures, clouded issues and intentional and unintentional obfuscation, the Peripheral Canal looms as the key point in the supply aspects of the California Water Plan. The California State Water Project Summary (Commissioner's Report) of November, 1973** contains a low-keyed statement under the heading "Future construction beyond the 1973 Project facilities":

> The Peripheral Canal, for protection of the Delta environment (particularly the striped bass and salmon fishery) and for more efficient transfer of project water across the Delta to the California Aqueduct.

The proposed Canal is a $220 million project that is designed to tap the Sacramento River before it enters the Delta and to transport water to the diversion pumps in the Southern Delta. Officially, the reasoning behind the plan is that the Canal is the best solution to some serious water quality and fishery problems arising from the diversions in the Southern Delta. At one of the most recent meetings of the California State Water Commission, Mr. Teerink, the State's chief water engineer, reiterated the positive purposes of the canal in four major categories: (1) water quality, (2) improved flow conditions in the channel; (3) enhancement of quality in the east end of the Delta; and (4) correct flow direction.

The opposing position was presented by a spokesman for the Contra Costa County Water Agency. Citing a report by the Stanford Research Institute and testimony by a myriad of experts before the U.S. Council on Environmental Quality (February 1971) he stated summarily:

*Howard E. Ball, in Dorfman, op. cit., p. 107.
**Bulletin No. 132-73, Appendix C.

The County's official position as to the Peripheral
Canal is two-fold. Firstly, it has concluded, after
a careful consideration of this mammoth project,
that it is most dangerous and ominous insofar as
the Bay-Delta Estuary is concerned and one which
could (and in our opinion would) result in enormous
degradation and irreparable devastation in and to
the Bay-Delta System and its water resources.
Neither its authorization nor designing nor construc-
tion should be further considered until the many
scientific investigations and studies of its impact
upon the Bay-Delta System (as recommended by various
disinterested experts such as the Stanford Research
Institute) are first completed and thoroughly
evaluated.*

Making the point that the beneficial uses of the water in the Delta
must be protected by law, Mr. Port referred to litigation now in the
superior court in California as to which level of authority, the U.S.,
through the Bureau of Reclamation, or the State bore the legal respon-
sibility of protecting the Delta against increased salinity. Mr. Port's
contention was that statutory obligations vis-a-vis the Delta and
protection of it were already proper and binding and that new legisla-
tion from a Congress, in which re-alignments of rural vs. urban and
southern vs. northern interests were already manifest, could have a
deleterious outcome.

The Environmental Protection Agency report, prepared by a scientific
and engineering team, recommended that the 43-mile-long canal not be
built and, further, that all water resource development under the State
Water Project be halted until the plan could be subjected to a
thorough re-evaluation. This position has received strong endorsement
from conservationists, as well as from the Contra Costa Water Agency,
many civic groups and Representative Jerome R. Waldie. The EPA task
force said that the building of the canal would only work to the benefit
of the Southern California water buyers because it would postpone their
need for water reclamation and compensate for the decline of Colorado
River Water quality. They stressed the point that "export of the Delta
water raises the risk of harm to the ecology of the Delta and San Fran-
cisco Bay, which depends on the flushing action of the river water."**

The California Water Commission's position came through unmistak-
ably during the October 5, 1973 meeting. One of the members urged
immediate action on construction of the canal. He said that sufficient
information had been gathered and that the plea for more evaluation was
really a delaying tactic. Challenging claims that fish and wildlife

*Statement of Mr. Jack Port regarding Preservation, Protection and
Enhancement of the Water Resources of the San Francisco Bay-Delta
Estuarine System, before the California Water Commission, Concord,
California, October 5, 1973, p. 5.
**as reported by Dale Champion in the San Francisco Chronicle,
September 28, 1973.

would-be endangered, he cited instances where California Water Project developments had actually improved fishing, specifically where the Shasta Dam had contributed to conditions superior to the previous natural state in the Sacramento River. Questioning the validity of the Committee of Two Million as truly representative of the fishermen in the State, he recalled that he had found his own name listed erroneously as a member of this pressure group constituted to demand re-appraisal of the California Water Project. He did not want to be identified with these "fish freaks," and stated that the Commission was "tired" of the derogation. He then expressed the opinion that the Fish and Wildlife Divisions should "do better studies," presumably to show that damage and disaster were not the results of the projects completed and contemplated.

On this point, we were able to supply the Commission's secretary with an item that proved to be of interest to all concerned. It came from the Wall Street Journal of September 4, 1973 and told of efforts in the Northwest to save salmon from the dams and pollution on the Columbia River. Fishladders, such as had been discussed at the meeting in connection with California's problems, had been built at a cost of $180 million. These helped the fish climb over about 40 dams, but the runs are not healthy. "Afflicted by predators, confused by slow water, and killed by a dam-caused phenomenon called nitrogen super-saturation, which gives fish a lethal version of the bends, the ranks of salmon and steelhead trout reaching spawning grounds have declined." In 1966, two utility companies and the Corps of Engineers spent $16 million on elaborate fish ladders at six new dams. They have been scrapped. Downstream migration is even more of a problem. In 1970 it was discovered that nitrogen super-saturation was killing 70 percent of the young salmon at three new power and navigation dams built by the Corps of Engineers on the Snake River, an important tributary of the Columbia. Responding rapidly, the newspaper report continues, the Corps used $7 million of the allotted $12 million emergency appropriation to install slotted bulkheads in the dams. The bulkheads put into operation last year and soon dubbed "The Holey Gates," dispelled the gas well enough, but fish passing through them were chopped to bits.

For the Commission, the main item of concern still appeared to be how recreational aspects of the California Water Project should be paid for. They must be paid for by someone. There was the suggestion that, to the extent that benefits can be quantified, the user should pay; where indefinite, then the public would have to. If the figure of the Committee of Two Million can be taken as accurate, then it was estimated that fishermen comprise about 2 percent of the population and that they as beneficiaries, and not the golfers and other sportsmen, should be made to pay for fishery enhancement. The revenue from stamps and licenses was offered as evidence that they already pay, but even this turned out to be inequitable and inadequate. The consensus among the Commissioners appears to be that sportsmen have derived great benefit from the California Water Plan, but that they oppose most projects and do not pay nearly what they should. Further study on this matter was recommended.

D. Objectives of Our Future Studies

The developing story of the Peripheral Canal as an example of the social-political-economic complex of factors that impinge on decisions relating to water resources can only be mentioned in vignette form in this report. We are trying to convey the magnitude and intricacy of the web of forces that enter into managing the water resource so as eventually to learn how, where, and when remote sensing data acquired by ERTS and other vehicles could be incorporated into the decision-making processes with respect to supply.

VII. SUMMARY

It is apparent from the material contained in this Chapter that the study is progressing rapidly to the point where information requirements of the Department of Water Resources will be defined and the potential of remote sensing to satisfy some of those requirements can be evaluated. In this effort, a number of people in the Sacramento office of the Department of Water Resources have been particularly helpful and have given quite willingly of their time in assisting the investigators and supplying written material critical to our work. Specifically, thanks are due to John Anderson, Ron Bachman, John Baughex, Barry Brown, Jim Doody, Charles McCullough, Clayton Magonigal, William Mierke, Lawrence Mullnix, and Glenn Sawyer for their assistance.

As our work progresses in the identification of information requirements we will move on to the next step, i.e. an attempt to enumerate benefits or economic worth which can legitimately be ascribed to various types of information and to ascertain what the costs of acquiring such information are using currently available methodology. For example, it is felt that the strategy employed in determining water release schedules at the Oroville facility are well understood, and that the critical information inputs, specifically streamflow forecasts and weather forecasts have been defined. The question remains, however, as to what the marginal benefit attributable to an incremental improvement in forecast accuracy or timing might be. In addition, it is felt that considerable effort should be expended during the next few months to more specifically ascertain information requirements of those responsible for management of the watershed areas (as opposed to management of water control facilities), and monitoring of water quality in those areas affected by the California Water Project. This would, of course, then be followed by an evaluation of information value and cost similar to that described above.

Concurrent with these studies, both the CRSR and Algazi groups are continuing in the development of advanced image processing and interpretation techniques for use in extracting environmental information from remote sensing data. This work, described in Section V of this Chapter, will ensure that our evaluation of the usefulness of remote sensing techniques in contributing to the solution of water management problems will be based on the most up-to-date and efficient interpretation methods possible.

The specific details of the investigation that are planned for the rest of the fiscal year, as well as those proposed for the next fiscal year are detailed in the Introduction to this chapter. In particular, Figure 2.2 illustrates the planned activities of each of the groups involved and the tentative time schedule of their activities on various aspects of the study. Thus the overall scope of the project is described in the Introduciton, while the progress made to date is presented in the ensuing sections of the chapter.

Chapter 3

WATER DEMAND STUDIES

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I. INTRODUCTION

A. Location, Scope and Objectives of the Water Demand Studies

     The areas of focus of the Santa Barbara and Riverside groups in
conducting their water demand studies are the Central and Southern
California regional test sites, respectively. These areas have been
the locales of most of the previous work accomplished with respect
to this integrated study by our two groups. However, in accordance
with the reorientation of the overall study, major emphasis within
our geographic areas is being given to water demand aspects. In both
the Central and Southern California regional test sites, sub-areas
have been selected for use in the making of detailed studies. Within
each of these sub-areas an in-depth evaluation currently is being made
by our two groups as to the capability of remote sensing systems to
provide pertinent data relative to water demand phenomena. These
more limited sub-areas are (1) Kern County and the San Joaquin Basin
for the Santa Barbara group, and (2) the Chino-Riverside Basin and
the Imperial Valley for the Riverside group. (See Figure 3.1)

     1. The rationale for selecting these sub-areas included the
following: Much of our previous remote sensing research had been
conducted in these areas and hence a great deal of remote sensing
imagery and pertinent ground truth for these areas already was
available to us.

     2. Kern County, one of the study areas, is under the juris-
diction of the Kern County Water Agency (KCWA) which is responsible
for the forecasting of water demand (on both a short- and long-term
basis) as well as the allocation of water to 15 separate water dis-
tricts within the county (2 municipal and 13 rural districts). In
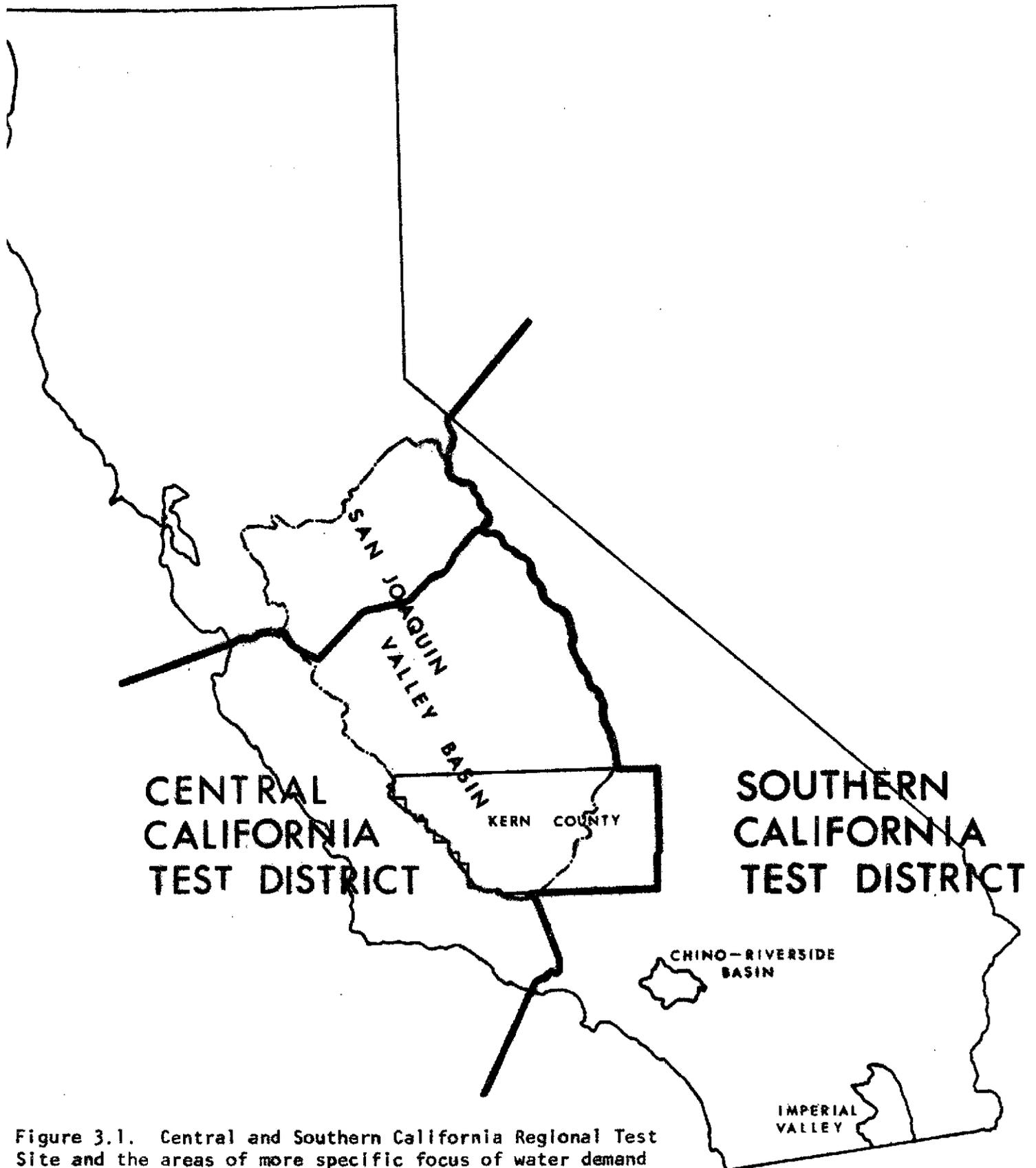order to perform its job effectively, the KCWA has developed an

Figure 3.1. Central and Southern California Regional Test
Site and the areas of more specific focus of water demand
prediction studies: Kern County, the San Joaquin Valley
Basin, the Chino-Riverside Basin and the Imperial Valley.

operational water demand model upon which water management decisions are currently based. Consequently, it was decided that this would be a "tailor-made" area for a detailed study of the use of remote sensing techniques for generating input information into a water demand model. Because the area is one of agricultural expansion, effective water resource management is made all the more important. Furthermore, the GRSU has an excellent working relationship with personnel of the KCWA.

3. The San Joaquin Valley Basin, another of the study areas, was selected because the California State Department of Water Resources has water resource management jurisdiction over this area and has developed a water demand model which is utilized as a data source in their management decision process.

4. The Chino-Riverside Basin which is the third study area, was selected because it is representative of areas in which cities (in this case metropolitan Los Angeles) are expanding into nearby agricultural areas. As a result of this expansion, such areas typically undergo important changes in the nature of their demands for water and hence in the nature of the water demand model applicable to them.

5. The Imperial Valley was selected as our fourth study area because it appears to be a "truly controlled arid environment" within which virtually all of the water needed for crop production must be applied by irrigation. Lack of a local source of water (e.g., wells) makes it possible in this area to measure all applied water by monitoring the sole water import facility (the All-American Canal). This fact facilitates the testing of water demand models which have been developed by Riverside personnel based on previous studies by the Department of Water Resources (1955) and the University of California Extension Service, Imperial Valley.

B. Investigation Tasks

In our study of the sub-areas listed above, special attention was given to each of the following aspects: (1) a determination of the critical parameters that constitute inputs to water demand models; (2) a determination as to which of these parameters are amenable to study and/or inventory through the use of remote sensing techniques; (3) an evaluation of the usefulness of remotely sensed data as inputs to the models; (4) a comparison of the costs and benefits associated with the obtaining of such information using remote sensing techniques vs. conventional techniques; and (5) an evaluation of the potential economic and social impact of using remote sensing techniques for generating water demand data.

Owing to the recent reorientation in the emphasis of the integrated project, few of the tasks described above have as yet been evaluated in depth. Significant progress has been made, however, and the cooperation which has now been established with user groups

will insure thorough coverage of all of the above-listed topics in our future reports.

Just as the Feather River Watershed in Northern California is predominantly an area of water supply (as described in Chapter 2) so our test areas in Central and Southern California are predominantly areas of water demand. Furthermore, it is as a result of the transport of this water supply from Northern California to needy areas in Central and Southern California that much of the water demand of these latter areas is satisfied. This is one of several respects in which a high degree of integration truly exists in our overall "Integrated study."

II. WORK PERFORMED BY THE GEOGRAPHY REMOTE SENSING UNIT,

SANTA BARBARA CAMPUS

The major research activities of the GRSU during this reporting period include: (A) The completion of land use and vegetation maps which (although part of our pre-orientation research) provide valuable inputs for water demand models, and (B) the determination of critical inputs for water demand models. The latter task purposely paralleled similar studies of the Riverside group for reasons stated later. It entailed (1) the establishment of close working relations with agencies that have major roles not only in the prediction of water demand but also in making overall water management decisions within the Central·Regional Test Site; (2) examination of the KCWA Hydrologic Model currently being used; (3) understanding the construction of that model and the assumptions on which it is based; and (4) analysis of that model and of remote sensing inputs to it as applied specifically to agricultural lands inventories and perched water tables and associated soil salinity problems.

In part C of this section we will discuss our proposed future work.

A. Completion of Land Use and Vegetation Maps

Information on land use and vegetation types usually is essential as input for a water demand model. GRSU has been able to show that it is possible to map land use and vegetation within its primary study areas, utilizing both ERTS-1 satellite imagery, and high altitude color infrared photography, the latter being at a scale of 1:120,000. The specific focus of the work performed under the NASA Grant before the recent reorientation was on establishing a data base for land use and vegetation for the entire Central Regional Test Site -- an area of approximately 50,000 square kilometers. These data base maps, because of their accuracy, have provided us during the present reporting period with a means for rapidly inventorying, evaluating and assessing the significance of the distributional patterns of important input parameters to water demand models.

The original maps were constructed manually on mylar overlays using stereoscopic viewing and eight times (8x) hand magnifiers from 1:120,000 scale, color infrared photography flown by NASA during April 1971 and April 1972. The classification schemes employed in

the construction of these maps are shown in Tables 3.1 and 3.2 (the derivations of these schemes are explained in previous reports) and the resultant maps (which are divided into sections owing to their large size) are seen in figures 3.2, 3.3 and 3.4 (land use); figures 3.5 through 3.11 (coastal vegetation); and figure 3.12 (west side vegetation). As can be seen from these maps, it was possible to extract considerable information from the aerial photography and to translate this information into thematic maps of considerable value not only to water resource managers, but also to other resource management agencies. Furthermore, these studies, especially those dealing with land use and land use change, showed promise that such information could provide the basis for a decision to begin construction of maps of agricultural land use (irrigated agricultural holdings) in Kern County. Furthermore, such information could be used on an operational basis as input into the Kern County Water Agencies hydrologic model.

The production of these maps and their utility will be discussed later. In short, although the generalized maps completed in fulfillment of previous contractural obligation are not at present being used as inputs to water demand models, the experience gained in preparing them has provided us with a firm basis upon which subsequent operational studies of a similar nature can be performed in accordance with the reoriented focus of our study.

B. Determination of Critical Inputs to Water Demand Models

Before remote sensing techniques could be used to generate meaningful inputs for water demand models, it obviously was necessary to determine exactly what types of input were likely to be useful. A report of the work performed by the GRSU in making such a determination is described below in four sections: (1) contact with appropriate user agencies; (2) general discussion of the KCWA hydrologic model; (3) discussion of the construction of the KCWA model; and, (4) model analysis and actual determination of the inputs.

1. Agency contact

Following a period of research concerning the aspects of water resource management, and prior to the actual study of remote sensing inputs, personnel of the Geography Remote Sensing Unit made contact with those agencies (within the Central Regional Test Site) that have water resource management responsibilities and/or related expertise. The initial aim of this contact was to establish a working relationship with the agencies that have a direct and major interest in and responsibility for the coordination of planning for water supply, required distribution systems, and allocational policies. In the GRSU's test region, which is predominantly agricultural, these agencies were the Kern County Water Agency (KCWA) responsible for 15 Kern County water districts , and the California Department of Water Resources San Joaquin Valley District Office (DWR-SJD), responsible for the greater San Joaquin Valley (See figure 3.1). In addition to these contacts, agencies concerned with water-related parameters,

TABLE 3.1.   LAND USE CLASSIFICATION

KEY:

General Category ex. A (Agriculture)
Type within Category ex. t (tree crops)
Specific Type ex. c (citrus)
Total Code: Atc

Note that the more specific notation depends upon ability to identify
and additional types and specific types can be added to the system as
they are encountered.

	CODE
Agriculture	A
Crops	Ac
Grain Crops	Acg (type)
Horticulture	Ach (type)
Row Crops	Acr (type)
Tree Crops	Act (type)
Livestock	Al
Stock farming (beef)	Alsb
Stock farming (sheep)	Alss
Stock farming (dairy)	Alsd
Rangeland	Ar
Pasture (improved)	Arpi
Pasture (unimproved)	Arpu
Extractive	E
Seawater mineral recovery	Es (type)
Petroleum production fields	Ep (type)
Mining Operations	Em (type)
Public Facilities	G
Governmental-administrative	Ga (type)

TABLE 3.1 (Continued)

	CODE
Governmental-military	Gm (type)
Cemeteries	Gc
Protection- Police & Fire	Gf (type)
Hospitals	Gh
Prisons	Gp
Waste disposal (solid & liquid)	Gd (type)
Education	Ge (type)
Parks & Recreation	P
Campground	Pc
Golf Course	Pg
Park	Pp
Stadium	Ps
Marinas	Pm
Resort	Pr
Industrial	I
Primary Conversion	Ip
Steel mill	Ips
Ship building	Ipb
Saw mills (or pulp)	Ipw
Assembly	Ia
Auto	Iaa
Electronic	Iae
Food Processing	If
Canneries-fish	Ifc
Canneries-fruit	Iff

TABLE 3.1 (Continued)

	CODE
Storage	Is
Port warehousing	Isp
Rail warehousing	Isr
Transportation	T
Airports	Ta (type)
Highways	Th (type)
Railroads & Yards	Tr (type)
Canals	Tc (type)
Docks	Td
Commercial	C
Clustered	Cc (type)
Strip	Cs (type)
Residential	R
Single family	Rs
Multi-family	Rm (type)
Non Developed	N
Natural Vegetation	Nv (type)
Idle Land	Ni (type)
Barren Land	Nb (type)
Water Bodies	Nw (type)

Figure 3.2. Section I of land use map of the West Side of the San Joaquin Valley, California constructed from April, 1971, 1:120,000 scale color infrared photography.

Figure 3.3. Section II of land use map of the West Side of the
San Joaquin Valley, California constructed from April, 1971, 1:120,000
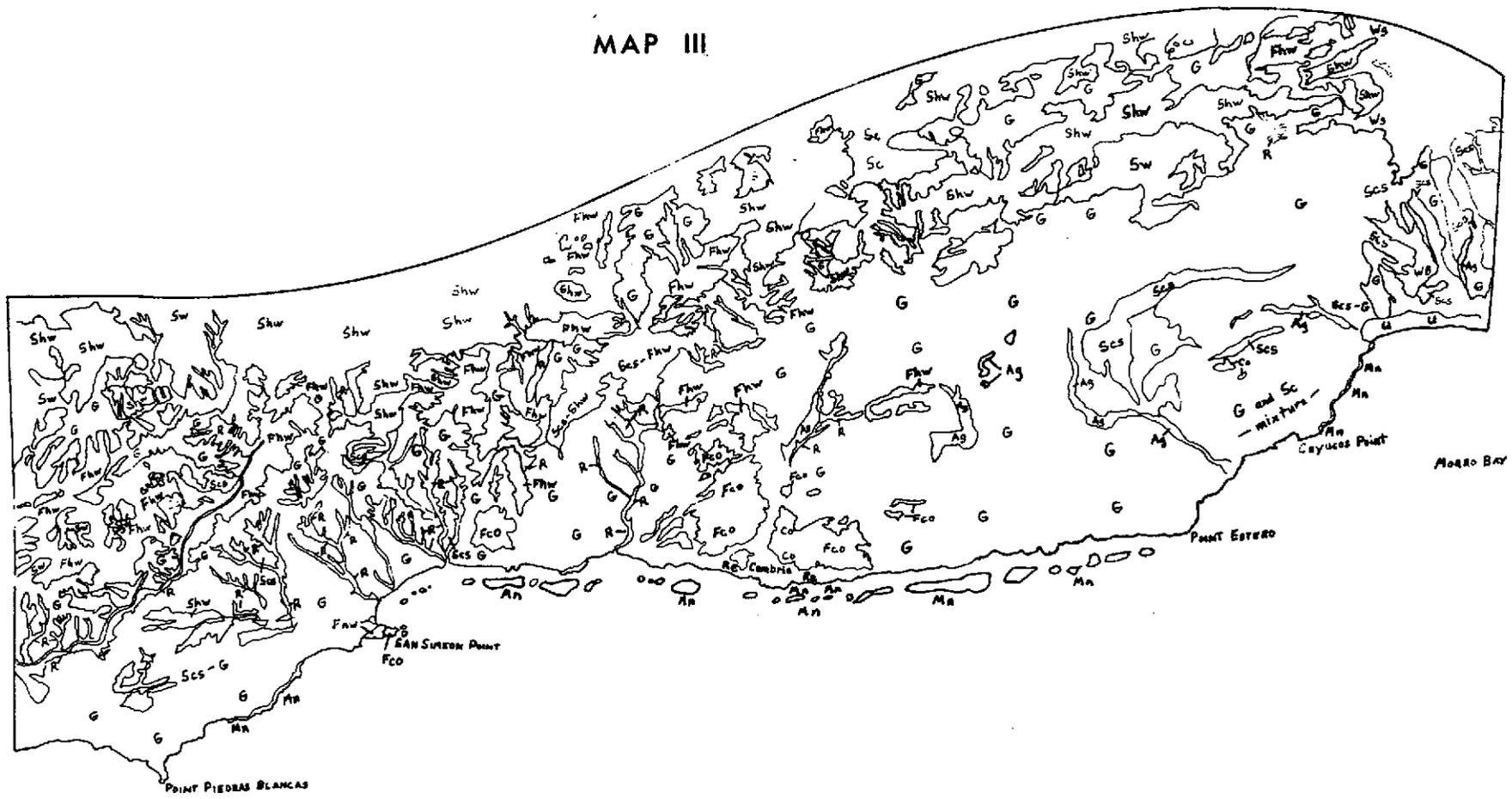scale color infrared photography.

Figure 3.4. Section III of land use map of the West Side of the San Joaquin Valley, California constructed from April, 1971, 1:120,000 scale color infrared photography.

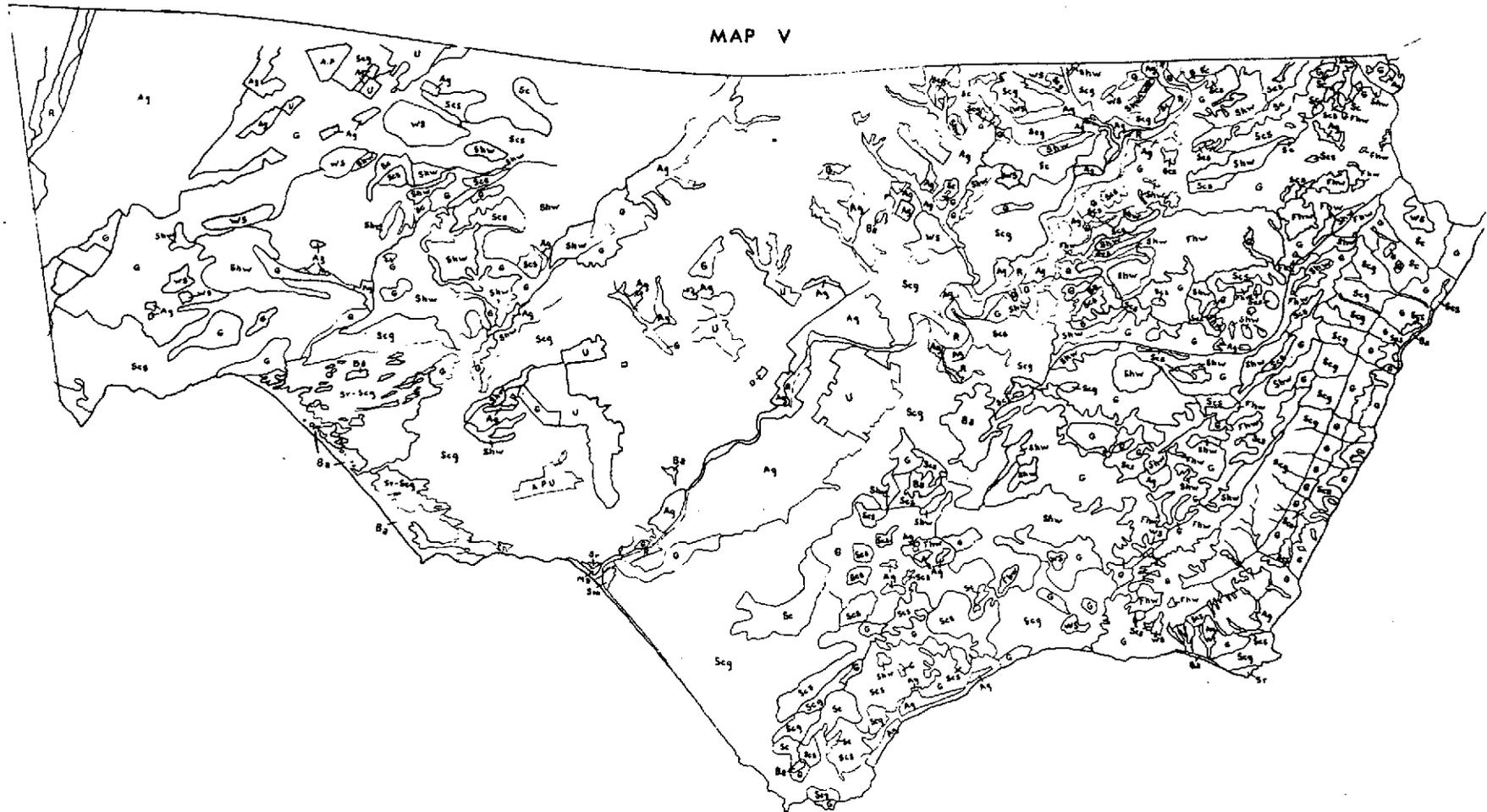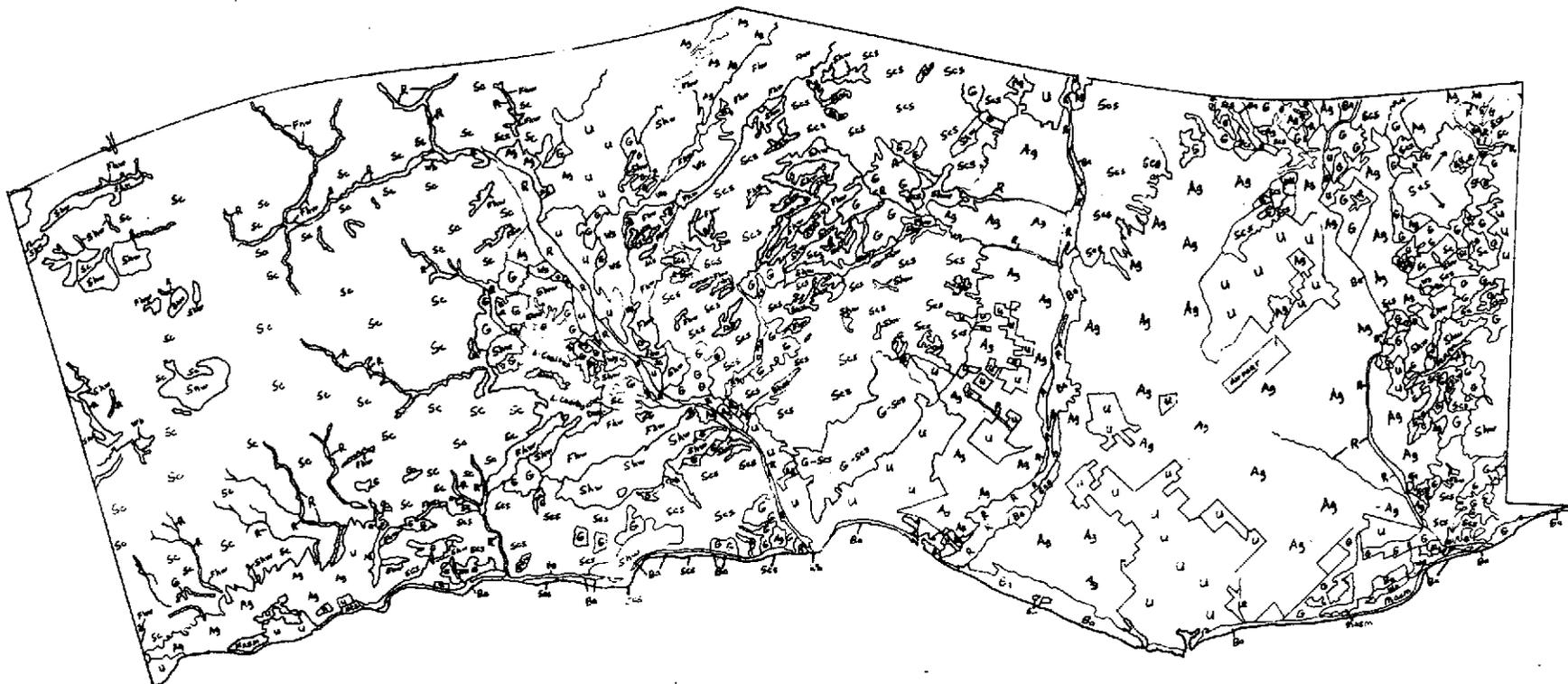Figure 3.5. Coastal Region Vegetation data base map I. Constructed from April, 1971, 1:120,000 scale color infrared photography.

MAP II

Figure 3.6. Coastal Region Vegetation data base map II. Constructed from April, 1971, 1:120,000 scale color infrared photography.

MAP III

Figure 3.7. Coastal Region Vegetation Data Base Map III. Constructed from April, 1971, 1:120,000 scale color infrared photography.

MAP IV

Figure 3.8. Coastal Region Vegetation data base map IV. Constructed from April, 1971, 1:120,000 scale color infrared photography.

MAP V

Figure 3.9. Coastal Region Vegetation data base map V. Constructed from April, 1971, 1:120,000 scale color infrared photography.

MAP VI

Figure 3.10. Coastal Region Vegetation data base map VI. Constructed from April, 1971, 1:120,000 scale color infrared photography.

MAP VII

Figure 3.11. Coastal Region Vegetation data base map VII. Constructed from April, 1971, 1:120,000 scale color infrared photography.

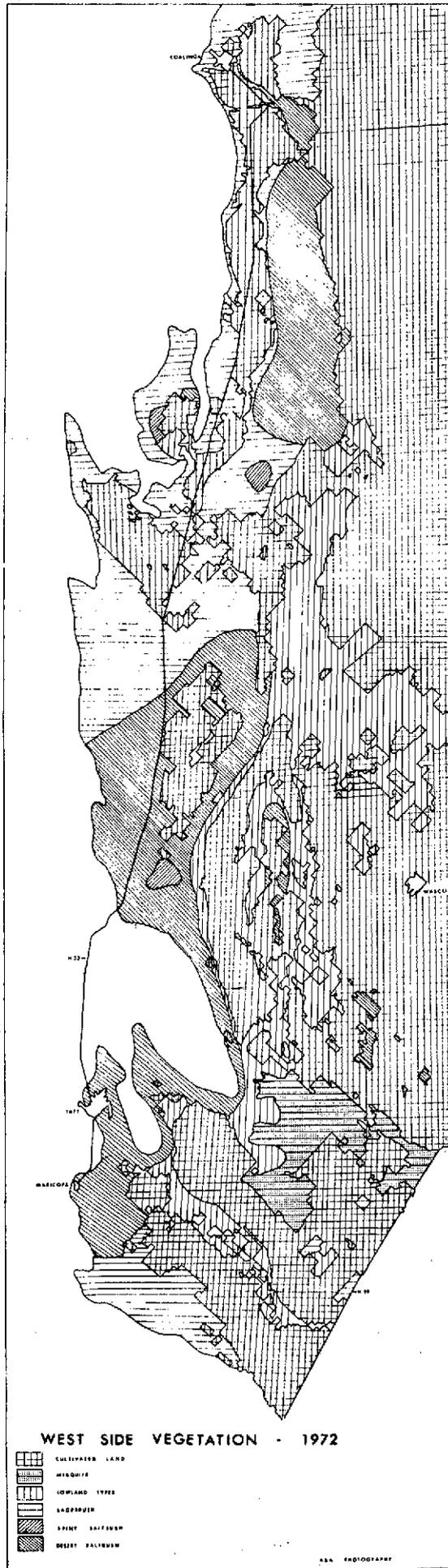WEST SIDE VEGETATION - 1972

CULTIVATED LAND
MESQUITE
LOWLAND TYPES
SAGEBRUSH
SPINY SALTBUSH
DESERT SALTBUSH

Figure 3.12

3-19

TABLE 3.2 NATURAL VEGETATION CLASSIFICATION

Plant Community	CODE
I. Aquatic	
A. Marine (Aquatic)	M
1. Nearshore (Kelp and seaweed)	Mn
2. Intertidal	Mi
B. Freshwater (Aquatic)	Fw
C. Marsh	Ma
1. Salt Marsh	Ma_{sm}
2. Freshwater Marsh	Ma_{fm}
II. Terrestrial	
A. Barren	Ba
B. Strand	Sr
C. Grassland	G
1. Coastal Prairie	Gcp
2. Valley Grassland	Gvg
3. Meadows	Gme
D. Woodland-Savanna	Ws
E. Scrub	S
1. North Coast Shrub	Snc
2. Coastal Sagebrush (soft chaparral)	Scs
3. Cut-over Forest	Scf
4. Chaparral (hard chaparral)	Sc
5. Scrub-Hardwood	Shw
F. Forest	F
1. Hardwood	Fhw
2. Mixed Evergreen	Fme
3. Coniferous	Co
a. Redwood	Co_{rw}
b. North Coast	Co_{nc}
c. Douglas Fir	Co_{df}
d. Pine Cypress	Co_{pc}
G. Riparian	R

or having an expertise in crops, soils, hydrology modeling, etc., were also contacted on an "as-needed" basis to aid, primarily, in the interpretation and definition of various environmental para- meters. Notable among these ancillary contacts were: United States Department of Agriculture-Soil Conservation Service (USDA-SCS) at Davis (for soils); University of California Agricultural Extension Service (UC-AES) at Bakersfield (for soils and cropping practices); Kern County Agricultural Commission at Bakersfield (for crop acreages in Kern County); and, Tempo (General Electric subsidiary) Center for Advanced Studies at Santa Barbara (for hydrologic modeling).

As might be expected, personnel of the various agencies contacted were generally unfamiliar with remote sensing and its capabilities -- some of them overestimating, but most of them underestimating its value as a data source. Accordingly, one of our most productive and thorough approaches has been to become familiar with and to analyze the on-going work and past publications of these agencies with special emphasis on developing lists of inputs to relevant models prior to actually meeting with personnel of the agencies and dis- cussing their possible use of remote sensing techniques for generating such data. By following this procedure, it was possible for us both to maximize the gathering of information regarding specific data inputs into water demand models and to familiarize the various agencies with the potentials of remote sensing technology as a solution to some of their data generation problems.

2. The KCWA hydrology model

The computer model, developed by KCWA with programming aid from Tempo of Santa Barbara, is not a water demand model, per se, in that its major purpose is the total simulation of water transmission and storage throughout most of the Kern County water basin. Therefore, the model might be more appropriately referred to as a "water account- ing model." Because Kern County is mainly a "water-deficit" environ- ment, that is, its arid climate and extensive agriculture holdings require extensive importation of water, it seems appropriate to examine all the model inputs for possible remote sensing applications.

Within the KCWA hydrology model, water demand is reflected in the amounts of water applied or consumed by various users throughout the county -- such as municipalities, industrial users, agricultural- ists, etc. With respect to demand, the model can be categorized as being "static" in that some important and dynamic variables such as changes in irrigable (but not irrigated) lands, water pricing, agricultural technology, and markets, are not incorporated into the model. Consequently the deduced demand is valid only for the values of these variables that exist during a given study period. Thus, a more timely and more frequent means of updating such inputs, possibly through the use of remote sensing could bring about con- siderable improvement in the present model. At present, the model is being verified by the Kern County Water Agency through the use of historical data collected between 1958 and 1966. When this work has been completed, short-term projections of water use can be computed and compared with actual conditions. Ultimately, it is anticipated

that some of the above mentioned variables will be incorporated into the model, thereby allowing longer term projections to be made. The addition of these factors will add the required dynamic dimension to predictions of water demand. As stated by the Kern County Water Agency:

> "Efficient use of the model in the prediction of future hydrologic conditions is dependent upon accurate collection of current land/water use information and a complete water supply inventory."

Other anticipated uses of the model include water quality studies, and determinations of future zones of benefit taxation schedules.

3. Construction of the KCWA Model

The construction of the model currently being utilized by the KCWA, is based upon the following assumptions: (1) that a real-world water basin consists of interbedded layers of sands, clay, silt and gravels which are saturated to some level with water and upon which a variety of land uses are superimposed; and, (2) that the mathematical modeling of such a complex, heterogeneous mass requires that the total complex be subdivided into more workable units of smaller size and greater homogeneity.

These subdivisions and the assumptions related to them include: (1) the subdivision of the surface area of Kern County into 235 polygons or nodal areas, most of which represent one quarter of a township or nine (9) square miles; (2) the designation of a center point in each polygon which is termed its "node" (all events or circumstances occurring in the area corresponding to a given polygon are assumed to occur at the node); and (3) the movement of water from one polygon to another is assumed to occur along the lines or "flow paths" connecting the nodes. The insert in Figure 3.13 illustrates how the system operates and depicts how the area of Kern County has been subdivided. It is on the basis of these subdivisions, that data are collected as input to the model, i.e., data are collected for each nodal region. The final model also takes into account complications resulting from the existence of multilayered aquifers, subsidence, perched water tables and other related phenomena.
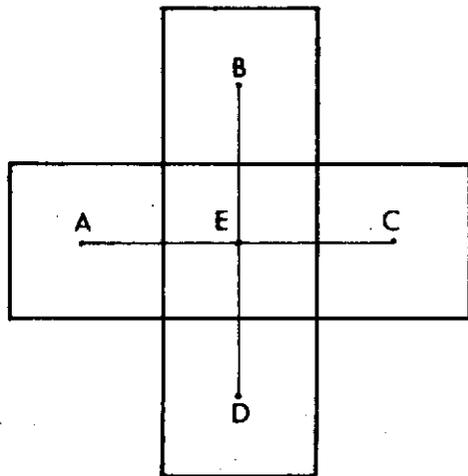
4. Model Analysis

Based on an analysis of the KCWA model, listings of all external quantities that serve as inputs to the model have been compiled and analyzed by GRSU personnel. With the aid of KCWA personnel, the following steps were taken in the analysis of the model: (1) related data inputs were grouped and categorized; (2) all terms in the model were precisely defined; (3) present sources of input data were identified; and (4) preliminary determinations were made with respect to

Figure 3.13. Map showing subdivision of Kern County on which the KCWA Hydrology Model is based.

EQUATION FOR NODE "E"

$$Q_{AE} + Q_{BE} + Q_{CE} + Q_{DE} + Z = \Delta S$$

Q = QUANTITY OF WATER

Z = NET WATER EXTRACTED OR RECHARGED TO THE POLYGON
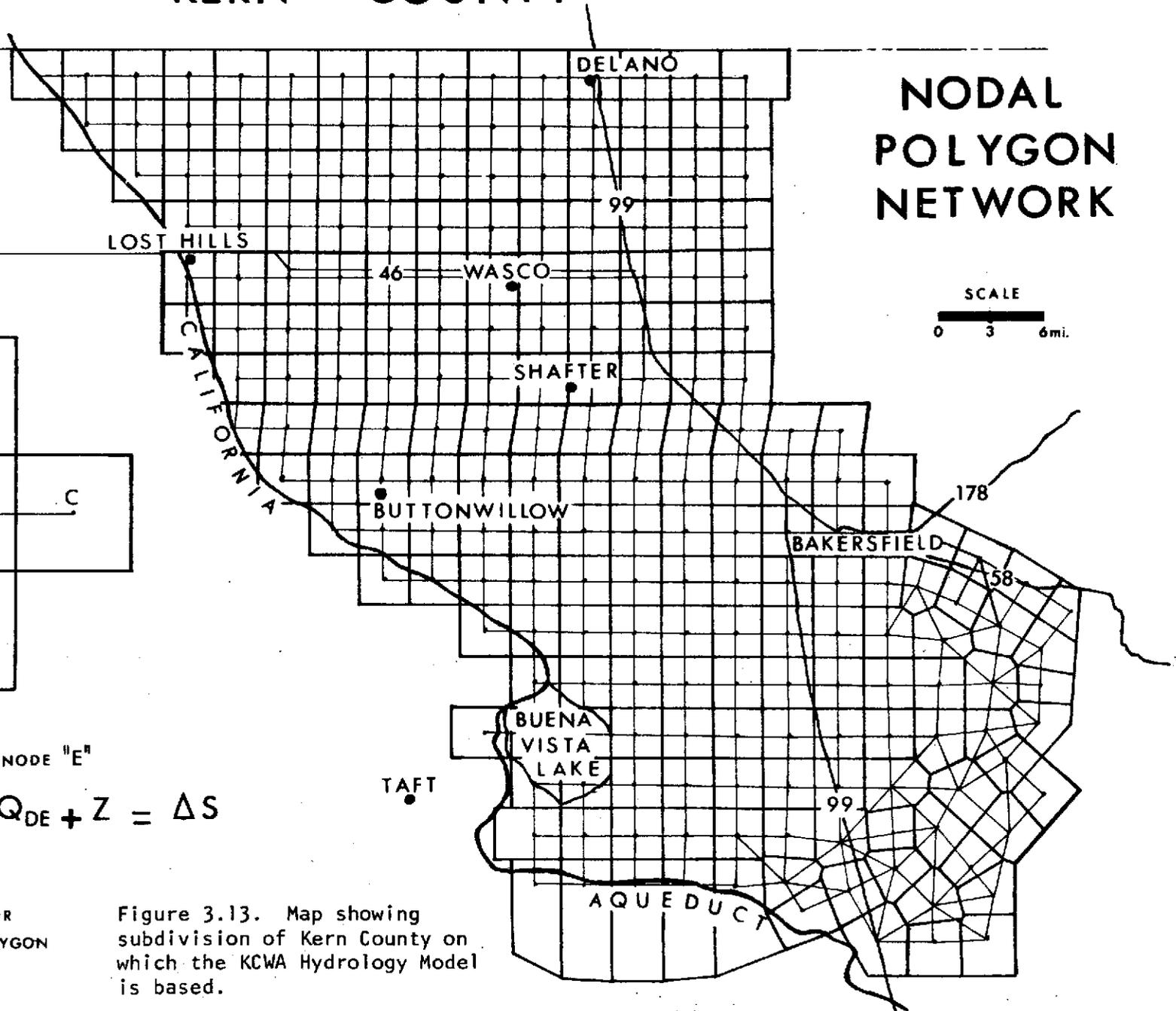
S = COEFFICIENT OF STORAGE

those inputs which could possibly be more efficiently generated utilizing remote sensing technology.

Table 3.3 is a compilation of these data. Precise informational requirements for each of the parameters listed there, (in terms of desired accuracy, timeliness, etc.), are difficult to determine. These difficulties are in most cases related to informational costs, which make some desired surveys prohibitive and others sporadic in nature. Moreover, no sensitivity analysis has as yet been undertaken to determine the relative importance of each input variable and the effects of variations in its value. In short, further research is required in these areas to determine the most accurate and cost-effective means of generating data for water demand models.

In many cases remote sensing technology may be the key to providing more accurate, more timely and incremental information, as well as more cost effective data. In our study of the nature and importance of the various input parameters a number of the more promising applications of remote sensing technology have been examined. Two of these applications have recently been examined in an attempt to interface them with both the KCWA and the DWR informational needs. These are: (1) an inventory of all Kern County agricultural lands; and, (2) a study of perched water tables and their associated areas of excessive salinity. Each of these will now be discussed.

a. The Agricultural Lands Inventory.

The principle objective of this study was to determine the utility of small scale high flight and satellite imagery for mapping agricultural cropland in Kern County. An up-to-date determination of the total acreage of agricultural cropland, in an area where water for irrigation is of utmost importance, has been one of the major concerns of those agencies and individuals who are involved in water resource planning in Kern County.

During the summer of 1972, a map of Kern County showing agricultural and non-agricultural areas was constructed using 1971 NASA color infrared, 70 mm high altitude photography (approximate scale 1:600,000). The photography was interpreted and recorded on an acetate overlay. Agricultural land included all land then under cultivation, cleared pasture land, plowed land, and land in a bare soil condition. Non-agricultural land included forests and woodland, urban, extractive industries and very poorly drained, saline land. Interpretation was performed visually, with the aid of an 8 times (8x) magnifier and, in instances where there was doubt, results were checked with NASA 1971 1:120,000 high flight infrared photography.

The map on the acetate overlay was then enlarged to a scale of 1:112,000 using a map-o-graph so that the resultant scale coincided with the Kern County nodal area map which the GRSU had obtained from Kern County (this scale has subsequently been adhered to for all

TABLE 3.3. KERN COUNTY WATER AGENCY: HYDROLOGY MODEL INPUTS

EXTERNAL QUANTITIES	DEFINITION	SOURCE(S)	REMOTE SENSING CAPABILITY (IDENTIFY-MEASURE)
Agriculture usage			
gross irrigated acres	total amount of irrigated acreage	periodic air surveys, modified in districts	irrigated
unit agricultural consumptive use	acre-feet per acre irrigation requirement by individual crops for evapotranspiration	Department of Water Resources, experimentation with individual crops	crops
irrigation efficiency	that % of applied water that is evaporated or transpired.	Iowa State University experimentation, by crops	
consumptive use by agriculture	water taken out of inventory by total evapotranspiration	summation of nodal consumptive use	agricultural lands
Municipal & industrial usage			
population x per capita factor (unit cu)	population by node	census data, modified by planning projections	urban areas
% of node in municipality	that % of node within a municipality	computed from crop surveys	urban areas
unit demand	acre-feet per person per year	Bakersfield and Kern County historical us g r t

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TABLE 3.3. (Cont'd)

EXTERNAL QUANTITIES	DEFINITION	SOURCE(S)	REMOTE SENSING CAPABILITY (IDENTIFY-MEASURE)
Municipal & industrial usage			
consumptive use	% of water considered consumed by municipal & industrial users	statistical analysis	
% deep percolation	% of municipal & industrially used water that becomes deep percolated	(varies from node to node - input from septic tanks, sewers, lawns, etc.)	
% sewerage	% of municipal & industrial water delivered to sewage treatment plants	sewage treatment plant records	
% sewerage applied	sewage treatment plant efflu- ent applied to crops	sewage treatment plant records	
oil field waste applied	oil field waste water applied to crops	oil company records or computed from crop survey	oil sumps
Recreational usage			
recreational irrigated acres	irrigated areas primarily de- voted to recreation (duck clubs etc.)	aerial photographs	recreational areas by types
unit recreational consumptive use	acre-feet used per acre	previous records of usage rates	

TABLE 3.3. (Cont'd)

EXTERNAL QUANTITIES	DEFINITION	SOURCE(S)	REMOTE SENSING CAPABILITY (IDENTIFY-MEASURE)
Surface & groundwater movement			
exports by source	water exported outside node (via pipeline or canal)	of record, water district and oil company records	
imports	water imported from outside basin	of record, water district and oil company records	
conveyance loss, deep percolation, by source	losses via deep percolation of water moving in unlined canals	by observation and/or calculated (92% of total losses)	
total flow by source	total flow by source in streams and rivers, into modeled area	measured by flow gauges and/or calculated	
applied water by source	water put onto agricultural land	by inventory from Districts and Canal Company	
recharged water by source	water applied to a recharge basin to artificially recharge supply	by inventory from Districts and Canal Company	
unit effective precipitation	acre-feet of precipitation per acre that occurs during growing season (reduces required irrigation)	weather bureau records and crop calendar, modified by formula	areas covered by rain storms

TABLE 3.3. (Cont'd)

EXTERNAL QUANTITIES	DEFINITION	SOURCE(S)	REMOTE SENSING CAPABILITY (IDENTIFY-MEASURE)
Surface & groundwater movement			
volume of moisture deficient soil	volume of unsaturated soil	calculated from field work (soil surveys)	soil moisture
% of deep percolation to moisture deficient soil	% of node overlying moisture deficient soil x nodal deep percolation	field investigation, test holes, etc.	
% to perched water table	% of node overlying perched water table x nodal deep percolation	field investigations	perched water table area
evaporation by source	evaporation of spread or ponded water	prior experience; 5% of spread water lost (8% of total losses) 5'/yr. of ponded water	ponded water area
subsurface inflow from outside basin	underground input to balance nodes in verified period		
clay flow (in clay, casings, gravel and total)	estimated flow from upper aquifer to lower aquifer through well bore and gravel pack and through continuing clay layer	trial and error with some mathematical control	

TABLE 3.3. (Cont'd)

EXTERNAL QUANTITIES	DEFINTION	SOURCE(S)	REMOTE SENSING CAPABILITY (IDENTIFY-MEASURE)
Extractions			
agricultural pumpage	residual (demand-applied correction for irrigation efficiency	analysis of demand-applied with irrigation efficiencies	
municipal extractions	% of a total municipal extraction from a particular node	municipal records	
presence of lower layer	presence or absence of a separation between upper and lower soil layers	soil surveys (in forebay area, no separation between upper and lower layer exists)	
% pumped in lower layer	% of pumpage (agricultural mainly) from lower layer	computed from well examinations	
lower layer extractions for export	total export from lower layer	examination of well data	
% export pumped in lower layer	% of nodal extractions from lower layer for export	export records and well examinations	
subsidence	amount of soil subsidences usually the result of water, oil, or gas extraction	measured in field, projected in time by rate	possibly by long-term repetitive low-flight imagery (comparative topography)

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completed agricultural/non-agricultural maps of Kern County, from which measurements were made).

Similar maps were also constructed using ERTS-1 imagery obtained for the following dates: July 1972, September 1972, March 1973, and July 1973. As with the high flight photography, agricultural and non-agricultural lands were interpreted and mapped onto acetate overlays. ERTS-1, 9 x 9 inches MSS bands 5 and 7 were found to be most useful for the purposes of identification. The agricultural areas appearing on each map were then measured, using a compensating polar planimeter. The resultant measurements of total acreage of agricultural land for Kern County are shown in Table 3.4.

TABLE 3.4 TOTAL ACREAGE OF AGRICULTURAL LAND: KERN COUNTY

1971 K.C. Crop Survey:	NASA 1971 High Flight:	1972 K.C. Crop Survey:	Jul 1972 ERTS-1:	Sept 1972 ERTS-1:	Mar 1973 ERTS-1:	Jul 1973 ERTS-1:
792,254	795,280	796,865	748,050	794,541	795,763	790,000

As can be seen from Table 3.4, figures obtained from the maps that were made using high flight and satellite imagery agreed very closely with those obtained through conventional on-the-ground surveys. The low acreage estimate for July 1972 is possibly the result of several factors. Two possibilities are: (1) interpreter inexperience with ERTS image interpretation; and, (2) early ERTS-1 imagery, such as that used for the July 1972 interpretation, had poorer resolution characteristics and less geometric fidelity increasing the potential for errors in interpretation and area determination, respectively.

As shown in Table 3.4, there was a difference of only 0.29% between the figures obtained from the September ERTS 1972 imagery and that obtained from the Kern County 1972 Crop Survey; similarly, an estimated difference of only 0.13% was the case for the March ERTS imagery.

Examples of agricultural land maps constructed from ERTS-1 satellite imagery, which have been forwarded to the KCWA as inputs to their hydrologic model, can be seen in Figures 3.14 and 3.15.

From this study, several observations can be made: (1) high flight and satellite imagery has very high potential for mapping agricultural land, and permits accuracies of from 95-99% to be obtained; (2) through the use of experienced photo-interpreters, results can be highly accurate; (3) crop data, especially total acreage, can be obtained on a more regular and frequent basis in order to provide more timely input data; and (4) the cost and time involved in conducting such surveys can be reduced considerably, as compared with

KERN COUNTY

AGRICULTURAL LAND

NON-AGRICULTURAL LAND

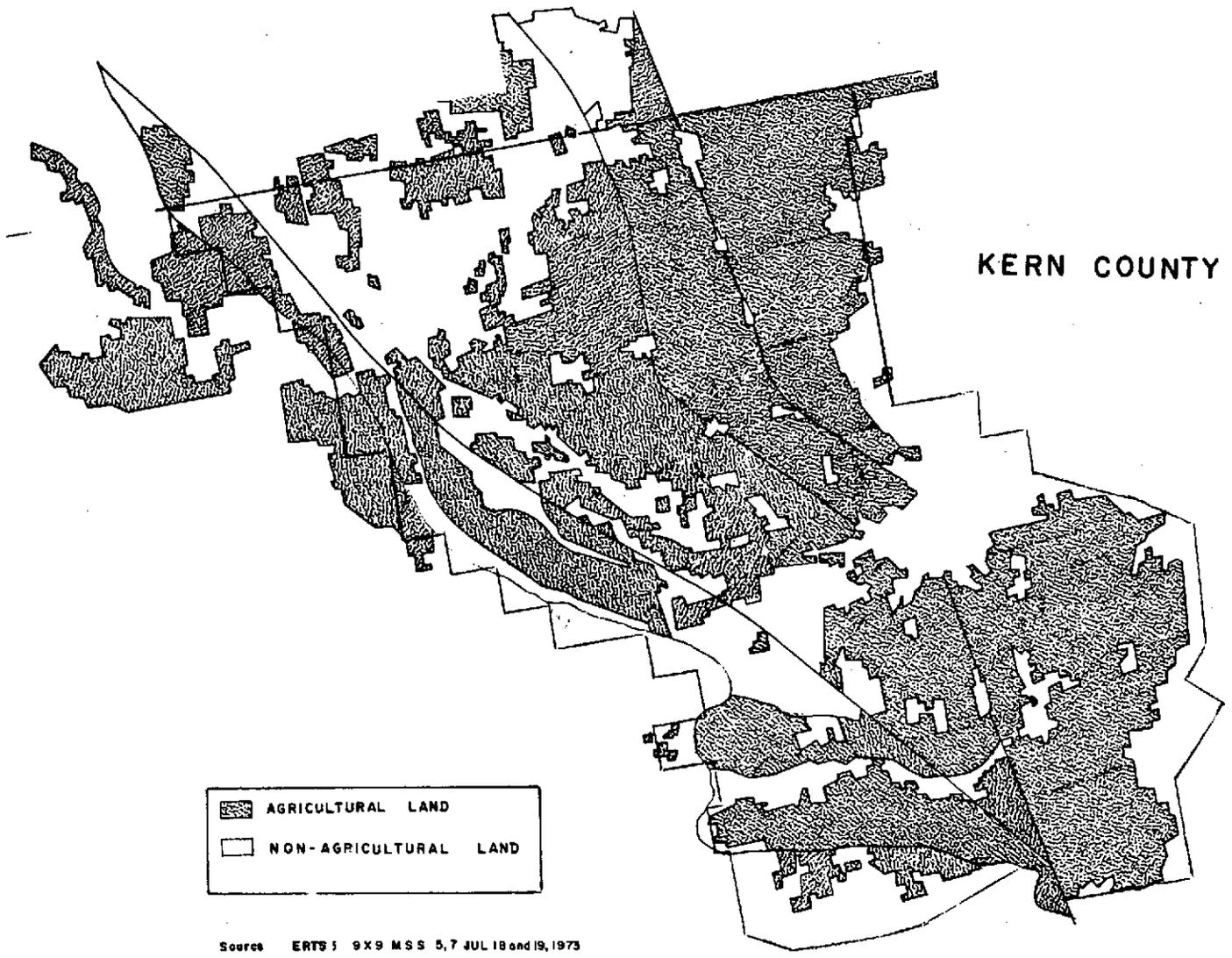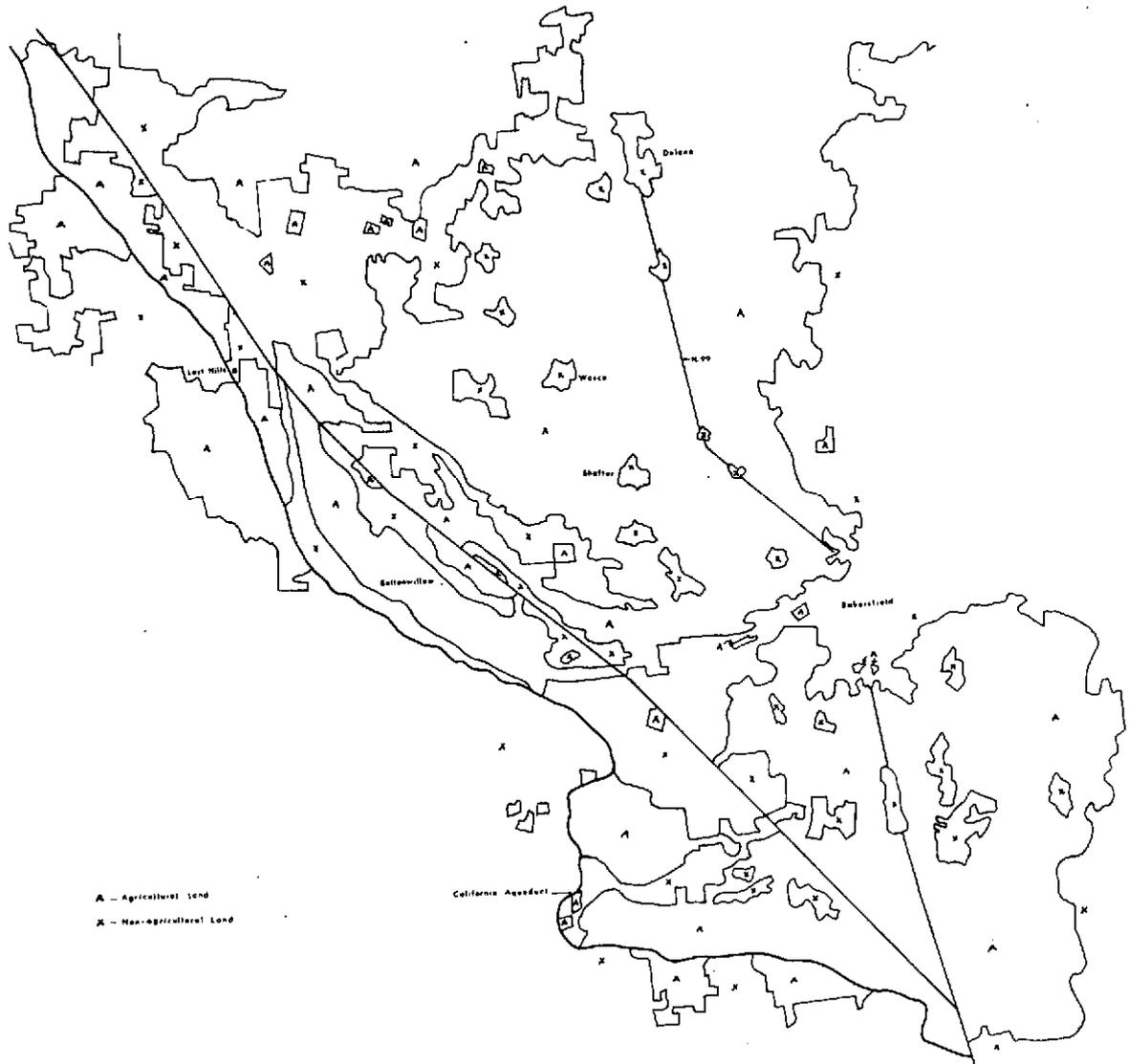Source   ERTS 1   9X9 M S S   5,7 JUL 18 and 19, 1973

Figure 3.15.   Map of Agricultural Land for Kern County prepared from July 1973 ERTS-1 imagery. The total area of agricultural land measured off this map is currently being used by KCWA as input to the hydrologic model.

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KERN COUNTY

A — Agricultural Land

X — Non-agricultural Land

SOURCE ERTS I Imagery MARIS, 73 n45 5&7

Figure 3.14. Map of Agricultural Land for Kern County prepared from March 1973 ERTS-1 imagery. The total area of agricultural land measured off this map is currently being used by KCWA as input to the hydrologic model.

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conventional techniques. For example, the cost figures supplied to us by the KCWA for completion of the survey of agricultural lands for Kern County was between $10,000 and $12,000, whereas the completion of the maps based on ERTS-1 and high altitude conventional photography (including interpretation, mapping and measurement) only requires about 15 to 20 man-hours, at a cost of little more than $100. Time consuming, costly, conventional ground surveys can be reduced to spot checks of "problem areas," that is, those areas for which the interpreter is unsure of the classification and/or new areas that are being cultivated for the first time.

Data being generated as a result of this study are being sent to, and used on an operational basis by, the Kern County Water Agency, as an important input to their hydrology model. As more high flight and satellite imagery is obtained, the information concerning total agricultural land for Kern County will be interpreted and mapped. Furthermore, detailed studies of the possibility of supplying crop information, especially in regards to acreage of major crops in the county, are presently being pursued. It is hoped that not only total agricultural acreage will become readily available, but also total crop acreage as well.

b. The Perched Water: Salinity-Soil Moisture Sub-study

The mean annual precipitation for the valley and desert areas of Kern County is only 3 to 7 inches (178 mm). The importation of water to sustain and expand croplands, somewhat ironically, has brought about new problems associated with water drainage. In some areas, it appears that the solution to drainage problems will be almost as expensive as, and perhaps even more expensive than the original costs of the water delivery system.

A great many drainage problems are related to the existence of "perched water tables" resulting from impermeable clay layers such as those which underlie most of Kern County. An initial study by KCWA of one problem area surrounding the Buena Vista Dry Lake Basin verified the presence of approximately 57,000 acres of agricultural land underlain by "perched water" within 10 feet of the surface. An additional area, between Buena Vista and Tulare Lakes, of over 250,000 acres (which has not been studied in depth), has been described by the Department of Water Resources (DWR) as having "potential drainage problems." With continued importation of surface water for irrigation it is predicted that both the areal extent and severity of the problems associated with perched water areas will increase, unless some drainage system is provided.

The high salinity of perched water and the associated soil salinity problems decrease both the variety and yield of crops that can be grown in a given area. In severe cases, eventual drowning of the root system as well as actual flooding of the plants can occur. With large areas of croplands at stake, it is important for the KCWA to be able to both monitor and assess the extent, variability and

severity of this problem.

The major objective of this study was to examine the operational use of high flight and satellite imagery for the mapping and evaluation of perched water tables, as indicated by high soil moisture and for highly saline deposits.

Problem areas surrounding dry lake Buena Vista (most of which were attributable to perched water tables and excessive soil salinity) had been previously field surveyed and mapped by KCWA personnel. These areas showed a strong correlation with dark regions visible on NASA high flight photography (1:120,000, IR, April 1971) and satellite imagery (ERTS-1, 1:1,000,000, various dates).* Owing to the existence of a variety of comparatively recent sets of remote sensing data, coupled with the outdated nature of the previous KCWA survey data, it was the strong desire of KCWA to have GRSU personnel attempt to provide any possible input to a survey of areas of perched water tables and excessive salinity. Immediate attention was focused upon mapping boundaries within the area from the 1:120,000 scale photography. Through the use of a general three-level classification scheme, including high, moderate and normal classes for soil moisture and salinity, the photography was interpreted and the information mapped onto acetate overlays (see Figures 3.14 and 3.15). Additionally, land use was classified as being either agricultural or non-agricultural.

A soil map for the same area, based on USDA Soil Conservation Service data, also was constructed, in an attempt to classify different soil groups as to their potential susceptibility to soil drainage problems (see Figure 3.18). Like the soil moisture and salt accumulation maps, this map is also broken down into a three-level classification system so that correlations between the two maps can be made. Examination of both maps and of repetitive satellite imagery suggests that there is a strong correlation between soil groups and the degree of soil moisture and salt accumulation, and that by exploiting variations over time these correlations can be detected and monitored using remote sensing data.

The results of field surveys conducted by KCWA will become available in the near future and will enable GRSU to perform comparative analyses and provide a check on the accuracy of our interpretation. Upon receipt of high flight photography for late November, 1973, more up-to-date interpretations will be completed which will be correlated with extensive soil sampling.

From the present preliminary studies conducted by GRSU, some general observations can be made: (1) high flight photography (1:120,000 scale CIR) and satellite imagery appear to be very useful and accurate in detecting and delineating the areal extent of saline deposits that are difficult to measure from field surveys; (2) although such delineations can generally be done on ERTS-1 images (band 5 tends to yield the most information), the additional resolution afforded by Skylab color photography makes possible a mapping accuracy approaching that obtained using high altitude, 1:120,000 scale photography; (3) differentiation

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*Some of these problem areas also appear dark on the Skylab imagery of Figure 3.17.

KERN COUNTY
SHALLOW WATER TABLE SURVEY AREA II

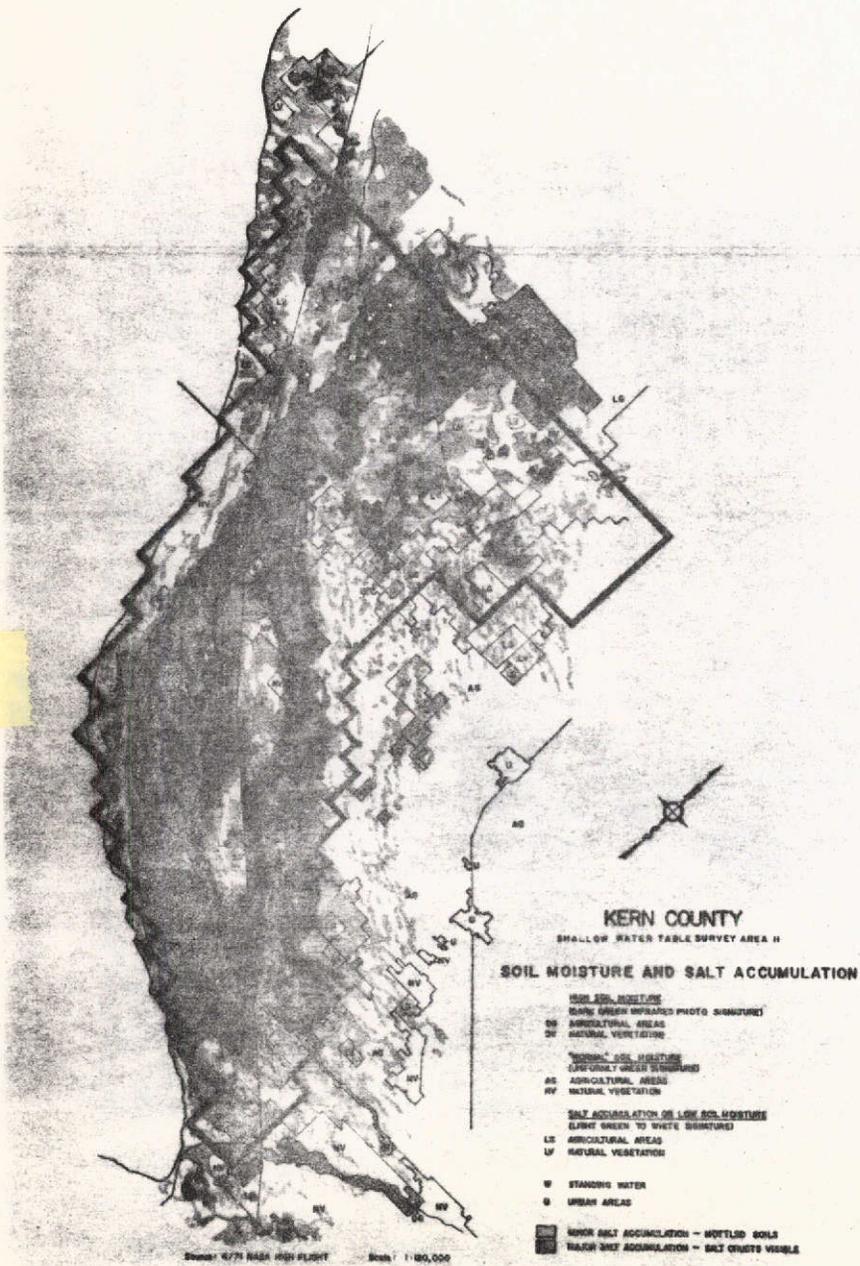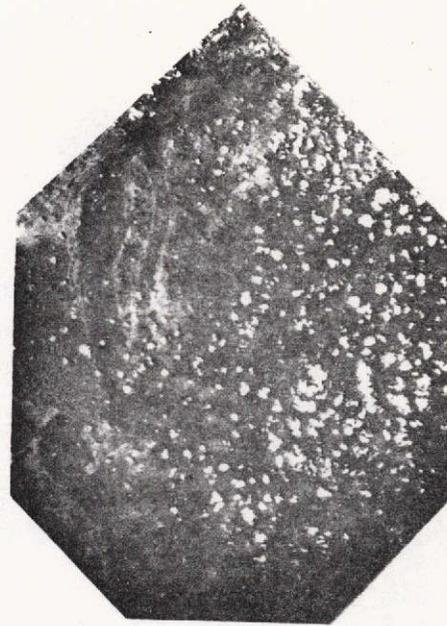SOIL MOISTURE AND SALT ACCUMULATION

Figure 3.16

Figure 3.17

Figure 3.16 (left) shows a map of soil moisture
and salt accumulation of a critical area within
Kern County constructed from NASA   1:120,000
High Flight Color Infrared photography.
Figure 3.17 (above) is a SKYLAB image of the
same area which, owing to its high resolution
also contains considerable information concerning
the distribution and areal extent of high moisture
and salt accumulation.

KERN COUNTY

SHALLOW WATER TABLE SURVEY AREA II

GENERAL SOIL TYPES

Severity of potential agricultural drainage problem areas based on natural drainage, subsoil permiability, runoff, inherent salts, slope, and soil texture.

LOW POTENTIAL-

Cd-TD -- Cajon-Tujunga association
Df -- Delano association
Gw-Hl -- Grangeville-Hesperia association
Gw-Pg -- Grangeville-Panoche association
Hl-Hd -- Hesperia-Hanford association
Kg -- Kettleman association
Rw-Cr -- Riverwash-Carrizo association

MODERATE POTENTIAL-

Ha-Wd -- Hacienda-Waukena association
Hq-MM -- Hilmar-Mocho association
MA-CE -- Merced-Chino association
Ma-Ru -- Merced-Rossi association
Pg -- Panoche association
Sb -- Sacramento association
Sh-Hl -- San Emigdio-Hesperia association
Tx -- Traver association

HIGH POTENTIAL-

Fv-Eh -- Fresno-El Peco association
Lo -- Lathent association
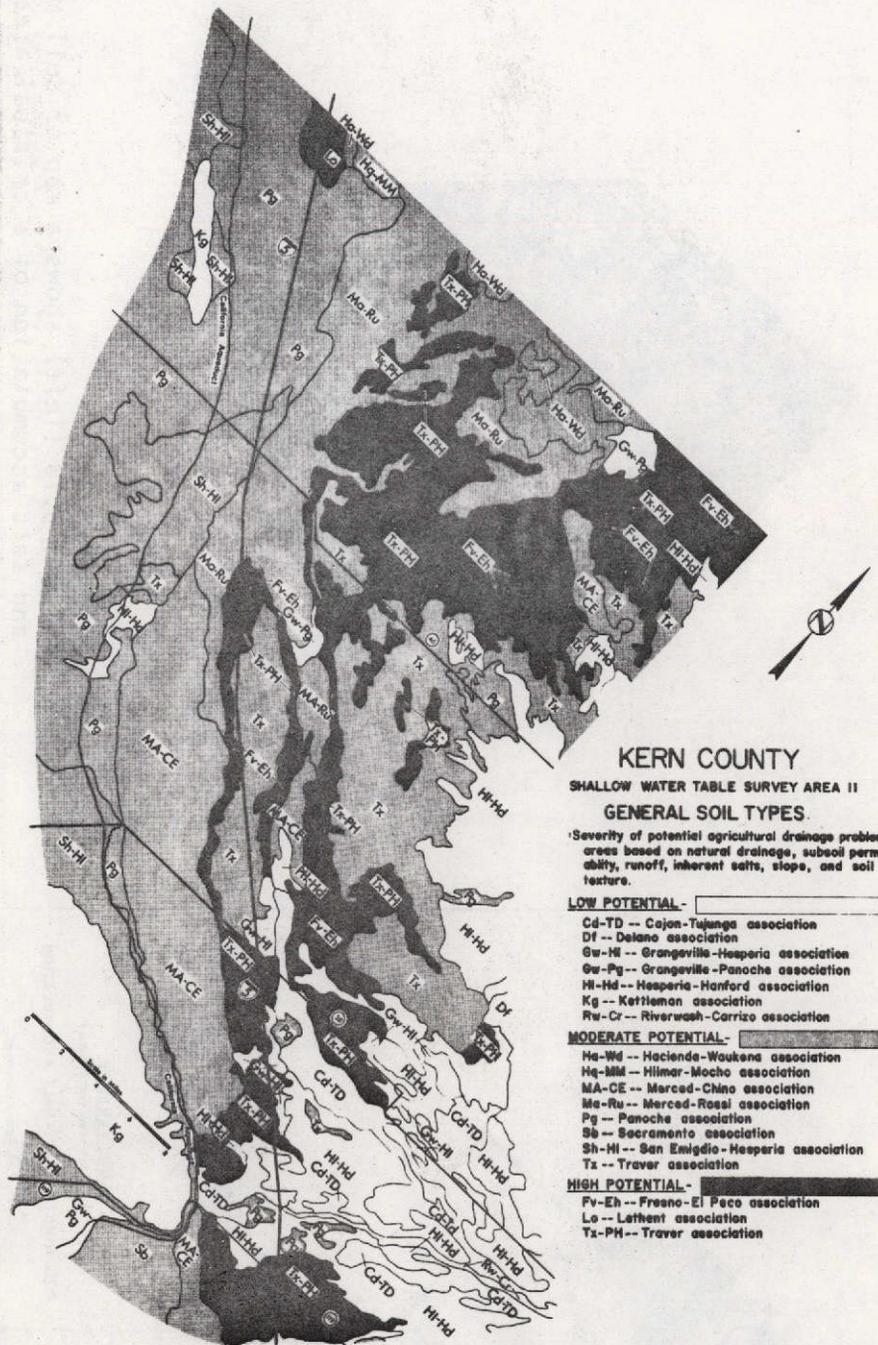Tx-PH -- Traver association

Figure 3.18. Soil Map of Kern County (based on USDA Soil Conservation Service Data) designed to classify different soil groups as to their potential susceptibility to soil drainage problems.

between "severe" and "moderate" or "normal" soil salinity and moisture
conditions is much more accurate than between "moderate" and "normal"
conditions because severe conditions are uniquely characterized by actual
salt crusts whereas some moderate conditions may be confused with dis-
contiguous sand deposits. This assumption is supported by the very
limited salinity tests conducted; (4) ERTS-1 and Skylab imagery and
especially high altitude, 1:120,000 scale NASA photography, appear to
be useful for detecting and delineating areas of perched water, as
evidenced by those areas with high soil moisture and salinity problems.
(Important in the delineation of these areas is the classification of
soil types, for which high flight photography is extremely useful in
determining boundaries); (5) Satellite coverage (ERTS-1) is very useful
because repetitive coverage is required for accurately assigning drainage
characteristics to different areas; (6) within the easily detected
problem areas, accurate measurements by remote sensing techniques of
salinity and moisture will be hampered owing to their opposing tonal
values -- light for saline areas and dark for moist -- which often mask
one another.

C. Future Work

The revised proposal for our integrated study (which was dated
30 September, 1973 and which has since been approved by NASA) described
the future tasks to be performed and indicated which of the participating
units would assist in the performance of each task. It was agreed that
our GRSU on the Santa Barbara campus would concentrate on the water
demand aspects of the integrates study, as listed in Figure 1.2. In our
case, however, as in the case of the other participants, due allowance
was given by NASA for completion of relevant projects which had been in
progress prior to reorientation of the overall study.

All of the work reported upon in the previous sections of this
chapter is in conformity with that agreement, as is the proposed future
work, which is presently to be described.

The proposed future work logically falls into two parts which
deal, respectively, with work to be performed (1) during the remainder
of the present fiscal year and (2) during the next fiscal year.

1. Work to Be Performed During Remainder of Present Fiscal Year

The work to be performed by the GRSU during the remainder of the
present fiscal year (which ends on April 30, 1974) includes the follow-
ing items: (a) a continuation of the assessment of critical input
parameters to water demand models; (b) an analysis of the economic
impact resulting from changes in demand information; (c) continued
testing and evaluation of remote sensing applications to the generation
of input data for water demand models; and (d) an evaluation of the
overall impact of the use of remote sensing, e.g., the social and
political as well as the economic implications of the project. Each of
these proposed activities will now be described.

a. Assessment of Critical Parameters

Continued emphasis will be placed on defining informational require-
ments of water demand models with particular focus on types of data
needed, accuracy desired, and the frequency with which such data are
needed, e.g., yearly, monthly, etc. As part of this work, an attempt
will be made to examine the sensitivity of any applicable water demand
model to determine the relative importance of the various input param-
eters, as well as the effect of variations within each model parameter.
Only after making such an analysis, will it be possible to accurately
determine the economic benefits of remote sensing inputs to a given model.

b. Analysis of Economic Impact Resulting from Changes in Demand Information

A concerted effort will be placed on finding out exactly how the
data generated utilizing remote sensing techniques (specifically data
supplied by the GRSU to the Kern County Water Agency, the Department of
Water Resources and other water management agencies) are being used. An
effort will also be made to determine how this information has helped
their water management capabilities. Similarly, attempts will be made
to ascertain the costs involved in generating the same data when using
conventional survey techniques, so that cost-benefit analyses can then
be made. Particular emphasis will be placed on a determination of the
benefits of more accurate data, incremental data, and more timely data
in improving the accuracy of water demand modeling. It is felt that
this stage of the study is of critical importance because many agencies
do not know the true economic impact of their management decisions, and
it will entail considerable research and interface with the respective
management agencies as well as with other personnel of our integrated
study group (e.g., those at Davis, CRSR, and Riverside, as well as the
group economist).

c. Testing and Evaluation of Remote Sensing Applications

Of equal importance to the determination of the potential economic
benefits of the use of remote sensing inputs to water demand models and
to the decisions based on these models, is the actual experimentation
with the remote sensing data (conventional photography as well as
satellite imagery). Accordingly, research will be focused on those
parameters which can best be studied using remote sensing data, as well
as on the development of optimum techniques for the extraction of
relevant information.

The studies conducted by GRSU described in the body of this report
(providing data on land use, irrigated agricultural land and perched
water tables and soil salinity), will be continued in order to further
improve the interpretive techniques, resultant accuracy and timeliness
of these data. Data on these parameters have already been given to both
KCWA and the DWR representatives who, in some cases, have already utilized
this information in the formulation of planning decisions.

Similarly, the GRSU will follow the same procedure with respect to other input variables such as standing water or ponded areas, soil moisture and/or soil moisture deficits, crop identification, the location of oil sumps, the location and measurement of recreational areas (such as duck clubs) or wildlife refuges which have an affect on water distribution and/or demand, flooded areas (at opportune times), and the expansion and classification of urban areas and their different functional units (residential districts, open land, industrial areas, etc.). In all cases, these parameters or phenomena will be identified and/or mapped using remote sensing data and the data forwarded to the appropriate water management agencies for their use and/or evaluation. Considerable work has already been accomplished in developing a system for identifying crop types, and by April 30, 1974 it is envisioned that total acreage estimates for all major crops within Kern County will be completed and forwarded to the KCWA as added input to their water demand model. The present crop information used by KCWA is either acquired on a spot check basis or is based on outdated 1969 conventional survey data. Individual crops and crop rotation patterns have changed considerably since 1969 and with the receipt of the balance of ERTS-1 imagery for the 1972 and 1973 growing seasons it should be possible to provide the KCWA with more timely and accurate crop data. Furthermore, because the KCWA has accurate cost estimates for their surveys, this phase of our study should provide an excellent basis for evaluating the economic benefit of utilizing remote sensing inputs.

Particular emphasis will be placed on comparing the accuracy of remote sensing data with that of conventionally generated data. For example, as part of the inventory of agricultural land, we already have found that a number of fields inventoried by GRSU personnel had been missed in the conventional ground survey conducted by KCWA.

Finally, after it has been possible for us to determine whether we can extract from various kinds of remote sensing imagery the information content required for identification, mapping, monitoring and/or evaluation of the above-mentioned parameters, our GRSU personnel plan to interface with the personnel of both R. Algazi's group and the Berkeley CRSR in an attempt to automate appropriate aspects of the data extraction stage. This interaction should be particularly applicable in the cases of crop identification (where the CRSR has already shown considerable success and accuracy in automated interpretation), as well as in the delineation of areas of perched water tables, and in the location of standing water.

d. Evaluating Overall Impact of the Use of Remote Sensing Data

In addition to the economic impact of the use of remote sensing data, the GRSU will also attempt to look at the social and political impact of using remote sensing imagery. For example, the KCWA has expressed a desire to use in their hydrology model data acquired from remote sensing on the location, distribution and extent of agricultural holdings. Such information also has great potential use as a basis for tax assessment. Such uses, as well as many other indirect impacts of

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the use of remote sensing data, will be examined carefully as part of our follow-on research.

In conclusion, personnel of the GRSU, during the remainder of the present fiscal year, will expand and intensify their current studies. We will continue to utilize our contacts with the major water management agencies in the San Joaquin Valley to supply these agencies with remote sensing data. Concurrently, attempts will also be made to determine the value of such data to these agencies. Studies on crop types, urban classification and expansion, etc. will be accomplished which will be forwarded to user agencies, and, finally, we will begin to tie down and define the economic and social implications of the use of remote sensing imagery as inputs to water demand models.

2. Work to Be Performed During the Next Fiscal Year

The work plan proposed by the Geography Remote Sensing Unit, University of California Santa Barbara, for the coming fiscal year (May 1, 1974 to April 30, 1975) includes both the continuation and/or initiation of the following work items (see description of integrated work plan in Chapter 1): (a) analysis of the economic impact resulting from changes in demand information; (b) evaluation and testing of remote sensing applications, to provide input data into the models under examination; (c) a comparison of remote sensing techniques tested with conventional methods of data acquisition to evaluate their relative cost efficiencies; and, (d) estimation of the potential impact of using data generated through the use of remote sensing techniques in determining water demand. While it is not envisaged that the final work item in this list will have been completed by next fiscal year's end much of the stepwise progress leading to its completion will have been made, as described in the following paragraphs.

a. Analysis of the Economic Impact Resulting from Changes in Demand Information

Continued efforts will be made to determine the precise nature of the use which local water agencies are making of the data supplied to them. Particular emphasis will be placed on analysis of the impact of these data on the Fresno office of the Department of Water Resources, and on the Kern County Water Agency, as well as on local water agencies under KCWA jurisdiction. Efforts will also be made to determine whether the data generated have proved useful, and if not, the reasons and/or causes will be examined. Attempts will also be made to determine the relative cost efficiency between data generated utilizing remote sensing techniques and similar data acquired by conventional methods. Present user agency cooperation in these areas already has led us to believe that valid cost/benefit information can be generated through GRSU, Riverside, CRSR, Davis, and Berkeley groups. Emphasis will be placed in these investigations on a determination of the benefits to the water management agency of more accurate data, the potential for supplying incremental data, more timely data, and more accurate data. This is an extremely important phase in our investigation and close cooperation and

integration between the respective research and user groups will be maintained to insure that the product of this portion of our investigation will have maximum utility.

b. Evaluation and Testing of Remote Sensing Applications

Continued efforts will be made to assess the range of benefits produced through the application of remote sensing technology to the problem of supplying user agencies with water demand information. Attention will be focused on the cost saving and/or economic benefits of the use of remote sensing inputs to water demand models. Once we have identified clearly the critical parameters in water demand models, emphasis in our studies will be focused on further determining the extent to which each critical parameter is amenable to study using remote sensing techniques. With the studies such as those described in the attached progress report as a guide, GRSU, in close cooperation with Riverside and CRSR personnel, will continue to refine and improve data extraction techniques. Our focus will be to provide user agencies with the optimum operational strategies to fulfill their data requirements. In this portion of our investigations GRSU will continue to follow the procedures employed in its studies of agricultural land, perched water tables and soil salinity in the analysis of additional variables. Areas presently identified as requiring analysis, and for which work may already be underway by May, 1974, include: determination of the extent and location of standing or ponded water areas and soil moisture surplus and/or deficit areas; crop identification, in terms of type, location, and state of maturity; distribution of oil sumps; location of recreational areas; location of regions of flooding or of high susceptibility to flooding; and the location and classification of those areas in which urban expansion is occurring. Again, emphasis will be placed on ascertaining the specific information required by the user agency, selecting and testing for the optimum methodology for obtaining this information (with emphasis on the application of remote sensing techniques), and comparing the resulting methodology with conventional techniques to determine their relative cost benefits.

c. Estimation of Potential Impact of the Use of Remote Sensing Data

In addition to the more specific economic cost/benefit assessment of the use by water management personnel of remote sensing data, personnel of our GRSU, in cooperation with those of the CRSR, the Riverside group, and an economist, will attempt to gauge the broader social and political implications of the use of such data. The Kern County Water Agency has already expressed to members of our GRSU their desire for an evaluation of the potential of remote sensing techniques to provide information on the basis of which taxes can be assessed and differential taxes levied. These areas for further research, as well as others, will be carefully examined as part of our program for the coming year.

In summary, our GRSU proposes to continue and intensify its present studies of water demand. We will continue to use those water agency contacts which we have already established and to expand our contacts

with water agencies at the local, rural and municipal levels. Every effort will be made to identify, assess and evaluate those areas wherein remote sensing data can make either a cost effective and/or social and/or political impact in fulfilling the informational requirements of these user agencies. Finally, the strength of our present work and of our envisioned work seems highly dependent upon our continuing to interface with the actual user agencies who need the above-mentioned data. In all cases these agencies have been more than willing both to define their actual data requirements and to help us with an analysis of the social and economic benefits of all data supplied to them. We feel confident that we will continue to be able to: (1) familiarize user agencies with remote sensing generated data; (2) get them to use it operationally as a basis for management decisions; and, (3) receive from them considerable assistance in determining the dollar and/or indirect benefits of this new data source.

III. WORK PERFORMED BY THE GEOGRAPHY DEPARTMENT,
      UNIVERSITY OF CALIFORNIA, RIVERSIDE

The Riverside campus has concentrated much of its study effort during the present reporting period on the Upper Santa Ana River Basin (Figure 3.19) and the methods utilized by the California State Water Resources Board (DWR) for estimating long-term water demands. In this test site our investigators have focused on the problems being encountered by water agencies involved in supplying user needs.

The most notable deficiency encountered so far in the current investigation is the lack of current input data for water demand models presently employed by the Department of Water Resources (data as much as 10 years old are currently being used). A second problem involves the processes or techniques of reducing mapped data to statistical tabulation. The cutting and weighing of areas from land use maps is the current method of determining the total acreage of each type of land use. Department of Water Resources personnel do, however, realize that there are better methods, but they apparently have neither the time nor the money to develop more precise techniques. An important output of our efforts will be to provide DWR with more cost-effective methods for data reduction, and we already have achieved significant success in this regard.

During the short study period that has elapsed since the re-orientation of our project the Riverside group has concentrated its efforts on two aspects: (A) Determining the critical input data parameters of a long term water demand model that is applicable to the Southern California Region. (In so doing we purposely have paralleled the efforts being made by the Santa Barbara group for the Central California Region, the better to compare models in two areas which not only are distinctly different from each other but which also are jointly the two primary water demand areas for the entire California Water Project); (B) The development and testing of a water demand model, based upon remotely sensed data, within a controlled environment (the Imperial Valley) which is notably different than the environments dealt with in
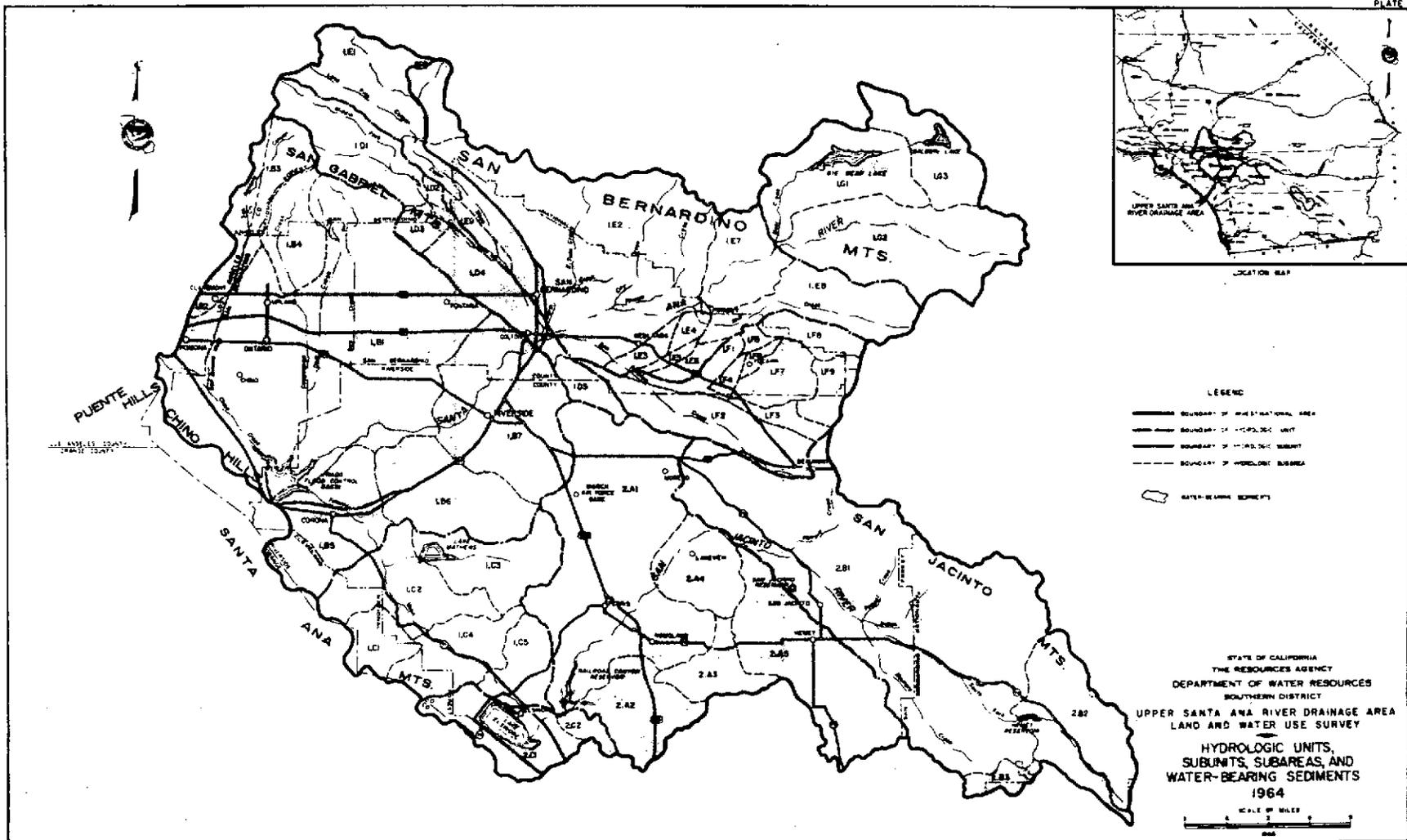
Figure 3.19. Land Use Map of the Santa Ana River
Drainage Area, Showing Hydrologic Units, Subunits,
Subareas and Water-Bearing Sediments.

the Central California studies. These two study efforts are reported
upon in the pages which follow.

A. Determination of Critical Inputs to Water Demand
   Models in the Southern California Region

In assessing water demand of an area, whether long or short term
needs are considered, it is necessary to analyze the parameters upon
which demand is dependent. In the Santa Ana Watershed, an area under
investigation with respect to long-term water demands, there are three
basic parameters to be considered: (1) land use factors; (2) climatic
factors; and, (3) economic factors, e.g., pollution of the underground
water from nitrates. Remote sensing techniques can be employed indirectly
or directly in the investigation of all three of these factors but at
present can make their greatest contribution in the area of land use.

It is a widely accepted fact that land use is a critical factor in
estimating water demand. The California State Department of Water
Resources (DWR) has devised a land classification system based on water
needs and has derived appropriate unit values of consumptive water use
for each category (see Tables 3.5 and 3.6). For urban areas, such a
method is quite feasible. In agriculture, however, a single value may
not be sufficient, as other factors must be considered, e.g., differing
needs of various crops and field rotation practices.

Timeliness of data is another critical item in prediction of water
demand. Drastic changes, especially as a result of the expansion of
the urban complex within our study area, have occurred within the last
ten years. At this time, land use within the study area is in a constant
state of change. The Chino-Riverside Basin (see Figure 3.20), reported
on in this study, exemplifies the dynamic land use situation. For such
an area, data acquired by DWR only once every ten years are not suitable
for short term predictions of water needs and cannot be utilized by
municipal water districts.

Climatic factors (specifically rainfall, evapo-transpiration,
runoff and percolation) must also be considered within the context of
water demand for, in some areas, they contribute an additional source
of applied water. Such data, especially the rainfall figures for which
thirty-year normal data are used, are best utilized in terms of long-
term needs. In regards to evapo-transpiration, techniques such as those
developed by Blaney and Criddell have been found to be of dubious value
because there are too many variables in terms of sources of incoming
water. This is especially true with respect to percolation factors.
There is a need for empirical data to do such calculations. Of value
here will be the Imperial Valley model, previously devised by the
Riverside group and reported below. With such a model, the exact amount
of applied water is known and can be carefully monitored. At this time,
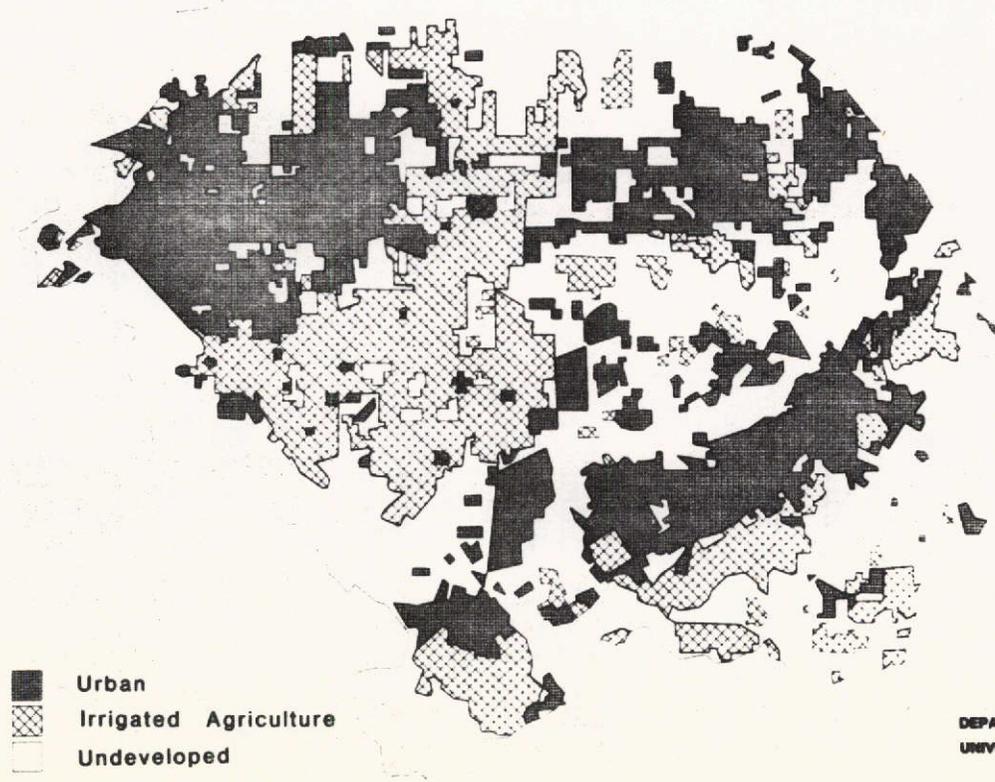runoff and percolation estimates are of unknown accuracy.

A final parameter which could potentially be the most critical is
the pollution of the underground water supply by nitrates and nitrogenous

CHINO RIVERSIDE BASIN

LAND USE

N

0 ————————————— 13
miles

3-45

Urban
Irrigated Agriculture
Undeveloped

Figure 3.20. Map Showing Land Use in the Chino-Riverside Basin, based
on Color Infrared Photography, Scale 1:120,000, acquired in July, 1972.

TABLE 3.5

ESTIMATED MEAN SEASONAL UNIT VALUES OF
CONSUMPTIVE USE OF WATER ON URBAN AND SUBURBAN LANDS,
UPPER SANTA ANA RIVER DRAINAGE AREA

In feet

Land use type	Consumptive use of applied water	Consumptive use of precipitation	Total
Residential, single	1.2	0.9	2.1
Residential, estate	0.9	0.9	1.8
Residential, multiple	0.3	0.6	0.9
Recreational residential	0.2	*	*
Campgrounds	0.1	*	*
Farmsteads	0.8	0.8	1.6
Commercial, strip	0.4	0.5	0.9
Commercial, downtown	1.1	0.5	1.6
Industrial, manufacturing	1.4	0.6	2.0
Industrial, cannery	5.5	0.6	6.1
Industrial, high water using	**	**	**
Schools	0.4	0.7	1.1
Parks, cemeteries, and golf courses	2.5	1.2	3.7
Dairies	1.0	0.9	1.9
Livestock and poultry ranches	0.6	0.7	1.3
Industrial, extractive	--	0.6	0.6
Vacant	--	0.6	0.6
Streets and roads	--	0.5	0.5

*Not determined
**Actual volume of water applied was used to determine water use

Source: Department of Water Resources, Bulletin No. 71-64, Upper Santa Ana River Drainage Area Land and Water Use Survey, 1964. July 1966, p. 64.

wastes. Such pollution is brought about by the leaching of nitrogen-rich fertilizers and from inadequate waste-disposal techniques. Although additional investigation of this problem is necessary, steps must be taken to rid the basin of these wastes.

While the parameters have been identified, the Riverside group is only at the initial stage of defining the problems involved in acquiring suitably accurate data relative to these parameters. The next step is to begin testing methods, based primarily on remote sensing techniques, to help solve these problems.

The following studies report in greater detail the efforts of the Riverside group during the present reporting period in seeking to identify and evaluate the critical parameters of a water demand model. These studies were based on our realization that the rapid development of an area requires an appropriate assessment of resulting land uses changes since the changes determine, in part, the hydrologic impact.

The Chino-Riverside Basin was selected for study because it was believed to be an area both representative of the recent expansion of metropolitan Los Angeles into an agricultural area and an area for which a variety of imagery is available (U-2 underflights and ERTS-1). The basin is delimited by the Puente Hills to the southwest, the Santa Ana Mountains to the south, the drainage divide between the Santa Ana and San Jacinto Rivers to the east, San Timeteo Canyon to the northeast, the San Jacinto Fault on the northeast, the San Gabriel Mountains on the north, and the San Jose Hills to the west.

Through the use of U-2 imagery, a generalized land use map was made of the basin, as shown in Figure 3.20, portraying urban and suburban areas, irrigated agriculture, and undeveloped areas. Residential, commercial, and industrial areas were grouped as urban areas; truck, vineyard, orchard, and irrigated field crops, as well as dairies and golf courses, were included in the irrigated agriculture classification. Undeveloped areas included all non-urban and non-irrigated agricultural areas.

The map was then digitized using the CALFORM program. Land use classification acreages were calculated by the computer for accuracy. These totals were then compared with historical land use data compiled and made available by the California Department of Water Resources. The results show increases in total urban acreage by 31 percent, decreases in irrigated agriculture acreages by 5 percent, and decreases in undeveloped areas by 12 percent. The figures are misleading in that much of the irrigated agriculture acreage that has been displaced by urban land use has in turn displaced former dry-formed areas which fall into the undeveloped category. Thus, the larger figure for decreases in undeveloped lands and the small decrease in irrigated agriculture.

Continued population growth suggests that a gradual change from a rural land use pattern to an urban environment is taking place. The transformation is most apparent around the cities of San Bernardino,

Riverside, Ontario, and Pomona. Corona is becoming a center of population growth for the spill-over from Orange County. Expansion and growth in the San Gabriel Valley has nearly eliminated all remaining agricultural land, and has resulted in an overflow into the Chino-Riverside Basin.

Much of the new urban and suburban development has been at the expense of former deciduous, citrus, and subtropical orchards. Based on 1964 data, citrus and subtropical orchards had at that time declined by 11 percent and deciduous orchards by as much as 64 percent. Acreage in truck crops also was down by 37 percent. San Bernardino County alone had lost 1000 acres of citrus by 1964 due to urban expansion.

These figures served to establish a general trend that still exists, in which urban development is increasing rapidly within the basin at the expense of prime agricultural acreage. With respect to the hydrologic significance of this trend, the effects on runoff, groundwater storage, and water quality are three important considerations for water resource management within the basin. Each of these is discussed separately in the pages which follow.

1. Runoff Characteristics

It has been previously established that alluvium in its natural state provides a significant degree of protection from flood hazard by virtue of its high infiltration rates. The general configuration of an alluvial fan also reduces the danger of flooding by providing an equal distribution of runoff over a wide area. However, when the operation of this natural flood control system is altered by surface diversions in the form of streets and feeder channels to artificial recharge basins, the potential for flooding is increased.

Compounding the problem in the Chino-Riverside Basin is the 55,000 acres of impermeable surface which now exists in the form of streets, patios, garages, driveways, housing foundations, parking lots, and sidewalks which divert precipitation and runoff into flood control channels and thence into the Santa Ana River.

Engineers have indicated that, within a residential area of average density, about 50 percent of the area is comprised of impermeable surfacing. The figure for commercial and industrial establishments ranges from 50 to 90 percent, depending on the nature of the individual complex. It is safe to conclude that, of the 111,500 urban and suburban acres in the basin, half (or 55,000 acres) consists of an impermeable surface. This represents about 14 percent of the total land surface area within the Chino-Riverside Basin which is still considered to be in a mixed urban-agricultural condition.

The runoff from this vast impermeable area is not lost from the groundwater basin; it is merely displaced. Runoff from the upper basin is carried off to the Prado Dam area by the Santa Ana River where it percolates into the ground water basin. Because subsurface outflow from the basin has essentially been cut off by the dam, the water is maintained

within the basin while a constant flow is discharged below the dam as surface flow. Indications of increased flow within the Santa Ana River (which could be present if this were occurring) are absent due to drought during the last twenty years. The floods of 1969 in this area are perhaps a better indication of what could happen, given increased precipitation.

2. Ground Water Storage

The potential storage capacity of the Chino-Riverside ground water basin was calculated to be about 18,300,000 acre-feet, most of which occurs in the central part of the basin. In 1934-35, the amount of ground water in storage was 12,650,000 acre-feet and in 1959-60, the total had dropped to about 12,000,000 acre-feet. The net decline of 650,000 acre-feet represents an average drop of 25,000 acre-feet per year.

The impact of this drop will be of major significance in areas of shallow wells such as those in the Riverside-Arlington area. Well levels there dropped 25 feet during this period while those in the Pomona-Claremont area declined 75 feet and those in the Colton-Rialto area dropped 50 feet.

In order for one to account for the decline in total volume of ground water, he obviously must weigh the inputs or supply to the basin against the output or extractions. Analysis of the supply factors (which include subsurface inflow, artificial recharge, percolation of delivered water, and percolation of precipitation) indicates that the definite decline in precipitation since 1944 is a major factor for consideration. Percolation of delivered water has remained relatively constant as has subsurface inflow. However, percolation of precipitation which relates directly to artificial recharge has decreased dramatically since 1944, the only notable exceptions being in 1952 and 1958. Every other year during this period was considerably below the previous twenty-six year average for the region.

Components of extraction or output from the basin include ground water pumpage, rising water, extractions by phreatophytes, and subsurface outflow, which is considered to be constant. Significant trends are indicated by the total ground water pumpage which has almost doubled since 1934 and by a decline in amounts of rising water. The increase in pumpage reflects the intensity of agricultural practices in the area and the increased trend toward irrigated crops rather than dry-farming. Since cultivated acreage has either remained constant or dropped since 1934, this fact reflects the displacement of dry-farmed areas by irrigated crops, primarily vineyards. The decline in rising water (water coming to the surface in stream channels) obviously reflects the decline in amounts of precipitation and associated runoff.

It can be concluded from the preceding analysis that the decrease in the total volume of ground water in the Chino-Riverside Basin has resulted from a persistent drought condition and from an increasing emphasis on irrigated agriculture, reflected in a doubling of ground

water pumpage. Thus the water supply has decreased while the utilization of existing supplies has increased.

The proper use of modern remote sensing techniques for monitoring the total irrigated acreage in this basin from high altitude platforms can play an important role in calculating its future water demands and also in estimating the impact of fluctuations in those demands. As a result of the contacts which we have established and which we continue to maintain with the many concerned individuals and agencies within this basin, it now appears quite certain that they will henceforth take the initiative in using such remote sensing techniques to achieve the necessary monitoring.

3. Water Quality

The utility of high altitude imagery for water quality analysis may not seem obvious. However, when coordinated with known hydrologic parameters, such as agricultural fertilization practices, dairy waste output per equivalent number of cows, or waste water production for a given urban or suburban land use type, land use mapping takes on a whole new importance for investigators in this important environmental problem.

For example, the rates of nitrogen fertilization on vegetable crops have increased markedly in recent times. Correspondingly, crop yields have increased substantially. However, the proportion of applied nitrogen that has been recovered in the crop has decreased, with the remainder presumably being tied up in the soil-nitrogen pool. Based on this presumption, by our knowing the amount of applied nitrogen and the amount recovered in the crop, we can calculate the residual in the soil.

With allowances for soil infiltration characteristics, denitrification within the soil, and losses to the atmosphere, the amount of nitrates reaching the ground water table can be computed. The same can be accomplished for all crops requiring nitrogenous fertilization, such as citrus, which presently requires up to 150 lbs. of nitrogen per acre per year.

Recent studies concerning dairy waste within the Chino-Riverside Basin indicate that a decrease of 100 TDS may result within the ground water basin if no new controls are implemented. The concern stems from the estimated output of 3.62 lbs. of salt per day per cow equivalent (= 1 milk cow or dry cow, 2 heifers, or 5 calves). The magnitude of the problem is exemplified in the number of dairies in the basin (384) and the number of cow equivalents (166,000). Dairies also generate 50 to 100 gallons of waste water per day per cow. In the Chino-Riverside area this could amount to 9 million gallons per day, most of which is diverted to irrigated pastures.

The impact of dairies on ground water quality is exemplified in nitrate levels at the surface of the water table. These levels average 250 ppm at the surface, but concentrations deeper in the aquifer average only about 26 ppm of nitrates. The maximum safe level in California for drinking is about 90 ppm of nitrates.

The rapid influx of population into the basin has created enormous problems of waste disposal. It is estimated that people and animals together annually contribute 40 million pounds of nitrogen to the Upper Santa Ana Basin. Most treatment plants are operating at or near capacity. In the activated sludge of secondary sewage treatment plants, the solids are separated from the water. The effluent is allowed to percolate into the soil for disposal and the solids are dried and disposed of in the topsoil. During treatment, about 50 percent of the nitrogen stays with the primary effluent. From 10 to 30 percent of this may be lost to the atmosphere in the secondary treatment process. The remaining nitrogen is in the sludge, where it is tied up in organic form.

Waste water production in the Chino-Riverside Basin has dramatically increased since 1934. Total production has increased from 10,900 acre feet in 1934-35 to 51,620 acre-feet in 1959-60. Much of the waste water is reused for irrigation, and the rest is, for the most part, discharged into streams or into artificial recharge basins. Thus increases in waste water production can be directly related to the increase in urban and suburban land uses within the region. For example, in the vicinity of the Ontario-Upland Sewage Treatment Plant, concentrations of nitrates in wells show levels of about 90 ppm, whereas downstream from the waste treatment plants at Jurupa, Corona, and Riverside Narrows, nitrate concentrations of 45-90 ppm are exhibited.

The potential for hydrologic analysis from high-flight photographs should be obvious from the previous discussion. With accurate land use mapping of the type which our previous studies have shown is best done by remote sensing with a knowledge of subsurface hydrology, the implications of man's encroachment on the land and the effects on runoff, ground water storage, and water quality can be deciphered and presented in an accurate and efficient manner.

The Chino-Riverside Basin is presently involved in a transitional period of change from a predominantly rural agricultural state to one comprising an urban-suburban fringe on the outskirts of the greater Los Angeles metropolis. The opportunity that our Riverside group has to study such an area already is providing some important answers for planners in this area, as well as for those in other areas undergoing similar changes.

B. The Evaluation and Testing of Remote Sensing Techniques for the

Production of Water Demand Data in a Controlled Environment

The Imperial Valley, California development of water demand models utilizing remote sensing data as a major input for either short term or long term water demands can be facilitated if model testing occurs in a controlled environment. Fortunately, a truly controlled environment in terms of total water importation does exist within southern California, viz. the Imperial Valley.

The arid climate of the Imperial Valley dictates that all of the water needed for the production of any crop must be supplied through irrigation methods. Furthermore, the lack of any local source of water (e.g. wells) makes it possible to measure all applied water through the only water import facility available in the area (The All-American Canal). The following report summarizes the development to date of a water demand model based upon empirical data obtained through ERTS-1 (satellite) remotely-sensed data, correlated with individual water usage factors developed for the Imperial Valley by the University of California Extension Service. When related to the models that have been developed by the Department of Water Resources for use in their long-term water demand studies, this method should prove to be the most usable "General Method" for determining water consumption. In the paragraphs which follow, some of the factors pertaining to such a method are reported upon, with emphasis on the role which remote sensing most likely will be able to play in its eventual implementation.

1. Water Demand Factors and Requirements

The prime input to most water demand models (Department of Water Resources, 1955) is the summation of the various land uses and classifications occurring within the region. Varying with climatic conditions, irrigated lands require up to 5 feet or more of water annually. Urban lands in the same region require one-half to two-thirds of the irrigated lands requirements. In arid lands, such as the Imperial Valley, we find that monthly consumption of water by an alfalfa field in August totals more than 0.8 of a foot while in December the same field requires only 0.4 of a foot of water (Agricultural Extension Service, 1972). Table 3.7 lists the monthly water requirements for the major crops of the Imperial Valley.

If it can be determined how many acres of urban land are contained in a region, and how many irrigated acres of agricultural land are producing crops, the water demand estimates can be made. However, the accuracy of the estimate will depend almost entirely on the knowledge of the irrigated lands: i.e., how much acreage is in production, how much land is lying fallow, and how much land is in some stage inbetween. Another factor that will improve the accuracy of the estimate is knowledge as to which specific crops are in production and for what specific time period.

A look at the ERTS-1 satellite imagery of the Imperial Valley has indicated to us that perhaps most of these demand factors could be determined, if not from a single image, then from a sequence of images.

2. Determination of Water Demand Factors from Remote Sensing Imagery

Creating a false color infrared composite image from three black-and-white multispectral ERTS images provided us with a ready means for distinguishing growing crops, as indicated by the red return of vegetative growth. A second obvious surrogate of the condition of the fields was the white barren look of dry fallow ground. This interpretation

TABLE 3.7

MONTHLY IRRIGATION WATER REQUIREMENTS - ACRE FEET

(Imperial Valley)

Crop	% of Annual Production	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
FIELD CROPS													
Alfalfa	37.8	.416	.416	.416	.416	.628	.814	.814	.816	.816	.616	.416	.416
Cereal Grain	20.9	.482	.504	.505	.505								.505
Cotton	6.5			.424	.424	.805	.975	.975	.975	.424			
Rye Grass	6.4	.327	.327	.606	.334	.606				.327	.327	.327	.327
Safflower	0.2	.500	.500	1.500	1.500	.500							
Sudan-Sorgham	2.1			1.000	1.000	1.000	1.000	1.000	1.000	1.000	.535		
Grain Sorgham	10.7			.500	1.010	1.010	1.010	.477					
Sugar Beets	14.2	.419	.419	.823	.434	.418				.824	.824	.419	.419
Weighted Field Crops	(84.5%)	.428	.431	.524	.573	.667	.874	.776	.847	.738	.633	.407	.432
VEGETABLE CROPS													
Melons	18.0	.795		.795	.795	.331	.285		.795	.795	.331		
Carrots	6.7		.559	.461						.931	.931	.559	.559
Lettuce	55.1	.491	.167							.983	.786	.786	.786
Onions	6.7	.757	1.136	.593								.757	.757
Tomatoes	3.1	.848	1.680	1.680	1.680	1.110							
Watermelons	4.4	.596		.596	.596	.596		.616					
Weighted Vegetable Crops	(12.8%)	.593	.361	.750	.872	.473	.285	.616	.795	.938	.696	.673	.761
Weighted Permanent Crops	(2.7%)	.105	.365	.378	.645	.378	.378	.494	.392	.378	.378	.105	.645
Weighted Total Crops		.451	.426	.533	.583	.659	.865	.775	.846	.753	.647	.468	.505

is quite obvious in the arid Imperial Valley, but fallow ground might
not be so discernible in more humid areas. The inbetween condition,
viz. plowed ground and wet irrigated seeded land, was not so easy to
distinguish. However, an attempt was made to identify such conditions
on each image and then to verify the findings by relating the condition
of each individual field over a sequence of four 36-day cycles. Rarely
can a crop be identified from a single satellite image, but from the
sequential ERTS-1 photos we were able to obtain four specific field
conditions that affect water consumption. The four conditions, as seen
on the color infrared type of "false color rendition," could be coded
as follows: (1) growing crops from their red appearance; (2) wet
irrigated, seeded, and bare land from their dark blue or brownish
appearance; (3) plowed land from its light blue or brown appearance;
and (4) dry bare fallow land for its white appearance. A fifth
distinction was made for the yellowish orange appearance of grain
stubble fields.

To take advantage of the sequential imagery it became necessary
to record the field condition for each specific field for each of the
four 36-day periods. This was accomplished by producing a map of the
Imperial Valley with every field delineated. For each of the four
dates the image was then superimposed on the map and the condition of
each field annotated on an overlay. The data were then transcribed to
machine card records for further processing. It was found, as suspected,
that errors in interpretation were encountered for fields that were
just commencing to grow, and for fields that had been irrigated, but
which were drying out just before germination of the seed occurred.
The result was that many emerging-growth fields that had a slight pink
tinge were in fact coded as being bare fields and many fields that were
seeded were interpreted as freshly plowed fields. The ability to follow
the sequential condition of each individual field enabled these errors
to be corrected. It was soon found that, for each growing season,
several specific patterns of field condition were both detectable on the
photography and of diagnostic value as indicated by the crop calendar in
Table 3.8. Alfalfa, for example, was found to reflect a code of all
1's indicating a growing crop on each of the four images. If a
sequence of 1 1 3 1 occurred it was quite probable that the third image
was misinterpreted and it became necessary to recheck that field on
the third image to insure an acceptable field condition sequence. A
computer program has been written that edits acceptable field condition
sequences for the period of time involved (usually a sequence of four
36-day cycles).

By comparing each sequence of field conditions to the crop
calendar in Table 3.8 the specific crop contained in each field can
be identified. A computer program to perform the identifications has
been developed and it is anticipated that a 90 percent identification
accuracy of specific crop types can be achieved over six 36-day cycles
of ERTS imagery.

Table 3.9 summarizes the field conditions and other pertinent
land use information derived from four sequential ERTS images taken
at a 36-day interval of time. These data provided the prime input to

TABLE 3.8

CROP CALENDAR BY FIELD CONDITION CODE
(Imperial Valley)

CROP TYPE	FIELD CONDITION CODE BY DATE			
	August 26	October 1	November 6	December 12
FIELD CROPS				
Alfalfa	1	1	1	1
Cereal Grains	4	4	3	2
Cotton	1	1	5	4
Rye Grass	4	3	2	1
Sudan-Sorgham	1	5		
Grain Sorgham	1	5	4	
Sugar Beets	3	2	1	1
VEGETABLE CROPS				
Carrots	3	2	1	1
Lettuce	3	2	1	1
Onions	2	1	1	1
Tomatoes			4	3
Melons	1	5	4	
Watermelons			4	3

FIELD CONDITION CODE LEGEND:
1 - (Red) Growing Crop

2 - (Purple or Blue) Wet Seeded Field

3 - (Lavender or Light Brown) Damp Plowed Field

4 - (White) Dry Bare Soil

5 - (Yellow) Harvested Stubble

TABLE 3.9

SUMMARY OF FIELD CONDITIONS DETECTED FROM ERTS-1
(Imperial Valley)

Field Condition	(Code)	August 26 (acres)	October 1 (acres)	November 6 (acres)	December 12 (acres)
Growing Crops	(1)	153,528	142,047	199,197	213,233
Wet Seeded	(2)	40,374	69,115	120,330	116,426
Damp Plowed	(3)	128,219	150,351	48,736	55,542
Dry Bare	(4)	123,025	83,642	80,221	62,262
Stubble	(5)	2,636	787	315	1,075
Permanent Crop	(8)	3,640	3,640	3,640	3,640
No Data	(0)	9,599	10,470	7,627	8,270
TOTAL PRODUCING		461,021	460,052	460,066	460,448
Feed Lots		2,698	2,703	2,747	2,734
Farm Associated		180	184	463	486
Offsites		54,436	54,495	54,512	54,459
Urban		11,712	12,112	12,280	11,880
TOTAL ACRES		530,047	530,546	530,068	530,007

the water demand estimates that were made for the months succeeding the date of each of the ERTS passes. At this point in time, the specific crop types had not been identified. Hence it became necessary to average some of the water requirements.

3. Determination of Monthly Water Requirements

The monthly water requirements as shown in Table 3.7 for each major crop in the Imperial Valley were given weights according to the average total number of acres in production of that crop as reported by the Imperial Irrigation District (1972). Alfalfa represents 37.8 percent of the total annual field crop production, cotton 6.5 percent, and sudan-forage sorghum 2.1 percent. In August of 1972 the only major crops in production were alfalfa, cotton, and forage sorghum. The weighted values of these crops become 81.5 percent for alfalfa, 14 percent for cotton, and 4.5 percent for sorghum. Referring back to Table 3.7 we can then adjust the weighted water requirement of alfalfa to 0.665, cotton 0.137, and sorghum to 0.045 yielding a total require-ment for all field crops in production in August to a total water requirement of 0.847 feet. Similarly the water requirement for the entire region can be given a weighted average for all producing crops for each month.

4. Estimation of Water Demand

Table 3.10 combines the acreage summary of each field condition with the average monthly water requirement to calculate the water demand for each field condition in acre-feet of water. The demand for water by growing crops and seeded irrigation crops obviously results from the total acres times the water requirement. However, the water demand for plowed fields must be adjusted to the number of acres that one anticipates will be converted to seeded irrigated fields within the forecast month. An "experience factor" for this conversion needs to be developed for each region. Without the experience factor for this study an after-the-fact value of actual acres converted was utilized. This value was established by computing the change in wet seeded fields between each 36-day cycle and the next. Dry bare and stubble fields obviously do not consume any water and were neglected in the water demand. Permanent crops utilized the computed values from Table 3.7. Experience of inter-pretation over the four cycles indicated that approximately 8,000 acres of fields would not be correctly identified because of several reasons. Those of less than 20 acres could not always be detected and ground survey showed that most of these fields were non-producing for one reason or another. Therefore, water demand was computed for only acreage above 8,000 acres when no data could be interpreted from the image. This value may be revised slightly downward with more experience factors. Feed lots have been found to consume approximately the same amount of water over a given period as irrigated fields; hence the same water requirement figure was utilized. The same reasoning applies to farm-associated land, which includes farmhouses and barnyards with associated lawns and swimming pools. Offsite categories include canals, highways, access roads, etc. and they have no water requirement of significance. The urban requirement for water has been increasing and

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TABLE 3.10

ESTIMATED MONTHLY WATER DEMAND (Imperial Valley)
(Acre-feet)

Field Condition	September	October	November	December
Growing Crops	115,606	91,904	93,224	107,682
Wet Seeded Land	30,401	44,717	56,314	58,795
Damp Plowed	21,642	33,136		
Dry Bare				
Stubble				
Permanent Crops	2,730	4,368	634	7,644
No Data	1,200	1,598		137
Feed Lots	2,032	1,748	1,285	1,380
Farm Associated	136	119	217	245
Offsites				
Urban	3,842	2,822	2,555	2,768
TOTAL ESTIMATED	177,589	180,412	154,229	178,651
ACTUAL DELIVERY	271,476	162,111	158,828	178,537
DIFFERENCE	-93,887	+18,301	- 4,599	+ 114
Percent ERROR	34.6%	11.3%	2.9%	0.1%

a firm figure was not established. However, a State Department of Water Resources Study (1955) predicted that by 1973 the consumptive water use for El Centro would average 42 inches annually. Utilizing a monthly percentage value of water consumption from the same water resources study a monthly urban water requirement was established.

5. Results

A comparison of the estimated water demands for the months of September, October, November, and December 1972 for the Imperial Valley with the actual water delivered beyond the Pilot Knob water gate is made in Table 3.10. It is quite obvious that a gross error occurred in interpreting the August 26 imagery. A check of the Imperial Irrigation Districts report of crops growing on July 15, 1972 shows that an error made by underestimating some 73,000 acres occurred in the interpretation of the image. Without the experience of a previous image it was difficult to interpret questionable fields. Obviously, in the dry month of August many fields were classified bare or plowed that had crops growing in them. If a previous image had been available a computer edit program would have shown the fields in which significant interpretation discrepancies occurred. With each succeeding sequential image the experience factor improved the results. The 0.1 percent error is unbelievable and probably represents a "random success" resulting from various compensating errors.

6. Conclusions

The method described herein should not be regarded as a polished detailed system for estimating water demands. It has been intended to illustrate that water demand estimates can be made from satellite imagery with a high degree of accuracy. If, in practice, it becomes desirable or necessary to utilize the satellite system it can become extremely accurate if care and long term analysis is made. If a system which monitors irrigated lands throughout the year could be utilized and the specific crop in each field could be identified we could expect a very accurate water demand prediction to be made. In areas where rainfall occurs or underground wells are utilized the demand would still be the same, but different sources of supply would provide the required water.

References

1. California Water Resources Board, 1955, Water Utilization and Requirements of California, Bulletin No. 2, pp. 39-58.

2. Agricultural Extension Service, 1972, Imperial County Crops - Guide Lines to Production Costs and Practices, Circular 104, University of California, El Centro, California, 58 p.

3. Imperial Irrigation District, 1972, Annual Inventory of Areas Receiving Water, El Centro, California, p. 2.

4. ibid., p. 216.

C. Future Work

The Riverside group proposes to conduct future work essentially as described in the September 30, 1973 proposal for the Integrated Study, which has since been approved by NASA. Consequently only the following details need to be given.

1. In concentrating its studies primarily on water resource utilization problems in the Santa Ana Watershed of southern California, the U.C. Riverside campus group works with the State Department of Water Resources (DWR), Los Angeles Division, and the Santa Ana Watershed Planning Agency. The primary objective is to investigate the role which remote sensing can play in water resources management, especially in regard to water utilization. More specifically, attempts are being made to assess the usefulness and cost-effectiveness of varied remote sensing techniques (multi-spectral, multi-platform, multi-period) in order to provide surrogates which can assist in overall water resource management of particular water using entities.

The study requires assessment of various water uses both by period of time and category of water utilization. The following objectives are included to achieve the overall objective:

a. Determination of remote sensing surrogates that can provide input data for water demand (utilization) models. A target date of April 1974 is anticipated for completion of this task.

b. Development of automated techniques to establish and maintain current land use maps by water utilization categories. The automated system includes both data storage techniques and subsequent automated cartographic display methods in addition to tabular data printouts. Land use maps of the Chino, Perris and San Bernadino areas are now complete and the supply and demand models will be produced during 1974.

c. Determination of the cyclic use of irrigated lands throughout the year in specified areas of the Santa Ana Watershed. Such information is used to determine the optimum period of time for water demand forecasts. Four season imagery now exists of most of the test site and will serve as the data base for demand forecasts. During 1974, a program of forecast potential will be presented to the Department of Water Resources.

d. Estimation of the direct cost-benefit to the Santa Ana Watershed Planning Agency of pertinent information provided by means of remote sensing.

The Riverside group has utilized multi-platform, multi-spectral, and multi-periodic imagery to develop surrogates which contribute to water resources management at the user level. A large contribution to the overall efforts is the utilization of automated cartographic facilities previously developed by this department.

Following the work plan outline the Riverside group proposes to:

a. Develop or determine the input requirements necessary for improved water demand and/or water utilization models. A highly accurate model is possible but requires the measureable input of Colorado River water and the measurement of local supply to a greater degree of accuracy. As a result, new slope, land use and hydrologic parameters of the upper elevations of the Santa Ana watershed must be measured. Present imagery, supplemented with some new high flight and space data, can fill this data gap. As the various input factors are determined we will study the imagery to determine which factors or what surrogates for the input factors can be determined from remote sensing.

Static demand factors, such as urban and industrial areas of land use, are differentiated and stored within automated processing data facilities. Likewise dynamic demand factors, such as irrigated agricultural land uses, are mapped and stored.

b. Methods and models for obtaining water management data from remote sensing, with due consideration being given to platform type, sampling periods, analytical procedures, data processing techniques, and data display methods are nearly developed. Additional effort is required, however, to put them in practical user form.

c. Acquisition of data will be performed concurrently with the development of methods and models. Periodic sampling of the irrigated lands will be accomplished a minimum of once for each 3-month period and, when available, on a 36-day cycle. A known deficiency in the current Department of Water Resources estimates is the absence of information relative to the cyclic activity of irrigated lands. Current estimates are made on an annual basis due, in part, to the unknown factors of annual land use. Climatically, the region is capable of producing up to three different crops on the same acreage annually. Presently, to what extent multi-cropping is practiced is unknown; the study will therefore attempt to determine crop rotation practices. We now have four times a year coverage of established test areas around Lake Perris and Chino and in addition, the lengths of time during which various irrigated farm acreages remain fallow are under investigation. Improvement of the water demand model can now be achieved by the summer of 1974 because the entire cycle of farming practices can be determined within the Santa Ana watershed. Periodic remote sensing of this area by ERTS-1 and high flight vehicles is of tremendous value in monitoring this cycle.

d. Remote sensing data will be analyzed and evaluated to determine the most cost-effective image scale, sampling period, updating procedures, and methods of data display. With the emphasis on storage of imported water in underground basins it will be necessary to analyze the data in order to determine what physical factors can be determined from remote sensing to provide information as to the

most effective utilization of underground water basins. The analysis
of the data also will include a consideration of those factors which,
although required to improve the prediction models, either cannot be
obtained from remote sensing (including Coulson's "image transfer"
and "polarization" studies), or can be better obtained by other means.
In this sense it will be essential to determine what effects, if any,
the local climatic variations and water supply may have upon the water
demand model within the Santa Ana watershed. This study is to be
undertaken in 1974.

     e. Evaluation of the accuracies of the test model developed under
this study have been made by preparing water demand forecasts and
comparing them to current estimates. The accuracy of the data obtained
from remote sensing will continue to be compared with that of the
presently obtained data.

     f. The activities of the Santa Ana Watershed Planning Agency
are being followed closely to determine which of their planning goals
might best be assisted by remote sensing. Eventually, we hope to
advise them on adequate substitutes for present "clumsy" methods.

     g. Current research at Riverside has involved the analysis of
economic, social, cultural and political impacts resulting from the
availability of water to southern California. The models developed
from previous research are to be utilized in the above studies.

2.   While the research efforts of the Riverside group are primarily
with respect to water demand, because of local surface and ground
water catchment, a certain effort is necessary to integrate both
internal and external water supplies. Consequently the Riverside
group proposes to investigate supply sources within the Santa Ana
Watershed during the next fiscal year.

     Our proposed budget for the next fiscal year is on the page
which follows.

University of California, Riverside Agency: NASA		From 5/1/74		Through 4/30/75
1. SALARY & WAGES PERSONNEL	TITLE OF POSITION	AGENCY FUNDED MAN-MONTHS	GRANTEE MAN-MONTHS	TOTAL AMOUNT REQUESTED
• L. W. Bowden	Assoc. Prof. III	3 Summer		6,007
C. W. Johnson	Assoc. Specialist II	11 Academic	(100%)	15,511
J. R. Huning	Asst. Specialist I	11 Academic	(50%)	5,657
(Salaries include 5% cost of living increase)				

*Principal Investigator   **TOTAL SALARIES & WAGES** $27,175

2. EMPLOYEE BENEFITS 12% of $21,168; 2% of $6,007 $ 2,660

3. CONSULTANT COSTS _____ $ -0-

4. EQUIPMENT (Itemize) _____

_____

_____

_____

                        TOTAL EQUIPMENT $ -0-

5. SUPPLIES & MATERIALS (Itemize)
Office, Photo, Misc. $500

Computer, Plotter, and
     Equip. Service   4,000
Local Aerial Survey   2,000

            TOTAL SUPPLIES & MATERIALS $ 6,500

6. TRAVEL (Destination & Purpose)_____
     A. Domestic Field Survey, Conferences, Symposia
     B. Foreign _____

                TOTAL TRAVEL EXPENSE $ 2,500

7. PUBLICATIONS_____ $ 500

8. OTHER EXPENSES (Itemize)
Geography Shop Services (See Attached)

_____

_____

              TOTAL OTHER EXPENSES $ 23,208

9. TOTAL DIRECT COSTS (1 through 8) - - - - - - - - - - - - - - - $ 62,543

10. INDIRECT COSTS   BASE:

     A. On Campus Rate ____ % of ____ on $ _____

     B. Off Campus Rate 21.2 % of TDC on $62,543

               TOTAL INDIRECT COST $ 13,259

11. TOTAL PROJECT COST (9 and 10) (Enter on Page 1, Item 3C) - - - $ 75,802

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UCR-RO Form B-150-A (10/73)

GEOGRAPHY SHOP SERVICES

Staff Research Associate	$4.57/hr. (2 @ 800 hrs.)	$ 7,312
Lab. Assistant	3.33/hr. (2 @ 800 hrs.)	5,328
Lab. Helper	2.87/hr. (3 @ 600 hrs.)	5,166
Senior Programmer	7.60/hr. (1 @ 100 hrs.)	760
		$ 18,566
Support 25%		4,642
		$ 23,208

(Salaries include 5% cost of living increase)

IV. WORK PERFORMED BY THE SOCIAL SCIENCES GROUP, BERKELEY CAMPUS

During the period covered by this report our research activities have been devoted to the gathering of information consonant with the revised proposal for this integrated study, dated September 30, 1973. As the following pages will indicate, in one phase of these activities we have been exploring the social, political and economic aspects related to water demand in the state of California, with particular reference to the California Water Project. More specifically, this section discusses the social environment of the management of the demand of water, including the various perspectives that influence and are influenced by the decisions made.

Just as with respect to supply, the technical aspects of demand are by no means trivial. Similarly, the social, economic, and political dimensions of demand are increasingly more crucial, for they reflect the rapidly changing social environment in which demand must be assessed and projected. Specific items for consideration in this connection are drawn from the State Department of Water Resources decennial report.[*] They include demography, with consideration of population distribution in the State (especially in relation to hydrologic study areas); attention is given to changing patterns of migration, fertility rates, and the like. The demands of an expanding and affluent society are reflected in industrial development. "For the most part the most significant water-using industries are directly related to California's population and its growth in the demands for goods and services," says the Report.

Increases in population and industry go hand-in-hand with escalation of electric power demands. Until the 1950's, hydroelectric generation was the primary source of electrical energy in the State. With suitable sites becoming scarcer and more costly, the major sources of power to meet growing demands are now seen to be of thermal generation, until recently oil- and gas-fired but likely to depend more and more in the future on nuclear fuels.

By 1985, it is expected that one-half of the electricity used in California will be of nuclear origin.[**] Although it is not our purpose or function to explore the pros and cons of nuclear power, it is nonetheless important to acknowledge that considerable controversy persists over siting of plants, safety of their operation, and methods of disposing of their radioactive wastes. Many of these matters are closely related to and intimately involved with water management and, beyond the technical aspects, with social, economic, and political considerations.

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[*]Water for California, The California Water Plan Outlook in 1970, op. cit.

[**]David L. Book, "Energy Resources" in California Water, ed., Seckler, op. cit., pp. 206-230.

A. The Demand for Water as a Coolant

What can appropriately be reported in the present context is that
all thermal power plants require large quantities of water for cooling
purposes. The cooling water required for a 1,000 megawatt unit is about
1500 cubic feet per second. Because the most economical cooling
process is of the once-through variety, the operation of the plant needs
a large body of water from which water can be drawn and into which it
can be returned. At this point, there are encountered problems of
thermal pollution, in that the warm water may have detrimental effects
on aquatic and marine life. When recreational aspects of water are
under consideration, such potential for damage cannot be lightly
dismissed. Thermal pollution is less of a problem in California,
however, where most sites discussed are on the ocean which is, at
present, an adequate heat sink.

B. Water as a Factor in Agricultural Development

Another item in the demand column has to do with agricultural
development; California prides itself on being the nation's leading
agricultural state, with its $4 billion annual cash crop. Agriculture
requires water; in fact the history of California agriculture is tied
to the availability of water. The farmer's need for water was once a
guiding principle in the development of the California Water Plan.
Land use changes are seriously affecting the agricultural picture. In
Los Angeles, Orange, Riverside, and Santa Clara Counties, once highly
productive agricultural regions, urban expansion has taken some 14,000
acres annually. Ninety percent of this spread has usurped former
agricultural land. Continued pressure on land uses, with attendant
increases in land values and taxes, has pushed the small farmer out
of business. Larger, corporate-type operations have emerged, with
crop types shifting to those having high value.

C. Water Demand in Relation to Urbanization and Industrialization

The water needs of an urbanized and industrialized California
differ greatly from those of an earlier day. The Report cites "require-
ments for household uses, fire protection, irrigation of lawns and
gardens, parks, golf courses, and industry and commerce" among them.*
With metropolitan districts paying a higher price for water than does
agriculture, these changes may not be altogether displeasing to the
purveyors of water. But there appear, nonetheless, to be many unresolved
issues, and these keep appearing whenever a long range plan is being
made. Urbanization and industrialization are no longer being regarded
as unmitigated blessings, and although there is little glorification of
or particular compassion about the California farmer, who, in the eyes
of some sectors, enjoyed a free ride at taxpayers' expense, there is

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*Outlook in 1970, op. cit., p. 45.

nonetheless a marked resistance on the part of the public to runaway growth. As was indicated earlier, this is a very significant development and one well worth watching in the context of changing land use, especially since the Water District and its financing were observed to have been used as the instrument for control. To judge by the agenda of the most recent meeting (November 29, 1973), in Anaheim of the California Water Commission, this is a trend already beginning to make an impact in the planning process. Although demographic in nature, it must be considered as a real factor in a hydrologic model reflecting demand.

D. Water Demand in Relation to Outdoor Recreation and Fish

   and Wildlife Development

Having earlier discussed in Chapter 2 the social and cultural factors impinging on estimates of water supply for recreational use and fish and wildlife planning, we hardly need repeat that these are factors which have assumed the role of recognized social needs. A policy statement (P. L. 89-72) at the federal level stipulates that outdoor recreation and fish and wildlife development will be accorded full consideration as purposes in the evaluation of water projects. In California the Davis-Dolwig Act of 1961 established State policy declaring recreation and fish and wildlife enhancement to be among the purposes of state water projects. But official sources report that appropriations have not kept pace with demand. An affluent society, transportable by cars, boats, and even aircraft over-utilizes available facilities. In the overall, the consumptive uses of water for these purposes may be comparatively small, but they can create serious water problems in certain areas and, more important, environmental purposes of one kind or another are becoming more significant sources of demand. Illustrative of man's impact on the natural setting and the resultant heightened need for new local water supplies is the explosive growth of recreational homesites. Non-resident population accounts for about 75 percent of the water requirements in the Tahoe Basin. In Nevada County, about 36,000 new lots covering 48,000 acres have been created through subdivision since 1964. Major new water supplies will have to be developed not only because of household needs but because the treated effluent discharge is expected to exceed normal minimum streamflows.

E. Water Quality Considerations

Our discussion of water supply and demand would not be adequate without some mention of water quality as an essential element. The generally accepted criteria for determining the suitability of water for municipal use are fairly straightforward, namely, the U.S. Public Health Service Drinking Water Standards, which specify limits for bacteriological, physical, radiological, and chemical constituents. At first glance, then, water quality appears to be a relatively open-and-shut matter, free of the social involvement, political entanglements, and jurisdictional complications that, we have seen characterize

supply and demand considerations. It soon becomes apparent, however, that the real measuring rod for water quality is TDS, totally dissolved solids -- the minerals and salts whose parts per million serve as the key. The lower the TDS, the higher the water quality. Thus, by this objective measure, the Colorado River, with a TDS of 900, the Delta with 200 to 400, and the East Bay Municipal Utility District, with 20 to 30, can be compared at a glance.

The social, economic, and political consequences of these differences in water quality manifest themselves in various ways. Good quality water has the economic and aesthetic advantage of tolerating longer periods of storage without deterioration. Nutrients grow and algae increase in Sacramento River water, for example. Because of the presence of nutrients resulting from agricultural wastes, copper sulfate has to be used in the reservoirs storing Sacramento River water. The superiority of East Bay Municipal Utility District water is being used as a factor in an interesting political skirmish which centers on its possible jurisdictional annexation of the Contra Costa County Water District. While it is argued that water supplied by that District and which comes from a slough in the Delta, could be considerably improved as a product for domestic consumption, the political roadblocks are enormous and the likely opposition from substantial industrial and agricultural customers could be considerable. Still, the possibility is being discussed openly and in high places. The result could have substantial and long-range significance in the northern California water scene.

The complications introduced by the quality dimension into the management of the water resource were exemplified by an event unprecedented in the history of California water. On September 11, 1973, Frank M. Clinton, general manager of the Los Angeles Metropolitan Water District, shut off delivery of northern water because of the foul smell and taste. The difficulty was traced to blue-green algae from the Castaic Reservoir (terminus of the 444-mile long California Aqueduct) itself, according to the view of an East Bay Municipal District official. Water from that reservoir proved to be especially vulnerable to nutrients and algae that cause deterioration in water quality, he said. The State Department of Water Resources, through its Chief Engineer, tried to dilute the algae by introducing more water; also contemplated was chemical treatment, which would probably have poisoned the fish in the Castaic Reservoir. Delivery of water was resumed on September 27, but the solution was acknowledged as temporary.

Another aspect of this long range water quality problem was described by Fred Garretson, an Oakland Tribune staff writer and long-time water-watcher as follows:[*]

> The waters from the north and south originate in different geologic provinces and have different chemistries. Scientists have already found that northern water, seeping into the ground through lawn watering, breaks down the chemical bonds in certain Southern California clays, causing landslides.

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[*]Fred Garretson, "L.A. Unhappy with Water from North," Oakland Tribune, September 18, 1973.

This allegation has not received universal support, but there is no disputing the importance of quality in the complex of decisions relating to supply and demand in water resource management.

Noteworthy are the international ramifications and repercussions of maintenance of water quality. There now have accumulated more than $150 million in claims that Mexican farmers in the Mexicali Valley have lodged against the U.S. for having polluted the river through its drainage practices. Drainage from irrigated land in the Western states has transported salt back into the river, with salinity level rising to double what it was in 1961. The Mexican farmers have charged that the high salt content, some 1500 parts per million, kills their crops. Among ameliorative measures taken by the U.S. are construction, in Arizona, of the world's largest desalting plant, at an estimated cost of $67 million; a concrete-lined canal to carry the salt water from the desalting plant to the Gulf of California, a distance of about 70 miles, at a cost of about $36 million; and an extensive program, through the Export-Import Bank, for rehabilitation and improvement of land damaged by the salty water.

F. Summary of our Research for the Present Reporting Period

Our research activities during the past six months have been devoted to gathering information consonant with the overall plan for the University of California's Integrated Study of Earth Resources in the State of California Using Remote Sensing Techniques. In concert with the engineers, hydrologists, geographers, remote sensing specialists, and other participants in the Study Group, we have explored the various dimensions of supply and demand as related to the management of California water resources. Our studies are far from conclusive; this report is intended to convey some understanding of the complexities of the task at hand and of our dedication to it. Much remains to be learned; it is through continued effort of this kind that we can ultimately ascertain the specific aspects of the water management process in which satellite and related technology could be of significant public service.

In this connection, we deem it appropriate to cite the Final Report to the President and to the Congress of the National Water Commission.* The point made and repeated in that document was that future considerations regarding water are not inevitable but derive from policy decisions and from social factors. "Forecasts of water supply and water demand should consider realistic maximum, minimum, and mid-range figures for population, technological development, consumer preferences, and governmental policies." The Report corroborated our emphasis on the quality aspects of water by reiterating the "recurrent theme" of a shift in national priorities from development of water resources to restoration and enhancement of water quality.

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*WATER POLICIES FOR THE FUTURE, Final Report of the President and to the Congress of the U.S. by the National Water Commission, Washington, D.C., June, 1973.

With the current and accelerating shortages in energy, the authors of that report saw an increased demand for water-related services sold in the marketplace, as, for example, in the generation of electric power. On this matter, they made the cogent statement, "An effective balancing process requires identification of the interests at stake, availability of information about consequences of alternative courses of action, procedures for hearing and considering divergent points of view, and appropriate decision-making bodies to evaluate benefits and costs, risks, and potential gains." They recommend that the "Crisis Scenario" be shunned, as too neglectful of long-range consequences. And they urged that water resource planning be tied more closely with land use planning.

G. Proposed Future Research

Proposed for the coming months, then, is continuation of our research through interviews with responsible officials, attendance at meetings, and study of pertinent documents. The considerably increased interaction between the various campuses and specialists involved in the Integrated Study and the greater coordination of effort has, we feel, contributed to sharper focus and a remarkable degree of cohesion. This has proved to be beneficial and will be foremost in our continuing studies.

Two related points of particular interest that we feel merit further and fuller exploration during the coming year are: (1) Water as a factor in the current "energy crisis," especially as related to the technological solutions for it; and (2) water as a factor in land use patterns, especially in the control and direction of pace and direction of changes. The economic, political, and social implications of these are important -- the first, because increased demand for water in power generation will cause fundamental changes in uses, create pressure for additional sources, and give impetus to technologies for recycling, reclamation, and purification; the second because contrary to historical precedent, where development of water resources was favorably regarded and publicly financed because it assured and fostered growth, there now appear counter trends, with water used as the key instrument to retard and discourage expansion. These are matters of great social significance, since they have direct bearing on the quality of life in the coming decade. They provide a logical focal point within the context of the Integrated Project and could give it the forward direction consistent with NASA's commitment to put its technological accomplishments to maximal and optimal social use.

Chapter 4

WATER IMPACT STUDIES

Robert N. Colwell

I. WORK IN PROGRESS

As indicated by the block diagram comprising Figure 1.2, an analysis of water impact stems directly from an analysis of water supply and demand factors of the type reported upon in Chapters 2 and 3 of this progress report. For this reason much of what we do in analyzing water impact in relation to the Feather River Project must follow the completion of some of the steps which we currently are performing relative to various water supply and water demand factors as reported upon in those two chapters. However, it might be argued that the meaningfulness of our entire research effort is best found in this "impact" portion of it. Mindful of this we therefore have been attempting to conduct some of the preliminary phases of our water impact analyses even during the present reporting period. For example, the special contribution by Dr. Merewitz which appears in Chapter 5 of this report under the title "On the Feasibility of Benefit-Cost Analysis Applied to Remote Sensing Projects" is very valuable in setting the stage for some of our forthcoming water impact studies.

II. FUTURE ASPECTS OF OUR WATER IMPACT STUDIES

With the aid of such preliminary studies, we now will begin to investigate the potential impact of using modern remote sensing techniques as an aid in managing, even on a day-to-day basis, the storage, flow and delivery of water made available through the California Water Project. The diagram of Figure 1.2 makes it clear that the amount of this impact depends upon the extent to which remote sensing is proven to be useful in improving predictions of both the amount of water that will be available and the amount that will be needed. Such information can best be obtained through the research which we currently are conducting as described in Chapters 2 and 3 of this progress report.

We also propose to investigate the potential impact of using modern remote sensing techniques as an aid in monitoring, and perhaps even in directing, changes in land use and life style being brought about through the increased availability of water in central and southern California as a result of the California Water Project. Such impact of remote sensing can be of appreciable significance only if (a) the induced changes are very substantial ones, (b) remote sensing is found, in this context, to be very useful and potentially very cost-effective, and (c) resource managers adopt this new technology.

Much of the work which we already are performing, as described in
Chapter 3 of this report, is permitting us to determine the nature and
magnitude of changes induced in our central and southern California
test sites as a result of the California Water Project. Such work will
also permit us to determine the usefulness of modern remote sensing
techniques in monitoring such changes.

However there also is a need to study the economic impact of the
increased water supply on land use change and development. Consequently
we propose to analyse the changing economic bases and the new land use
demands resulting from increased water availability in our central and
southern California test sites.

Among the indicators which we propose to study with the aid of
remote sensing are:

1. The conversion of non-agricultural and non-irrigated agri-
cultural land to irrigated agricultural land. This phase of our
proposed study includes a determination of the actual acreage of con-
verted land, the resulting new water demands, and an assessment of
realized land and crop value increases.

2. The actual increase, and potential increase (demand), of
industrial, extractive, and other manufacturing processes, due to
availability of an improved/increased water supply.

3. Any increase, or projected increase, in income-generating
recreation land development (e.g., water and land projects, including
lakes, parks, golf courses, etc.) or tertiary activities such as
service stations, restaurants, motels, etc.

Our future studies also will include an analysis of the effect of
the changing water supply, and concomitant land use development, on
various physical aspects of the environment, including:

1. Soil quality and composition (changes over time).

2. Erosion potential (as a result of flooding or increased water
application).

3. Groundwater and soil moisture modifications.

4. Micro-climatic changes (e.g., the effects of higher evapo-
transpiration rates on the regional climate due to introduced water).

5. Natural vegetation cover (possible increase in density or
extent due to recharged groundwater, or a decrease in the event of
physical removal for new land use).

6. Wildlife population (effect of increased water on the number
and distribution of wildlife, especially aquatic life, e.g., water fowl
and fish).

We also propose to make an analysis of the <u>individual</u> and <u>aggregate</u> (total) land use changes in a <u>sociocultural</u> context. This study would closely parallel our economic impact study but also would include:

1. Evaluating the "<u>growth-inducing</u>" characteristics attributed to increased water supply. Particularly important here is an analysis of the ability of a region to support or absorb new (and projected) demands in relation to its <u>total</u> "optimal" carrying capacity. Besides considering <u>physical</u> and <u>economic</u> factors, the study should attempt to <u>measure</u> the impact of <u>socio-cultural</u> parameters such as:

a. <u>Population</u> (e.g., using remote sensing techniques to determine increased urban extent and residential densities).

b. <u>Commercial</u> growth (as related to population growth).

c. <u>Industrial</u> and related development (as it effects the total population resources and cultural orientation of the area).

In addition we propose to study various <u>indirect</u> or <u>subtle</u> environmental effects, such as:

a. Growth of industry and urban extent, due to increased water availability, which may also increase land, water, atmospheric, and noise pollution, and

b. Modifications to the physical environment.

By means of the studies just described, we plan to analyze the <u>overall impact</u> of a changing water resource base and to use such data in constructing and testing a water impact model.

In summary of what has been said in this brief chapter, the primary kind of "impact" study which we propose to undertake deals with the impact of remote sensing on the management of California's water resources as exemplified by the California Water Project. A secondary kind of impact study, however, is one in which we propose to use remote sensing techniques to monitor the impact on land use, and indeed on the landscape in general, that results when greatly increased amounts of water are made available to a developing area. Both kinds of studies should produce findings that are of great potential value, not only to the managers of California's water resources, but to water resource managers in many other parts of the globe as well.

Chapter 5

SPECIAL STUDIES

Special Study No. 1 - ON THE FEASIBILITY OF BENEFIT-COST ANALYSIS
APPLIED TO REMOTE SENSING PROJECTS

Special Study No. 2 - MULTISPECTRAL COMBINATION AND DISPLAY
OF ERTS-1 DATA

Special Study No. 3 - POWER LAW TIME DEPENDENCE OF RIVER FLOOD
DECAY AND ITS RELATIONSHIP TO LONG TERM
DISCHARGE FREQUENCY DISTRIBUTION

Special Study No. 4 - INVESTIGATION OF ATMOSPHERIC EFFECTS
IN IMAGE TRANSFER

Special Study No. 5 - INTERCHANGE AND COOPERATION WITH USER
AGENCIES

ON THE FEASIBILITY OF BENEFIT-COST ANALYSIS
APPLIED TO REMOTE SENSING PROJECTS

By

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I Benefit-cost: Whence and What

Benefit-cost analysis of public expenditures started in earnest in the late fifties. There had been a time when government spending was advocated by many intellectuals without much regard to its purpose. Having learned the Keynesian lesson, they became aware that certain areas of spending could easily eat up whatever they were allowed. This was true in the area of defense because of the favorable and necessary image which that area had as a vestige of World War II and because of assumed urgency in "the Nuclear Age". It was also true in the area of water resource development because such spending served the political purposes of elected officials who decided on spending. If the major objective of a Congressman or Senator is to get re-elected, and if federal funds to build a dam would enrich his constituents, he had little incentive to exercise Puritan virtue in examining that dam. Benefit-cost analysis then became the tool of the Executive to discipline the Legislature. This is how the evaluative function came to be located in the Executive Office of the President which, through its Office of Management and Budget, has been called the central planning agency of the federal government. One could imagine paraphrasing an old American saying: "I'm from OMB. Show me."

Those of us who have read many benefit-cost analyses of individual projects find that the frequency of benefit-cost ratios over one far exceeds the frequency below one. This occurs because evaluations are typically written by advocates of the projects. A general principle emerges. Advocates cannot be trusted to evaluate their own projects. They have a conflict of interest. Yet advocates typically have a monopoly on the technology they pursue. The upshot seems to be that they are the only ones who can do the initial analyses of their own projects. It is much more preferable for them to analyze several projects at once, however. Their results are useful for ordinal rankings of their own projects if not for cardinal measurements which can be compared with other agencies' evaluations of their own projects. Thus, I find much more interesting a cost-effectiveness analysis in which several discrete alternatives are explored[1] than one which looks at a single isolated project[2].

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[1] Such as USDOT "Urban Commutation Alternatives": or Meyer, Kain and Wohl, "The Urban Transportation Problem"

[2] Examples are Foster and Beesley "Estimating the Social Benefit of Constructing an Underground Railway in London" Journal of the Royal Statistical Society vol. 126 (1963) or Van Beuren Stanbery "
" in Parsons, Brinckerholf-Tudor-Bechtel et al Composite Report.

It is silly to write an apology for remote sensing if it is clear that a single satellite is going to be put in orbit in any case and the study is simply to satisfy some form.

There is good reason to be skeptical of benefit-cost analyses of research and development projects in particular. Many of them claim to have fantastic benefits: for example, one in OMB's library is the U.S. Department of Agriculture, Benefit-Cost Analysis of Research on Live Poultry Handling which claims "a favorable benefit-cost ratio of 1164:1" and another Benefit-Cost Analysis of Research on Scab Resistant White Potato Varieties is able to be quite precise with its ratio of 92.8:1. One suspects that these studies are not very realistic with respect to the probabilities of finding preventions or cures or to the application of the results they find. Nevertheless, one might through the use of several studies by USDA on poultry handling, white potato varieties and Southern White Pine genetics with claimed ratios of 1164, 92.8 and 12.3 to 1, respectively, begin to create a hierarchy for R&D projects in Agriculture.

The decision on what subsequent (post ERTS) remote sensing devices to use is one which has to be made. Research on the benefits of remote sensing would seem to be appropriate to help allocators of federal funds make their decisions on how many subsequent satellites or conventional aircraft to support. The most immediate concept of benefits is cost savings. Remote sensing via satellite or conventional aircraft may obviate programs of data collection now being pursued. This is true if data from remote sensing is equivalent to that gathered at present. If it is less desirable or more desirable, then costs saved is not a good concept of benefits. If additional data of benefit to the state of California and not previously collected can be obtained through remote sensing, then, within the context of this report, increases to Gross State Product is the proper concept of benefits.

It will be appropriate to discuss below present programs of data collection used in California relating to the supply of water and the demand for water.

An earth resources technology satellite produces several types of services. If we seek to segregate the costs attributable to aiding in the management of California water, we face a very recurrent problem: that of common costs, sometimes loosely called joint costs. Total costs of the satellite are incurred not only to manage water but for other possible applications as well, and not only in California but, potentially, on a global basis. We have read the analyses of Willow Run Laboratories[3] on possible applications of ERTS-1 in such varied fields as land use planning, exploration for mineral resources, and the charting of doubtful shoals under water. It would be desirable to have an equitable means

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[3]Designs of a Study to Evaluate Benefits and Cost of Data from the First Earth Resources Technology Satellite (July 1972)

to allocate the common costs for comparison with the benefits. Unfortunately,[4] perhaps, a more rational approach is to sum the benefits from all purposes and compare them to the toal costs. This solves the problem of dubious or arbitrary allocations of common costs.

II Considerations Relative to the Supply of Water

Let us review what we have learned on data acquisition programs relative to the supply of water in California.

The U.S. Army Corps of Engineers maintains daily precipitation records.

A California Co-operative Snow Survey is pursued under the auspices of the State Department of Water.

Most of the pertinent facts regarding data sources on California's water supply will be found in Chapter 2 of the Progress Report. The costs of these data collection efforts should be sought from the Budget of the State of California. A judgment as to what fraction of these data collection efforts could be accomplished through remote sensing will be needed.

The Value of the Weather by W. J. Maunder[5] reports on benefit-cost analyses of information on the weather. Benefit-cost ratios from 2 to 20 (and higher) have been reported. We intend to read this book carefully in the near future. This book states "It is now generally accepted that the overall benefit-cost ratio of a National Meteorological Service is approximately 20:1."[6] This sounds suspiciously like a number that was offered once hesitantly to meet a deadline, was quoted in several places, and by apparent corroboration was ensconced as an accepted fact. A similar experience transpired for an estimate of the total costs to the U.S. of air pollution.

III Considerations Relative to the Demand for Water

Water is used for a great many purposes, including community water supply, industrial water supply, flood control, power generation, salinity repulsion, river flow requirements for fish, and irrigation.

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[4] While common costs can sometimes be allocated through statistical methods or regression analysis when there are several repetitions or satellites, this is not likely to be possible in a remote-sensing application.

[5] (New York: Harper and Row, 1970)

[6] Ibid., p. 259

Each of these uses creates a demand for water to be drawn down from a reservoir. Several might be called "nonconsumptive uses of water" e.g. flood control, power generation, and river flow requirements. Flood control creates a demand for drawdown to leave room in a reservoir for possible runoff. There is a demand for water throughput to generate hydroelectric power, but once the water passes through the generators it can be used for other purposes. Similarly with water to augment the flow of a river.

Water needed for irrigation varies with desired levels of agricultural output. Discussions with W. Ward Henderson of the California Crop and Livestock Reporting Service have indicated the major data collection activities relative to California agriculture. Data are collected on field crops, fruits and vegetables. Fruit crops are described in most detail e.g. by age, variety and country. Data gathering currently is facilitated by use of aerial photographs obtained from the USDA Photographic Laboratory (Salt Lake City). Some small contracts are let for the flying of additional aerial photography. Verbal and mail surveys are employed as well.

IV   Some Final Caveats Relative to Benefit-Cost Analyses

One wonders what the impact of a benefit-cost analysis would be, if rigorously applied to the remote sensing of California's water resources. There have been at least thirteen similar studies done already on such widely varying topics as rural roads, soil classification, crop inventories and yield, increased harvest of marine life, water source monitoring for power generation efficiency, grazing land management, estuarine and coastal management, water management in the Columbia River Basin, management of wheat crop yield and inventory, early detection and control of wheat rust, land use, mineral resources exploration for copper, and nautical charting of doubtful shoals.[7]   Several of these previous cost-benefit studies appear to be closely related to one which might be done on the management of California's water resources, especially the study of water management in the Columbia River Basin and water sources monitoring for power generation efficiency.

As applied to California, estimates of benefits accruing from the use of remote sensing in relation to many of the other topics listed above would not be harmful. Total claimed benefits are likely to be astronomical. A Canadian estimator surveyed the first ten of these applications and ventured the range of $25 to 250 million per year for benefits, with $140 million the most likely number. If the life of a remote sensing satellite could be considered as infinite, and the applicable discount rate were 8 per cent, the total value would be about

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[7]Willow Run Laboratories, op. cit., pp. 137ff.

$1.75 billion for Canada. If the same satellite could serve the U.S., who knows the great heights to which claimed benefits might climb?

The first concept of benefits would be cost savings. This is not a controversy-free concept of benefits. Whenever jobs are obviated many people consider the enterprise a loss.

In those instances where remote sensing is found to be capable of gathering useful data which is not presently collected, the value of this information needs to be calculated. The value of any such piece of information is the expected utility of the optimal action taken in the presence of the piece of information minus the expected utility of the optimal action taken in its absence.

A benefit-cost ratio in excess of one does not imply that a project should be undertaken. If there is a budget constraint, many projects with ratios above one might not fit into an optimal program of projects which is feasible in the sense that it satisfies the budget constraint.

Before one undertakes a benefit-cost analysis he would do well to ask what decision the analysis is expected to illuminate. Who is the client for the analysis, i.e., who will use the results? Benefits have meaning only in the context of a stated objective and it is the clients' objectives that one needs to serve. Perhaps we could get information on these questions by inquiring what decisions the 13 previously mentioned benefit-cost analyses illuminated and for whom.

There are several reasons why a traditional benefit-cost analysis is inadequate for making social decisions. The heart of the analysis is the question of value. How do we evaluate the outputs of a project? These values are in many ways dependent on the status quo. They depend on the prevailing distribution of income among people. Groups with high incomes register their preferences and create effective demand for the goods and services which they desire. Unless there is a good reason to do otherwise, economists typically take market prices for unit values of goods and services. Those market prices can frequently be misleading because of monopoly, artificially government-controlled prices, failure to account for the scarcity value of a good, like water, which appears free but is actually limited. It is the task of a good benefit-cost analysis to create shadow prices, where needed, to correct market prices.

There is another reason why values expressed in benefit-cost analysis can be misleading. They are very fragile. As awareness of energy shortage grows, many relative prices change: urban land rents may grow relative to rural rents, the relative price of labor may decline, etc. And yet energy is really no more scarce than it was two months ago. Only public awareness has changed relative prices. If a benefit-cost analysis had been done before the changed awareness, it probably would have used faulty prices.

A benefit-cost analysis is more illuminating if it examines several alternatives rather than one alternative. Useful alternatives might be:

1. the present means of gathering data
2. a satellite remote-sensing device
3. conventional aircraft at 20,000 feet and requiring, say, 300 flights
4. high performance aircraft at 50,000 feet, and requiring, say, 100 flights
5. a combination of (2) and (3) with the number of flights variable
6. a combination of (3) and (4) with the number of flights variable

It is not harmful to do a benefit-cost analysis so long as its severe limitations are recalled and it is supplemented with socio-economic impact studies.

V Suggested Procedure for Subjecting Remote Sensing Techniques to a Benefit-Cost Analysis

The following step-wise procedure for making a benefit-cost analysis of using remote sensing techniques could be used either in the limited context of the present progress report (i.e. as applied solely to California's water resources) or in a context as broad as the making of integrated resource surveys of the entire earth resource "complex" on a statewide, regional, national or global basis. Obviously a higher benefit-cost ratio would be expected in the latter context.

1. Survey all present data-collection efforts which can be accomplished by remote sensing techniques.

2. By careful inspection of the State of California <u>Budget</u> and the <u>Budget of the United States Government</u> find the annual cost of each of these data collection efforts.

3. Decide the extent to which remote sensing can obviate each of the data collection efforts.

4. Sum the annual costs of all data collection which can be equivalently accomplished through remote sensing. Call this amount b_1.

5. Decide what additional data could <u>and would</u> be collected through remote sensing.

6. Estimate the value of this information. This is a difficult task involving subjective estimates as to whether decision makers will actually change their behavior because of the existence of new data. A definition other than the one used in this document for the value of information may be chosen. Call this annual benefit b_2. One concept might be the expected value of the change in Gross State Product due to the new information.

7. These benefits may change over time, but for simplicity let us assume they stay constant at $b_1 + b_2$. Sum these over the life (T years) of the remote sensing alternative and discount them to present value

e.g.

$$B_w = (b + b) \quad 1 + \frac{1}{1+r} + \frac{1}{(1+r)^2} + \cdots + \frac{1}{(1+r)^{T-1}}$$

where r is the selected discount rate.

Reasonable values for r are about 8 percent. If annual benefits vary, then

$$B_w = (b_{11} + b_{21}) + \frac{(b_{12}+b_{22})}{1 + r} + \frac{(b_{13}+ b_{23})}{(1+r)^2} + \cdots + \frac{(b_{1,T} + b_{2,T-1})}{(1+r)^{T-1}}$$

8. Do steps 1 through 7 for each of the alternatives examined.
9. Do not make direct comparisons with costs. B_w would be available to add to benefits forthcoming from uses other than the management of water resources.

$$\text{Then } B_{grand} = \sum_{j=w,m,etc} B_j$$

The net benefits, N, of the remote-sensing alternative would then be

$$N = B_{grand} - C$$

where C is the cost of the satellite or other alternatives.

10. $C = K + \phi \quad 1 + 1/1+r + \cdots + 1/(1+r)^{T-1}$

where K = initial or capital costs
ϕ = annual operation, maintenance and repair costs.

Alternatively, one might define several alternatives of constant effectiveness, from which the same data might be collected. The problem then would be to find the alternative with the smallest costs. This is called a cost-effectiveness analysis.

One concept of benefits is the change in Gross National Product, presumably positive. This leaves out effects which are widespread on large numbers of people but which do not change production. This is true of nuisances which are pervasive like air pollution or noise. They decrease the welfare of huge numbers of people a small amount each. The welfare loss is considerable but production is not decreased. In fact the GNP might increase as people buy goods to shield themselves from the nuisance like constant noise generators to counteract random street noise.

MULTISPECTRAL COMBINATION AND DISPLAY OF ERTS-1 DATA

By

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INTRODUCTION

A significant problem in the use of ERTS-1 data is the extraction of information pertinent to each application and the presentation of that information in a form most suitable to users.

When the information is to be displayed for visual study by an observer, then the problem can be reduced to two independent steps:

1. Dimensionality reduction, an objective procedure which attempts to preserve most of the ERTS-1 information in a smaller number of components.

2. Display of the reduced number of components for "optimum" visibility by an observer.

A specific dimensionality reduction technique has been applied to ERTS-1 data for several geographical areas in California and distinct types of Earth Resources.

In the display of the reduced number of components, consideration has to be given to properties of the human visual system and the statistics of the data to be displayed. Our previous work on digital image enhancement (1) is applied to this problem to generate color composites which contain and display most of the information provided by the ERTS-1 sensors.

MULTISPECTRAL DATA COMBINATION: PRINCIPAL COMPONENTS

ANALYSIS AND DIMENSIONALITY REDUCTION

The motivation for extracting the most significant three spectral components from the 4 spectral MSS bands of ERTS-1 is that the space used for display, the perceptual space, has only 3 dimensions corresponding to the 3 primary colors.

Generally, the problem of processing and display of multispectral data is to map a set of N spectral components $\{I_k\}$ into a 3 dimensional perceptual space. A common approach is to choose the "best" three I_k's out of N.

Another approach, described briefly here, is to apply a set of invertible transformations to the multispectral data and then to choose the best subset of transformed components.

Let $\underline{I}'$ be the set of transformed spectral components.

We write

$$\underline{I} = [A]\underline{I}' \qquad (1)$$

in which [A] is an NxN matrix, corresponding to a linear transformation of $\underline{I}'$ into $\underline{I}$. The columns of [A] are taken to be orthonormal vectors.

Assume that L< N components of $\underline{I}'$ are used and the others discarded. By entering N-L zero components into $\underline{I}'$ we form a new vector $\underline{I}''$ which generates by (1)

$$\hat{\underline{I}} = [A]\underline{I}'' \qquad (2)$$

$\hat{\underline{I}}$ is an approximation to $\underline{I}$. The goodness of the approximation is measured in a mean-square sense.

$$\varepsilon_L = E[||\underline{I} - \hat{\underline{I}}||^2] = E[\sum_k (I_k - \hat{I}_k)^2] \qquad (3)$$

for a given L, a question of interest is the optimum choice of the set of transformed components $\underline{I}'$ and therefore of the transformation matrix [A].

The solution to this problem for the criterion of (3) is known as the decomposition into principal components or as the Karhunen-Loeve representation of $\underline{I}$, reported in the literature. Let $[\mu]$ be the covariance matrix of the data, then the vectors $\underline{e}_k$, K=1, ...N columns of the matrix A are obtained by solving the matrix equation

$$[\mu]\underline{e}_k = \lambda_k \underline{e}_k \qquad (4)$$

in which the λ_k's are positive numbers, also to be determined. Equation 4 is the formulation of a classical mathematical problem with known solution. The λ_k's and $\underline{e}_k$'s are denoted eigenvalues and eigenvectors of matrix $[\mu]$ respectively.

Once the λ_k's and the $\underline{e}_k$'s are obtained, the transformed vector $\underline{I}'$ is obtained by the matrix operation

$$\underline{I}' = [A]^T \underline{I} \qquad (5)$$

From $\underline{I}'$, one obtains $\underline{I}$ back by (1) since

$$[A]^T[A] = [I] \qquad (6)$$

in which $[I]$ is the identity matrix.

The mean-square error approximation of equation (3) is expressed easily in terms of the λ_k's. It can be shown that

$$\varepsilon_L = E(\sum_k (I_k - \hat{I}_k)^2) = \sum_{k=1}^{L} \lambda_k \qquad (7)$$

Since $\hat{\underline{I}}$ is obtained by retaining only L of N transformed components $\{I'_k\}$, one can readily determine, from the λ_k's, the mean-square error incurred by discarding N-L components.

Note that the choice of the transformation matrix $[A]$ and the resulting mean-square error (7) are dependent on the covariance matrix $[\mu]$ and thus on the data used in the estimation of $[\mu]$. In the case of ERTS-1 data we expect significant variations in the covariance matrix with the type of natural resource and the seasons.

APPLICATION TO ERTS-1 DATA[*]

We have applied the approach just outlined to ERTS-1 data, and the results are interesting, both in terms of the small mean-square error caused by the dimensionality reduction, as well as for the examples of enhanced images we have obtained.

We examined the mean-square error introduced by a dimensionality reduction for 3 areas of California: The Bucks Lake region, a wildland area; the farmland south of Isleton; the East Bay cities which include part of San Francisco Bay and some woodlands. Two questions of interest are: What is the percent mean-square error introduced by a dimensionality reduction? What are the corresponding eigenvectors and thus corresponding spectral combination used?

The answer to these questions can be obtained from the Tables 1 and 2 and for two of the 3 geographic areas.

The normalized covariance matrix (correlation coefficient matrix) indicates the pairwise linear similarity and correlation of the data for the 4 spectral components. As noted earlier MSS bands 4 and 5 and MSS bands 6 and 7 are highly correlated in all cases.

The variances of spectral components are also given (within a scale factor) to indicate their relative ranking. Ratios of variances range from 3 to 1 to 8 to 1.

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[*] See References 5 and 6 for additional discussion of principal component analysis applied to Remote Sensing Data.

TABLE 1. Eigenvalues and eigenvectors used in optimizing the choice of ERTS-1 spectral bands for enhancing wildland resource features in the NASA Bucks Lake Test Site as explained in the text.

$$
\begin{bmatrix}
1.0000 & .9356 & .5097 & .3341 \\
.8356 & 1.0000 & .4317 & .2429 \\
.5097 & .4317 & 1.0000 & .9633 \\
.3341 & .2429 & .9633 & 1.0000
\end{bmatrix}
$$

$[\rho]$ Normalized Covariance Matrix

| 109 | 283 | 791 | 600 | Variances |

$$
\begin{bmatrix}
.8685 & -.4939 & -.03927 & .001917 \\
.07850 & .1941 & -.6708 & .7114 \\
.4659 & .8220 & -.05041 & -.3232 \\
.1492 & .2060 & .7388 & .6240
\end{bmatrix}
$$

$[A]^T$, Rows are Eigenvectors

| 9.278 | 10.79 | 325.1 | 1439. | $\{\lambda_k\}$ Eigenvalues |

TABLE 2. Eigenvalues and Eigenvectors used in Otpimizing the Choice of ERTS-1 spectral Bands for enhancing agricultural resource features in the Isleton portion of our NASA San Joaquin Valley Test Site, as explained in the text.

$$
\begin{bmatrix}
1.0000 & .9537 & .2323 & .0187 \\
.9537 & 1.0000 & .1226 & -.0881 \\
.2323 & .1226 & 1.0000 & .9629 \\
.0187 & -.0881 & .9629 & 1.0000
\end{bmatrix}
$$

$[\rho]$ Normalized Covariance Matrix

| 467 | 947 | 860 | 411 | Variances |

$$
\begin{bmatrix}
.1515 & .0120 & -.5699 & .8074 \\
.8118 & -.5689 & .0208 & -.1292 \\
-.2358 & -.4330 & .6859 & .5349 \\
.5120 & .6990 & .4517 & .2123
\end{bmatrix}
$$

$[A]^T$ Rows are Eigenvectors

5-12

| 7.540 | 25.16 | 1186. | 1467. | $\{\lambda_k\}$ Eigenvalues |

Turning to the eigenvalues and using (7) we have the following table for percent error due to dimensionality reduction.

TABLE 3

Entries are percent mean-square error

		Bucks Lake	Isleton	East Bay
1	component discarded	.52	0.28	0.81
2	components discarded	1.13	1.21	2.1

We see that in all cases, by linear transformation, it is possible to generate 3 equivalent components which represent the 4 spectral MSS bands with less than one percent error.

The relatively larger mean-square error for the East Bay image, which contains a substantial area of water, suggests that significantly different results may be obtained by handling the water area separately.

To test this hypothesis we processed the East Bay image and also a large image of the Bay Area containing water, land and partial cloud coverage. The principal component analysis was carried out separately on land, water, and clouds. The separation of these distinct areas is done quite well by using a threshold on MSS 7 radiometric data to generate a water area mask since in the infrared the reflectivity of water is very low. Clouds are also easy to remove by thresholding.

For the East Bay Image we have the results of Table 4. This table shows markedly different results for water and land in that the spectral combinations (eigenvectors) needed for optimal dimensionality reduction are quite different. Also dimensionality reduction is significantly less effective for water than it is for land.

TABLE 4

East Bay Cities. Principal Component Analysis

352	290	544	725	Variances (MSS 4,5,6,7)	
-.32	.06	.74	-.58		
-.60	.76	-.20	.15	Eigenvectors	Land only
.68	.60	-.70	-.40		
.26	.24	.63	.69		
23.1	25.4	541	1322	Eigenvalues	

Table 4 (continued)

				Variances	
80	35	4	8.5	(MSS 4,5,6,7)	

$$\begin{bmatrix} .07 & -.16 & .98 & -.02 \\ .07 & -.10 & .00 & .99 \\ -.48 & .85 & .18 & .12 \\ .87 & .49 & .02 & -.02 \end{bmatrix}$$

Eigenvectors   Water only

3.7	8.3	14	101	Eigenvalues

Thus, although from the eigenvectors of Tables 1 and 2 it appears that some fixed combination of spectral components may lead to acceptable results in all cases, Table 4 indicates that the issue has to be examined more carefully with regard to each specific objective.

DISPLAY OF THE SIGNIFICANT DATA

When the data has been reduced to 3 principal components, it remains to combine these components in a color composite which provides acceptable visual discrimination of the information contained in the data.

One has to choose first the color primaries, or color coordinates to which the principal components will be assigned. The statistics of each principal component (histogram) can then be used to maximize the average visibility of the data.

In the assignment of color primaries we have considered an assignment of Red, Green and Blue coordinates to the principal components. The examination of the eigenvectors, for each specific geographic area, allows an assignment which matches as closely as possible the conventional color assignments of the standard NASA color composites of ERTS-1 data.

Other assignments of color primaries have been considered. These assignments try to exploit more fully the space of visual perception and visual discrimination and the large differences in the variances of the principal components. One possible choice is to assign the component with the largest variance to luminance and the two other components to chrominance. In several examples this approach is disappointing and leads to flat images. Further work is underway on this basic problem in the display of multispectral data, which is due to the high correlation of the sensor outputs themselves.

After all data transformations, best use is made of the perceptual space available by enhancement of each display component as discussed in [1]. Thus, histograms are generated and a nonlinear mapping of data values I_{RD}, I_{GD}, I_{BD}, to display values I_{RV}, I_{GV}, I_{BV} is done using the relations:

$$I_{RV} = g_R (I_{RD})$$

$$I_{GV} = g_G (I_{GB}) \tag{8}$$

$$I_{BV} = g_B (I_{BD})$$

and

$$g_R(I_{RD}) = K_1 \int_{-\infty}^{I_{RD}} [f_R(x)^{\frac{1}{2}} dx + K_2] \tag{9}$$

in which $f_R(x)$ is the histogram of the data assigned to Red and K_1 and K_2 are chosen to match the range available for display. Similar mappings are used for the green and blue signals.

DISCUSSION OF THE RESULTS AND CONCLUSIONS

Dimensionality reduction by principal component analysis, exploits, in an optimal way, the redundancy and correlation which exist in ERTS-1 data. The results presented here for distinct geographic areas indicate that it is possible to represent with 3 principal components the 4 band MSS ERTS-1 data with little loss of radiometric accuracy. Since this approach depends on statistics or average properties of the data, some care is needed in assessing the relevance of a global transformation and of global measure of approximation to each specific application.

The separation of ERTS-1 data into land, water and clouds, which is possible with fairly simple techniques, is important in the analysis and display of ERTS-1 data. In particular Table 4 indicates that water and land may require different transformations and for the purpose of display it certainly appears desirable to enhance water separately because of the small range of data values recorded.

We note also that the results presented here did require a radiometric correction of the digital data to reduce or eliminate stripping. The technique used for sensor response equalization has been reported [2].

Principal component analysis established a firm theoretical basis for multispectral data combination, but requires an algorithm adapted to the data being processed. Some of our results indicate that a fixed multispectral combination, not dependent on specific statistics but suggested by statistical analysis, may be satisfactory in many cases. A detailed study is needed to determine and assess such a multispectral combination in applications.

In applications, dimensionality reduction is of use in automatic classification or in the study of images by photo interpreters. Personnel of the Center for Remote Sensing Research at the University of California, Berkeley [3] have used some images enhanced and displayed by

techniques previously reported [1] to detect and classify total commercial conifer in the Sierra Nevada in California, by photo interpretation. Other work on the delineation of sediments in water has also been done [4]. Results are indicative of the merits of the enhancement technique and it is expected that combining dimensionality reduction with image enhancement will provide significantly better results.

AN ILLUSTRATIVE EXAMPLE

As an example of multispectral data combination and display we processed a large portion of the San Francisco Bay area, 1165-18175. The first image, Figure 1, shows the result of processing the 4 MSS bands. Principal components are extracted separately for land and water and the corresponding transformation applied. Clouds are not processed. A composite image is generated by juxtaposition of subimages. The composite image appears to convey a large amount of information, but a detailed study remains to be done.

In Figure 2 we show another example of principal component analysis and display for multispectral data. For the farmland south of Isleton 1003-18175 we have a principal component extraction, which results in a mean-square error of only 0.28 percent. Color assignment gives now greenish color for most vegetation.

Figure 1. Bay Area, Image 1165-18175

MSS 4,5,6,7 Principal Components, Enhanced

Figure 2.   Farmland South of Isleton, Image 1003-18175

MSS 4,5,6,7 Principal Components, Enhanced

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Special Study No. 3

POWER LAW TIME DEPENDENCE OF RIVER FLOOD DECAY
AND ITS RELATIONSHIP TO LONG TERM DISCHARGE FREQUENCY DISTRIBUTION

By

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During the period covered by this report we have continued to
investigate the possibility that significant information on stream
flow rates can be obtained from aerial and satellite imagery of river
meander patterns by seeking a correlation between the meander and dis-
charge spectra of rivers. Such a correlation could provide the basis
for a simple and inexpensive technique for remote sensing of the water
resources of large geographical areas, eliminating the need for much
hydrologic recording. The investigation of the nature of the meander
and discharge spectra and their interrelationship can also contribute
to a more fundamental understanding of the processes of both river
meander formation and drainage of large basins.

A large number of correlations which we and others have already
made clearly suggest that there is a relationship between meander
wavelength and discharge but its quantitative form is not yet clear.
We believe that this disagreement may result primarily from the over-
simplification inherent in using a single meander wavelength and a
single discharge to characterize the river rather than using the
complete spectrum of wavelengths and discharges.

The idea of using a spectral analysis of the reach of a river as
the basis of a correlation rather than a subjective estimate of an
assumed single length scale is a necessary generalization in describing
the connection between a river's meander pattern and its discharge.
However, a single discharge can perhaps be correlated with the multiple
length scales. Just as there is an essential difficulty in attempting
to characterize a meander pattern by a single length scale, there is a
fundamental problem in trying to choose the dominant discharge, i.e.
that discharge most effective in establishing the system of meanders.
With the aid of ERTS-1 imagery we are testing the further generalization
of the correlation to include the time-behavior of the discharge in the
belief that it may bring an order to the relatiohship between the total
meander pattern and the complete record of the discharge. Hopefully
this more general correlation will be sufficiently reliable to quanti-
tatively assess a river's flow rate from a spectrum of its meanders,
thus making the knowledge of a region's water resources accessible from
aerial or satellite imagery of the area.

As a basis for this study we have developed a fully automated
system for obtaining both the discharge and meander wavelength spectra.
Discharge spectra (probability of discharge per unit discharge vs.
discharge) are constructed from historical records of daily stream
discharge. Generation of meander power spectra involves three elements:

digitization by photoelectric optical tracking of stream banks on each frame of imagery; collation and matching of successive frames into a single data record for each stream; and a Fourier transform analysis of the data. This system has been developed to facilitate the analysis of the large number of rivers required to assure the statistical reliability of the correlation.

In the present reporting period we have given particular attention to river discharge frequency distributions, based on long term records of daily stream flow. As detailed in the remainder of this report, we have found that such distributions often have an inverse power law dependence on discharge. This is shown in our studies to reflect the short term decay of individual river floods which are found to have an inverse power law dependence on time. There is evidence that this relationship will allow forecasting of river discharges with about ± 5% uncertainty for as much as 30 days after flood peaks.

The discharge frequency distribution of a river is the probability per unit discharge that its discharge, or flow rate, Q, lies within the interval ΔQ at Q. The integral of this distribution over discharge is the flow duration curve commonly used in hydrologic studies. If historical records of daily river discharge are available, the frequency distribution can be determined by the fraction of time the discharge lies within the prescribed interval per unit interval. We have obtained historical hydrologic data for a large number of rivers from the Water Resources Division of the U.S. Department of the Interior and have constructed discharge frequency distributions, a number of which are shown in Figure 1. The daily discharge data on which each distribution was based extends over the indicated time interval for the particular gauging station identified by number according to the convention adopted by the USGS [1964].

A remarkable property of a large number of these discharge frequency distributions is their nearly linear character on the log-log plots of Figure 1 for values of discharge larger than the mode. The slopes of the linear portions of these distributions vary from river to river and even from station to station on the same river over the range from less than -1 to -5. Flow duration curves have previously been interpreted as representing a random process described, for example, by a log-normal distribution [Leopold et al., 1964]. Our results, however, show that such an interpretation is not appropriate for a large number of rivers, since it is inconsistent with the clearly linear character of the log-log frequency distribution plots. Instead, we suggest that the distribution for discharges greater than the mode must be essentially deterministic in nature, reflecting the decay phase of the flood hydrograph. We have not found any previous suggestion of a direct relationship between the form of the flow duration curve and the flood hydrograph.

From a discharge record of length T, the discharge frequency distribution which we calculate is $\frac{1}{T} \cdot \frac{\Delta t}{\Delta Q}$ where Δt is the portion of time the
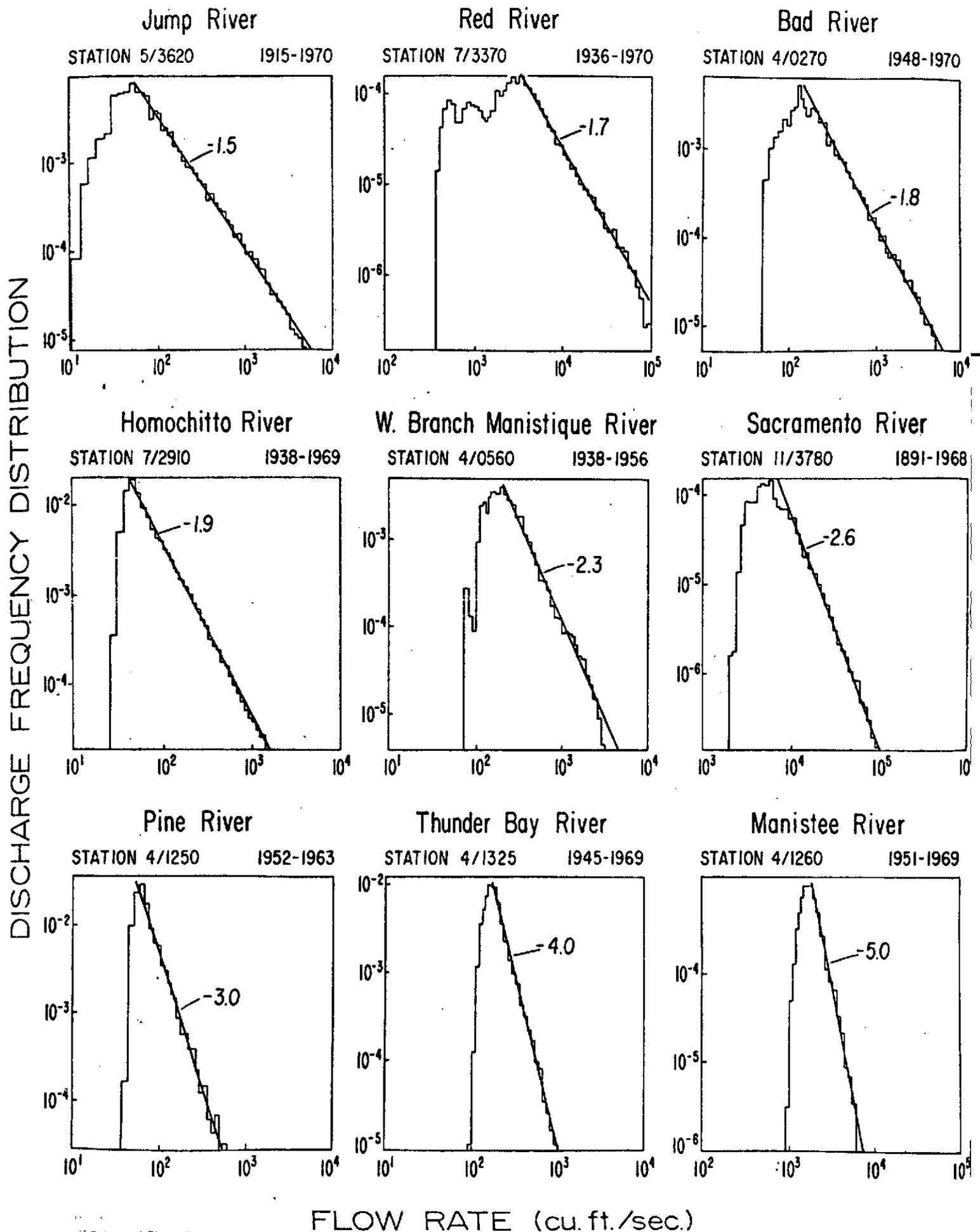
Figure 1. Relationship between flow rate and discharge frequency distributions for nine rivers

discharge lies within ΔQ at Q.   If s is the slope of the log-log
frequency distribution, then

$$\frac{dt}{dQ} \propto Q^s \qquad (1)$$
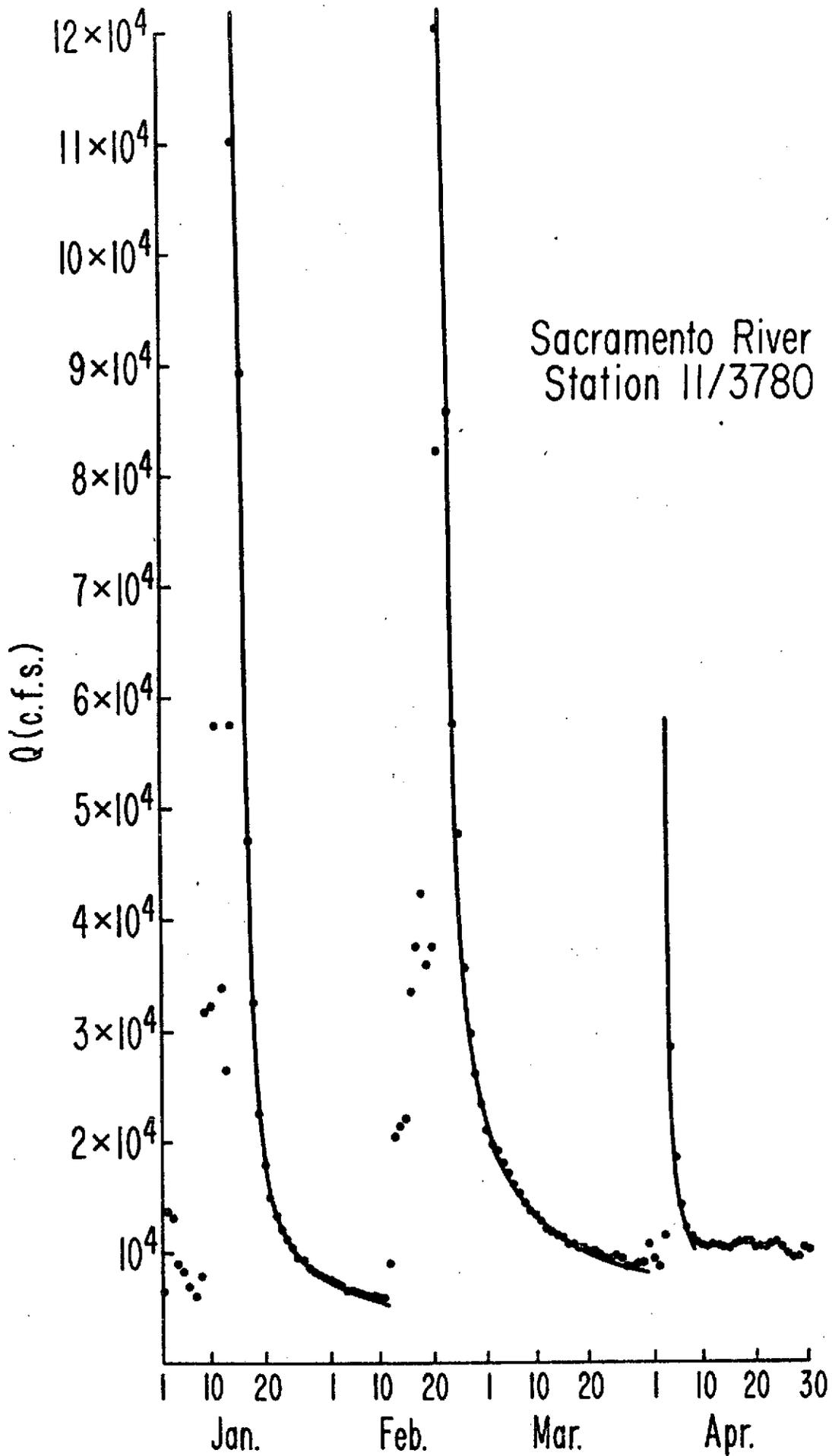
Integrating (1) we find

$$Q \propto t^{\frac{1}{s+1}} \qquad (2)$$

Since the observed values of S lie between about -1.5 and -5 the exponent
$\frac{1}{s+1}$ would range from about -2.0 to -0.25. We suggest that (2) represents
the decay phase of the flood hydrograph, where t is measured from a time t_0
near the flood peak.   The time t_0 can be uniquely determined from any two
discharge measurements Q_1 , Q_2 at times t_1 , t_2 during the flood recession
by

$$t_0 = \left\{ t_2 \left(\frac{Q_1}{Q_2}\right)^{s+1} - t_1 \right\} / \left\{ \left(\frac{Q_1}{Q_2}\right)^{s+1} - 1 \right\} . \qquad (3)$$

The inverse power law dependence of the discharge on time, which we
find here, differs from the superposition of several exponential decay
curves, which have previously been used to empirically fit the flood
recession (e.g. Barnes, 1940).

To test our suggestion that the linear nature of the log-log fre-
quency distribution represents the recession portion of the flood hydro-
graph, we have compared the time dependence of the discharge predicted
by (2) and (3) with the measured decay of discharge following individual
flood peaks on the various rivers studied. We find that the predicted
decay at each station does indeed describe the measured discharge fol-
lowing all flood peaks at that station. An example of the agreement
between predicted and measured flood recession is shown in Figure 2 for
the Sacramento River near Red Bluff, California, in 1936. As can be
seen, the curves of the theoretical flood decay are an excellent fit to
the data points which indicate the measured values of the daily dis-
charge. The theoretical curves are based on a value of s equal to -2.6
(see Figure 1) and values of t_0 equal to 16 January, 22 February and 4
April for the respective floods shown in Figure 2. At this station on
the Sacramento River, floods decay according to the rule $t^{-0.625}$, which
allows the recession to be determined for as long as a month following
the flood peak! From the hydrograph of Figure 2 it can be seen that the
deterministic flood decay extends down to discharges of about 10^4 c.f.s.
at this station. Below this discharge level the flow rate variations
appear to be stochastic in nature. This also is consistent with the

Figure 2. Hydrograph showing degree of agreement between predicted powerlaw flood decays and actual measured flood recession on the Sacramento River   5-22

fact that the linear relationship in the log-log frequency distribution (Figure 1) ceases at discharges below about 10^4 c.f.s. at this station.

Additional examples of the agreement between predicted power law flood decays and measured flood recessions are shown in Figures 3 and 4 for 3 consecutive flood decays on the Homochitto River (7/2910) and the Bad River (4/0270), respectively. The power law decays are excellent fits to the observed values of daily discharge during the flood recessions. Values of s equal to -1.9 and -1.9 (from Figure 1) for the Homochitto and Bad Rivers, respectively, were used to construct the power law decays shown in Figures 3 and 4. The floods at this station on the Homochitto River decay according to $t^{-1.11}$, while on the Bad River station the recession follows the relationship $t^{-1.25}$.

It is noteworthy that the flood decays on the Sacramento River (Figure 2) extend from discharges of about 10^5 c.f.s. down to 10^4 c.f.s., while on the Bad River (Figure 4) the recessions extend from 10^4 c.f.s. down to below 10^3 c.f.s. and on the Homochitto River the transients cover the discharge range from more than 10^3 c.f.s. to below 10^2 c.f.s. The power law flood decays are thus seen to be excellent representations of the measured discharges for recessions which extend over 3 orders of magnitude in discharge. Moreover these rivers are from widely separated regions and represent widely differing hydrologic systems. From Figure 1 it can be seen that the Red River (7/3370) is similar to the Sacramento in that power law flood decays range from 10^5 c.f.s. down to below 10^4 c.f.s. Also from Figure 1 we note that the Manistee River (4/1260) like the Bad River (4/0270) has power law flood decays in the discharge range 10^4 - 10^3 c.f.s. and the Pine (4/1250), Thunder Bay (4/1325) and West Branch Manistique (4/0560) Rivers, like the Homochitto River (7/2910), have power law flood recessions in the discharge range 10^3 - 10^2 c.f.s. The Jump River (5/3620) has power law transients over a two order of magnitude discharge range, from nearly 10^4 c.f.s. to below 10^2 c.f.s.

To firmly establish the validity of our suggestion that the slope s of long term discharge frequency distributions reflects the short term decay of individual river floods according to $t^{\frac{1}{s+1}}$, we have used the power law decays with the appropriate value of s, to fit ten sample flood recessions at each of the gauging stations of Figure 1. The results are summarized in Table 1 which lists, for each river in Figure 1, the inclusive dates of the sample flood recessions, the root mean square (rms) errors in the power law fits of the recessions, and the average rms error of fit for the 10 cases. The flood recessions listed in Table 1 were selected by scanning the available hydrologic data in the Water Supply Papers to find the longest uninterrupted flood decays for each river. Each recession was terminated when the flood had decayed to the stochastic level of discharge as indicated by the data. The rms error of the power fits of the 90 flood recessions listed in Table 1 are remarkably small, averaging only about 5 percent, a value comparable
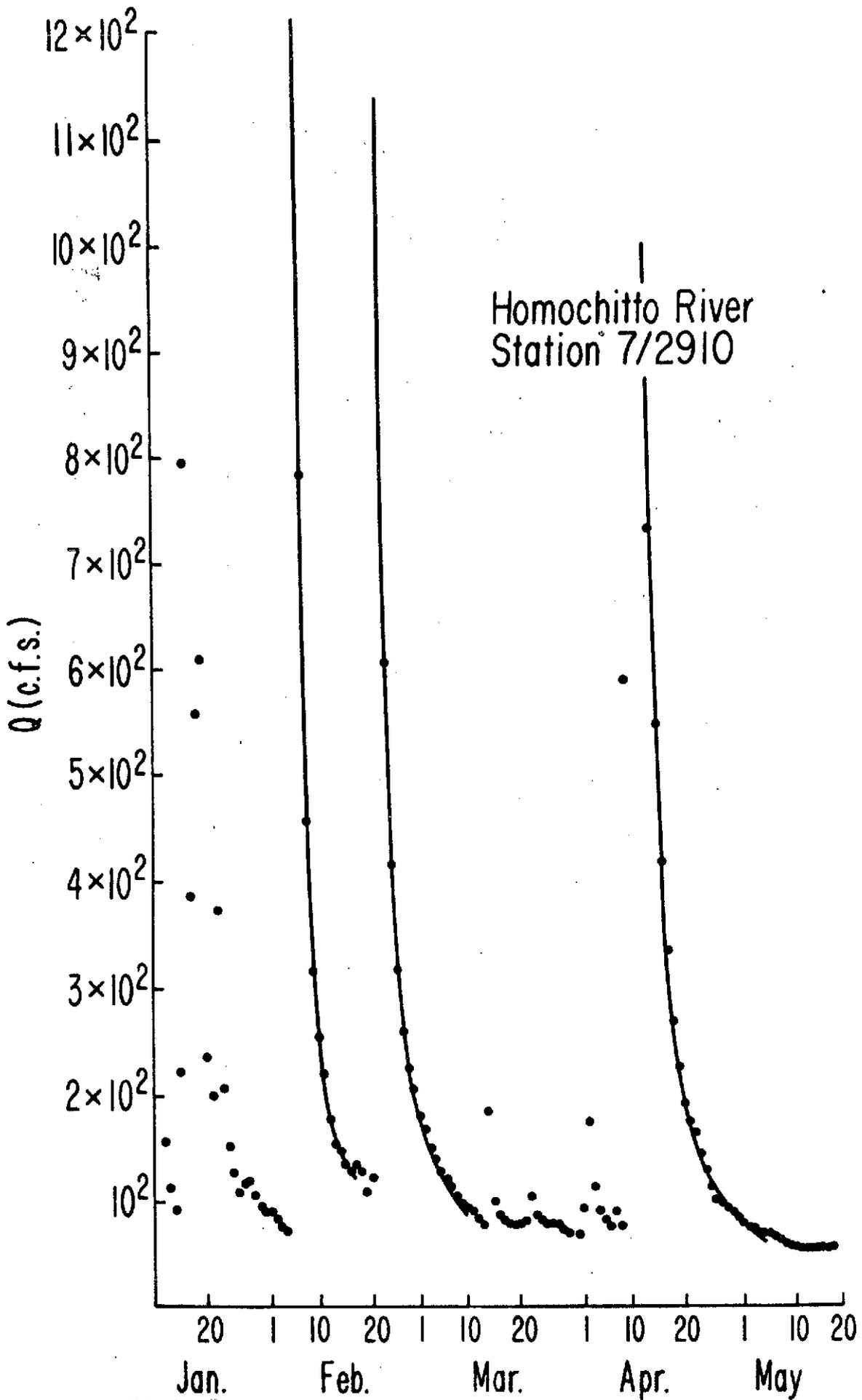
Figure 3.   Hydrograph showing degree of agreement between predicted
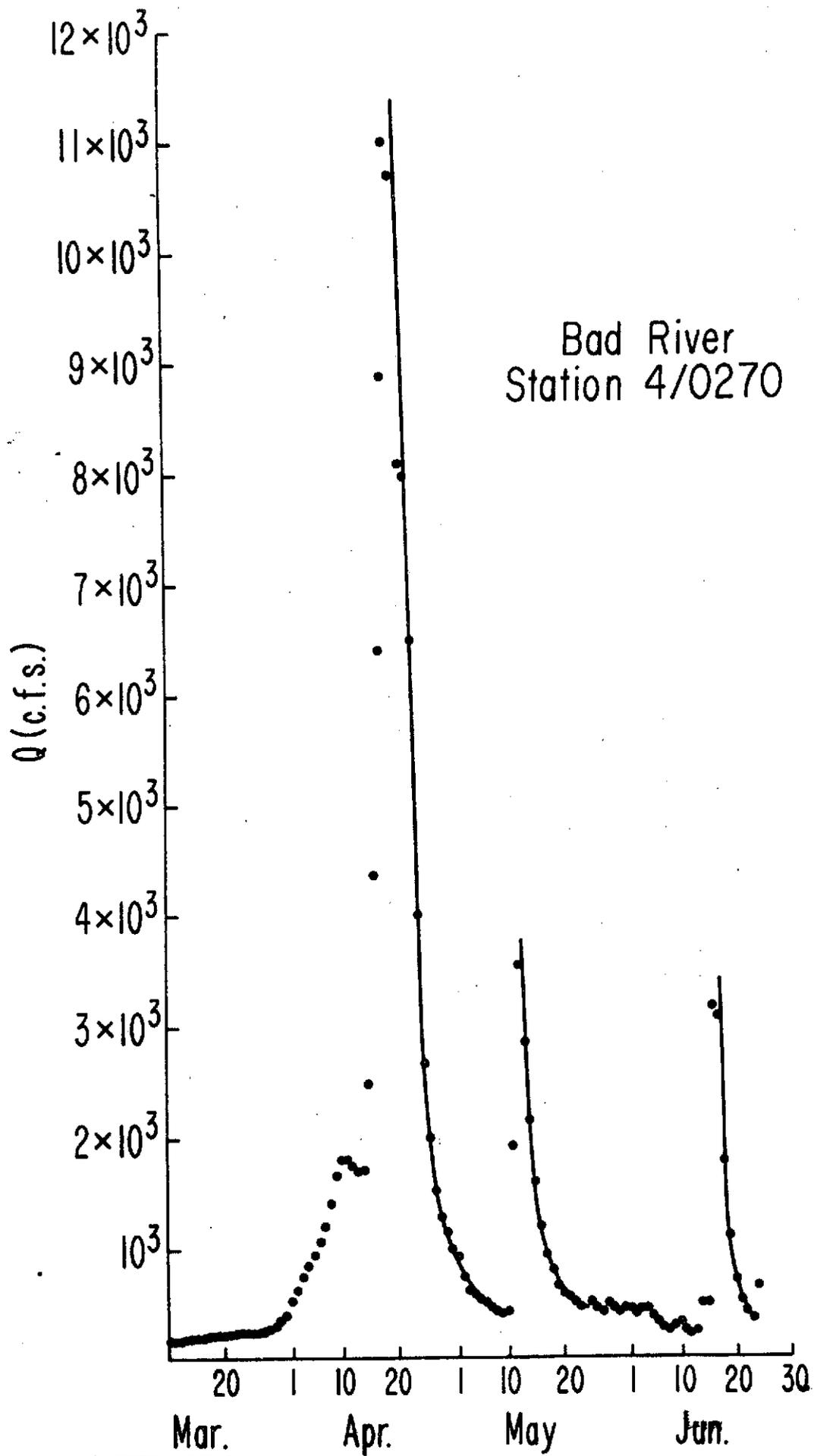powerlaw flood decays and measured flood recessions on the
Homochitto River   5-24

Figure 4. Hydrograph showing degree of agreement between predicted
power law flood decays and measured flood recessions on the
Bad River.   5-25

TABLE 1.   POWER LAW FITS TO RIVER FLOOD DECAYS

RIVER	INCLUSIVE DATES OF FLOOD DECAYS	RMS ERROR OF FIT	MEAN RMS ERROR
MANISTEE RIVER 4/1260 s = - 5.0 $Q \propto t^{-.25}$	4/11-4/14/59, 7/26-7/30/52, 11/21-11/24/58 4/7-4/10/56, 10/8-10/11/54, 4/11-4/14/58 6/5-6/8/54, 7/14-7/18/57, 4/22-4/25/60 5/30-6/2/53	1.7%, 7.1%, 1.6% 1.7%, 5.2%, 1.4% 0.4%, 1.1%, 2.4% 3.3%	2.6%
THUNDER BAY RIVER NEAR HILLMAN, MICHIGAN 4/1325 s = - 4.0 $Q \propto t^{-0.33}$	5/23-5/30/59, 4/7-4/13/59, 4/9-4/26/56 4/27-5/9/57, 3/25-4/3/53, 3/23-3/30/48 10/18-10/26/54, 4/13-4/22/47, 4/9-4/15/54 3/15-3/21/46	1.3%, 3.3%, 5.5% 8.7%, 2.4%, 3.8% 3.8%, 8.6%, 4.0% 6.0%	4.7%
PINE RIVER NEAR LEROY, MICHIGAN 4/1250 s = - 3.0 $Q \propto t^{-0.5}$	5/21-5/30/60, 7/10-7/20/57, 10/18-10/26/54 6/27-7/6/54, 5/7-5/14/54, 3/24-4/2/53 5/4-5/16/53, 4/8-4/21/58, 4/9-4/15/59 11/19-11/25/58	6.7%, 4.3%, 5.8% 5.4%, 1.7%, 3.9% 1.9%, 4.7%, 3.9% 6.7%	4.5%
SACRAMENTO, NEAR RED BLUFF 11/3780 s = - 2.6 $Q \propto t^{-0.625}$	1/17-2/10/36, 2/24-3/23/36, 3/31-4/15/05 2/6-2/16/07, 4/9-5/9/07, 2/27-3/13/10 2/15-2/28/11, 3/22-4/1/32, 4/18-4/30/20 2/21-3/8/26	3.6%, 2.9%, 3.0% 5.2%, 8.0%, 3.2% 6.6%, 6.2%, 2.7% 5.5%	4.7%
WEST BRANCH OF MANISTIQUE RIVER NEAR MANISTIQUE, MICHIGAN 4/0560 s = - 2.3 $Q \propto t^{-0.769}$	4/14-4/25/53, 4/16-4/27/51, 5/6-5/21/47 5/5-5/14/40, 4/21-5/13/42, 4/13-4/23/56 3/22-4/15/46, 4/30-5/20/54, 4/23-5/10/55 4/26-5/9/52	5.8%, 4.5%, 4.1% 2.7%, 3.3%, 5.4% 6.1%, 6.9%, 8.5% 3.5%	5.1%

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TABLE 1. (continued)

RIVER	INCLUSIVE DATES OF FLOOD DECAYS	RMS ERROR OF FIT	MEAN RMS ERROR
HOMOCHITTO RIVER 7/2910 $s = -1.9$ $Q \propto t^{-1.11}$	2/16-2/29/56, 5/20-6/4/53, 4/14-4/29/55 2/7-2/14/55, 3/28-4/5/42, 2/27-3/9/53 2/23-3/9/55, 4/18-4/27/57, 4/10-4/20/51 4/24-5/4/51	5.9%, 7.2%, 4.2% 5/6%, 3.3%, 1.8% 5.5%, 6.7%, 3.8% 7.4%	5.1%
BAD RIVER 4/0270 $s = -1.8$ $Q \propto t^{-1.25}$	5/15-5/28/56, 6/2-6/13/59, 10/31-11/8/55 7/6-7/15/53, 6/4-6/13/51, 7/6-7/15/51 5/11-5/23/50, 5/14-5/23/52, 4/23-5/5/52 5/7-5/18/49	4.7%, 9.9%, 6.7% 4.4%, 5.7%, 6.7% 3.2%, 4.0%, 4.3% 4.2%	5.4%
RED RIVER 7/3370 $s = -1.7$ $Q \propto t^{-1.429}$	7/19-7/26/48, 2/21-3/2/56, 2/24-3/7/51 3/1-3/9/39, 2/7-2/15/41, 10/3-10/10/36 4/4-4/14/45, 2/26-3/8/38, 4/28-5/8/52 11/7-11/17/41	5.7%, 8.0%, 8.9% 7.7%, 8.9%, 8.1% 3.4%, 7.2%, 4.8% 8.2%	7.1%
JUMP RIVER NEAR SHELDON, WISCONSIN 5/3620 $s = -1.5$ $Q \propto t^{-2}$	7/16-8/5/58, 5/7-5/18/58, 5/12-5/21/50 6/11-6/21/40, 11/6-11/17/34, 11/24-12/15/34 4/25-5/10/20, 11/13-11/24/19, 12/24-1/11/19 11/18-11/27/26	10.5%, 5.4%, 7.9% 5.8%, 3.3%, 10.5% 8.6%, 4.8%, 8.1% 8.3%	7.3%

to the uncertainties in the measured daily discharges themselves. The smallness of these rms errors clearly establishes that floods decay with an inverse power law time dependence.

In conclusion, we have found that floods decay with an inverse power law dependence on time. The exponent of this dependence varies from river to river and even from station to station along the same river. Nonetheless, despite the complex interactions of the large number of factors which undoubtedly affect the flow at any point on a stream, the resultant time dependence of flood decays can be described by a single parameter, which can be uniquely determined from long term records of the discharge. This power law time dependence makes possible the forecasting of river discharge with an uncertainty of about 5% for as long as a month following the flood peak. Finally we should note that an inverse power law dependence of the flow rate on time is characteristic of diffusive and random walk processes, suggesting a direction for future hydrologic modeling of the flood recession.

Funding for our aspect of this Integrated Study will terminate at the end of the project's present fiscal year, which is April 30, 1974. Between now and then we plan to digitize ERTS-1 imagery of the Feather, Sacramento, Red and Pearl Rivers and to analyze the power spectra of their meanders in relation to stream discharge rates as in our previous studies.

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INVESTIGATION OF ATMOSPHERIC EFFECTS IN IMAGE TRANSFER

By

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I Introduction

Activities on this part of the investigation have been mainly in (a) theoretical work oriented toward computations of the effects of atmospheric aerosols on the transfer of images through the atmosphere, (b) measurements of the polarization field in the cloud-free atmosphere as an indicator of the existence and characteristics of atmospheric aerosols, and (c) the design of a video-polarizer system for the detection and display of the polarization field of light utilized in remote sensing of the environment. In addition, a camera system is under development for characterizing the polarization properties of a scene (landscape, city, etc.) by photographic means. Each of these aspects will be discussed in the following sections.

II Theoretical Work

The purpose in recent months in dealing with numerical models has been to find an atmospheric model that is complete enough to describe experimental data obtained with the polarimeter. A previous program was looked at, but it was decided that a more flexible program was needed. Work was then begun on setting up the codes to vector programs, as developed by Dave (1972), so that they would run on the campus computer, a Burroughs 6700. Dave's programs for Mie scattering are made up of four major sub-programs.

The first of the vector sub-programs requires the specification of the index of refraction for the particles, and a set of parameters that determine the particle size distribution. The value of a given index of refraction and a size parameter are used in calculating the coefficients of the Legendre poly-nomials that describe a set of modified scattering functions.

The scattering functions take the form:

$$R^{(j)}(x, m, \theta) = \sum_{K=1}^{n} L_K^{(j)}(x, m) P_{k-1}(\cos \theta)$$

where $R^{(j)}(x, m, \theta)$, $j = 1, 2, 3, 4$ are the unnormalized modified scattering

functions,

      $P_{k-1}(\cos \theta)$ are the ordinary Legendre polynomials

      X is the size parameter

      m is the index of refraction

The coefficients of the Legendre series for a given $R^{(j)}$ (X, m, θ), and the

three efficiency factors are printed on magnetic tape for use in the second

vector sub-program.

The second vector sub-program calculates the normalized coefficients for

the Legendre series used in calculating the scattering functions $R^{(j)}$ given by:

$$R^{(j)} = \sum_{K=1}^{n} \Lambda_K^{(j)}(r_e) P_{k-1}(\cos \theta)$$

where P_{k-1} (cos θ) are the Legendre polynomials. The coefficents are integrated

over a given range of radii ($r_{min} \longrightarrow r_e$) as follows:

$$\Lambda_K^{(j)}(r_e) = \frac{\lambda^2}{\pi \theta_3(r_e)} \int_{r_{min}}^{r_e} L_K^{(j)}(x, m) n(r) \, dr$$

where n(r) is a size-distribution function that may be of the form of a dis-

continuous power law, a modified gamma function, or a lognormal function. The

values $L_k^{(j)}$ (x,m) are the coefficients of the unnormalized Legendre series that

were used in calculating the unnormalized scattering functions, $R^{(j)}$, for a

single particle in the first vector sub-program. The values $\Lambda_K^{(j)}(r_e)$ provide

the main input into the third vector sub-program.

The third sub-program is the most time consuming, and hence, the most

expensive to run. It expresses in a fourier series each element of the

normalized scattering phase matrix for a unit volume containing a specified particle size distribution.

When working with a problem of multiple scattering in a plane parallel model of the atmosphere, it is easier to transform into a system of azimuth and zenith angles, instead of scattering angles.

Chandrasekhar (1950) performed this transformation to derive a normalized 4x4 scattering phase matrix, $\underset{\sim}{M}(\mu,\varphi;\mu',\varphi')$, the elements of which Dave (1972) has expressed in a fourier series. The even functions, ij = 11, 12, 21, 22, 33, 34, 43, and 44, are given by:

$$M_{ij}\left[\mu,\mu',(\varphi'-\varphi)\right] = \sum_{n=1}^{m(\mu,\mu')} M_{ij}^{(n)}(\mu,\mu')\,\cos\,(n-1)(\varphi'-\varphi)$$

while the odd functions, ij = 13, 14, 23, 24, 31, 32, 41, and 42 are given by:

$$M_{ij}\left[\mu,\mu',(\varphi'-\varphi)\right] = \sum_{n=1}^{m(\mu,\mu')} M_{ij}^{(n)}(\mu,\mu')\,\sin\,(n-1)(\varphi'-\varphi)$$

The elements $M_{ij}\left[\mu,\mu',(\varphi'-\varphi)\right]$ of the scattering matrix are expressed by Dave (1972) in terms of μ,μ', and a set of functions, $F_n^{(j)}(\mu,\mu')$, that are given by:

$$F_n^{(j)}(\mu,\mu') = (2-\delta_{1n}) \sum_{k=n}^{K} \Lambda_k^{(j)}\, Y_{k-1}^{n-1}(\mu)\, Y_{k-1}^{n-1}(\mu')$$

where the values $\Lambda_k^{(j)}$ are those coefficients of the normalized Legendre series used to describe the $R^{(j)}$ functions in the second sub-program. The values Y_{k-1}^{n-1} are the renormalized associated Legendre functions.

The main output for the third sub-program are the values $M_{ij}^{(n)}(\theta',\theta)$, where $\theta = \cos^{-1}\mu$ and $\theta' = \cos^{-1}\mu'$. The values for the angles θ and θ' are $\theta' = 0°(2°)180°$ and $\theta = 0°(2°)90°$, giving 4186 total combinations for each element of the matrix. Due to certain identities among the elements, there are only 14

independent elements that must be calculated. This gives 58,604 total combinations of $M_{ij}^{(n)}$ (θ', θ) for a given n.

The fourth sub-program solves the transfer equation for a plane parallel inhomogeneous atmosphere bounded by a Lambert ground surface, and containing an arbitrary vertical distribution of ozone.

The phase matrix is given by:

$$\underset{\sim}{P}(\tau; \mu, \varphi; \mu', \varphi') = T(\tau) \underset{\sim}{M}(\mu, \varphi; \mu', \varphi') + [1 - T(\tau)] \underset{\sim}{R}(\mu, \varphi; \mu', \varphi')$$

where $T(\tau)$ is the turbidity factor

$\quad\quad \underset{\sim}{M}(\mu, \varphi; \mu', \varphi')$ is the 4x4 normalized matrix for a unit volume of

$\quad\quad\quad\quad\quad\quad$ Mie scatterers

$\quad\quad \underset{\sim}{R}(\mu, \varphi; \mu', \varphi')$ is the Rayleigh scattering matrix

When expanded in series form, the matrices $\underset{\sim}{M}$ and $\underset{\sim}{R}$ can be expressed as follows:

$$\underset{\sim}{M}_{ij}(\mu, \varphi; \mu', \varphi') = \sum_{n=1}^{N(\mu, \mu')} M_{ij}^{(n)}(\mu, \mu') \, f_{n-1}(\varphi' - \varphi)$$

where M_{ij} (μ, μ') and $N(\mu, \mu')$ are given by the third sub-program.

$$\underset{\sim}{R}_{ij}(\mu, \mu') = \sum_{n=1}^{3} R_{ij}^{(n)}(\mu, \mu') \, f_{n-1}(\varphi' - \varphi)$$

where $R_{ij}^{(n)}$ (μ, μ') are calculated in the fourth sub-program. Thus the ij elements of the scattering phase matrix can be expressed as:

$$P_{ij}(\tau; \mu, \varphi; \mu', \varphi') = \sum_{n=1}^{N(\mu, \mu')} P_{ij}^{(n)}(\tau; \mu, \mu') \, f_{n-1}(\varphi' - \varphi)$$

where

$$P_{ij}^{(n)}(\tau; \mu, \mu') = T(\tau) M_{ij}^{(n)}(\mu, \mu') + (1 - T(\tau)) R_{ij}^{(n)}(\mu, \mu')$$

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The basic transfer equation is

$$\mu \frac{d \underset{\sim}{I}(\tau; \mu, \mu')}{d\tau} = \underset{\sim}{I}(\tau; \mu, \varphi) - \omega(\tau) \underset{\sim}{J}(\tau; \mu, \varphi)$$

where $\underset{\sim}{J}(\tau; \mu, \varphi)$ is the source matrix expressed as

$$\underset{\sim}{J}(\tau; \mu, \varphi) = \frac{1}{4} e^{-\tau/\mu_0} \underset{\sim}{P}(\tau; \mu, \varphi; -\mu_0, \varphi_0) \cdot \underset{\sim}{F}$$
$$+ \frac{1}{4\pi} \int_{-1}^{1} \int_{0}^{2\pi} \underset{\sim}{P}(\tau; \mu, \varphi; \mu', \varphi') \cdot \underset{\sim}{I}(\tau; \mu', \varphi') \, d\mu' \, d\varphi'$$

If we expand the intensity matrix, $I(\tau; \mu, \varphi)$, and the source matrix, $J(\tau; \mu, \varphi)$, we obtain the relations

$$I_y(\tau; \mu, \varphi) = \sum_{n=1}^{N(\mu_0)} I_y^{(n)}(\tau; \mu) \, f_{n-1}(\varphi_0 - \varphi)$$

$$J_y(\tau; \mu, \varphi) = \sum_{n=1}^{N(\mu_0)} J_y^{(n)}(\tau; \mu) \, f_{n-1}(\varphi_0 - \varphi)$$

where y = e, r, u, or v in the Stoke's notation.

The values given above for Iy $(\tau; \mu, \varphi)$ and Jy $(\tau; \mu, \varphi)$ are then substituted into the transfer equation resulting in a set of uncoupled integro-differential equations:

$$\mu \sum_{n=1}^{N(\mu_0)} \frac{d I_y^{(n)}(\tau; \mu)}{d\tau} f_{n-1}(\varphi_0 - \varphi) = \sum_{n=1}^{N(\mu_0)} I_y^{(n)}(\tau; \mu) \, f_{n-1}(\varphi_0 - \varphi)$$
$$- \omega(\tau) \sum_{n=1}^{N(\mu_0)} J_y^{(n)}(\tau; \mu) \, f_{n-1}(\varphi_0 - \varphi)$$

With the proper boundary conditions, the set of uncoupled equations is solved for y = e, r, u, and v for a given n. For each n the atmosphere is divided into a number of layers for which the set of 4 equations given above is solved.

We have found that while Dave's codes are very complete, they are very demanding in computer time. It would be more feasible to run these codes on a dedicated mini-computer system.

While looking at the possibility of running such large codes on a small computer, it was noticed that the angular dependence could be separated in

the governing equations. Since the angular dependence could be expressed in closed form by spherical harmonics, which are well known, only the coefficients would have to be calculated and stored. This not only makes the calculations less involved, but gives the coefficients much more physical significance. By use of this more economical method a sensitivity analysis becomes feasible, where it would not otherwise. The following derivations are meant to show that the angular dependence can be separated in the governing equations.

The phase matrix using spherical harmonics is of the form:

$$\underset{\sim}{P}(\tau;\mu,\varphi;\mu',\varphi') = T(\tau)\,\underset{\sim}{M}(\mu,\varphi;\mu',\varphi') + [1 - T(\tau)]\,\underset{\sim}{R}(\mu,\varphi;\mu',\varphi')$$

which can be expanded in closed form giving the following:

$$\underset{\sim}{P}(\tau;\mu,\varphi;\mu',\varphi') = \sum_{\substack{\ell m \\ \ell' m'}} \underset{\sim}{P}_{\substack{\ell m \\ \ell' m'}} Y_{\ell m}(\theta,\varphi)\, Y^{*}_{\ell' m'}(\theta',\varphi')$$

where $Y_{1m}(\theta,\varphi)$ are spherical harmonics.

If we write the intensity and source matrices in the form:

$$\underset{\sim}{I}(\tau;\mu,\varphi) = \sum_{\ell,m} \underset{\sim}{I}_{\ell,m}(\tau)\, Y_{\ell m}(\theta,\varphi)$$

$$\underset{\sim}{J}(\tau;\mu,\varphi) = \frac{1}{4}\, e^{-\tau/\mu_0}\, \underset{\sim}{P}(\tau;\mu,\varphi;-\mu_0,\varphi_0) \cdot \underset{\sim}{F}$$
$$+ \frac{1}{4\pi} \int_{-1}^{1} \int_{0}^{2\pi} \underset{\sim}{P}(\tau;\mu,\varphi;\mu',\varphi')\, \underset{\sim}{I}(\tau;\mu',\varphi')\, d\mu' d\varphi'$$

and introduce the expanded forms of $\underset{\sim}{P}(\tau;\mu,\varphi;\mu',\varphi')$ and $\underset{\sim}{I}(\tau;\mu',\varphi')$ into the equation for the source matrix we obtain:

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$$\underset{\sim}{J}(\tau;\mu,\varphi) = \frac{1}{4} e^{-\tau/\mu_0} \sum_{\substack{\ell m, \\ \ell'm'}} \underset{\sim}{P}_{\substack{\ell m, \\ \ell'm'}}(\tau) \underset{\sim}{F} Y_{\ell m}(\theta,\varphi) Y^*_{\ell'm'}(-\theta_0,\varphi_0)$$

$$+ \frac{1}{4} \int_{-1}^{1} \int_{0}^{2\pi} \left[\sum_{\substack{\ell m, \\ \ell'm'}} \underset{\sim}{P}_{\substack{\ell m, \\ \ell'm'}}(\tau) Y_{\ell m}(\theta,\varphi) Y^*_{\ell'm'}(\theta',\varphi') \right]$$

$$\left[\sum_{\ell''m''} \underset{\sim}{I}_{\ell''m''}(\tau) Y_{\ell''m''}(\theta',\varphi') \right] d\mu' d\varphi'$$

Simplifying the expression for J ($\tau;\mu,\varphi$) yields

$$\underset{\sim}{J}(\tau;\mu,\varphi) = \frac{1}{4} e^{-\tau/\mu_0} \sum_{\substack{\ell m, \\ \ell'm'}} \underset{\sim}{P}_{\substack{\ell m, \\ \ell'm'}}(\tau) \cdot \underset{\sim}{F} Y_{\ell m}(\theta,\varphi) Y^*_{\ell'm'}(-\theta_0,\varphi_0)$$

$$+ \frac{1}{4} \sum_{\substack{\ell m, \\ \ell'm', \\ \ell''m''}} \underset{\sim}{P}_{\substack{\ell m, \\ \ell'm'}}(\tau) \cdot \underset{\sim}{I}_{\ell''m''}(\tau) Y_{\ell m}(\theta,\varphi)$$

$$\cdot \int_{-1}^{1} \int_{0}^{2\pi} Y^*_{\ell'm'}(\theta',\varphi') Y_{\ell''m''}(\theta',\varphi') d\mu' d\varphi'$$

But

$$\int_{-1}^{1} \int_{0}^{2\pi} Y^*_{\ell'm'}(\theta',\varphi') Y_{\ell''m''}(\theta',\varphi') d\mu' d\varphi' = \delta_{\ell'\ell''} \delta_{m'm''}$$

and therefore

$$\underset{\sim}{J}(\tau;\mu,\varphi) = \sum_{\ell m} \left[\frac{1}{4} e^{-\tau/\mu_0} \sum_{\ell'm'} \underset{\sim}{P}_{\substack{\ell m, \\ \ell'm'}}(\tau) \cdot \underset{\sim}{F} Y_{\ell'm'}(-\theta_0,\varphi_0) \right.$$

$$\left. + \frac{1}{4} \sum_{\ell'm'} \underset{\sim}{P}_{\substack{\ell m, \\ \ell'm'}}(\tau) \cdot \underset{\sim}{I}_{\ell'm'}(\tau) \right] Y_{\ell m}(\theta,\varphi)$$

To simplify further we let

$$\underset{\sim}{J}_{\ell m}(\tau) = \frac{1}{4} \sum_{\ell'm'} \left[e^{-\tau/\mu_0} \underset{\sim}{P}_{\substack{\ell m, \\ \ell'm'}}(\tau) \cdot \underset{\sim}{F} \cdot Y_{\ell'm'}(-\theta_0,\varphi_0) \right.$$

$$\left. + \underset{\sim}{P}_{\substack{\ell m, \\ \ell'm'}}(\tau) \cdot \underset{\sim}{I}_{\ell'm'}(\tau) \right]$$

$$\underset{\sim}{J}_{\ell m}(\tau) = \frac{1}{4} \sum_{\ell'm'} \underset{\sim}{P}_{\substack{\ell m, \\ \ell'm'}}(\tau) \left[e^{-\tau/\mu_0} Y_{\ell'm'}(-\theta_0,\varphi_0) \underset{\sim}{F} + \underset{\sim}{I}_{\ell'm'}(\tau) \right]$$

We can therefore write the source matrix in the form:

$$\underset{\sim}{J}(\tau;\mu,\varphi) = \sum_{\ell m} \underset{\sim}{J}_{\ell m}(\tau) Y_{\ell m}(\theta,\varphi)$$

The transfer equation is:

$$\mu \, \frac{d\underset{\sim}{I}(\tau; \mu, \varphi)}{d\tau} = \underset{\sim}{I}(\tau; \mu, \varphi) - \omega(\tau) \underset{\sim}{J}(\tau; \mu, \varphi)$$

If we substitute in the appropriate expressions:

$$\sum_{\ell m} \frac{d\underset{\sim}{I}_{\ell m}(\tau)}{d\tau} \mu \, Y_{\ell m}(\theta, \varphi) = \sum_{\ell m} \underset{\sim}{I}_{\ell m}(\tau) \, Y_{\ell m}(\theta, \varphi)$$

$$- \omega(\tau) \sum_{\ell m} \underset{\sim}{J}_{\ell m}(\tau) \, Y_{\ell m}(\theta, \varphi)$$

But

$$\mu \, Y_{\ell m} = \frac{1}{\sqrt{2\ell+1}} \left[\sqrt{\frac{\ell^2 - m^2}{2\ell - 1}} \, Y_{\ell-1, m} + \sqrt{\frac{(\ell+1)^2 - m^2}{2\ell + 3}} \, Y_{\ell+1, m} \right]$$

$$= \alpha_{\ell, m} \, Y_{\ell-1, m} + \beta_{\ell, m} \, Y_{\ell+1, m}$$

Substituting this equation into the lefthand term of the equation of transfer
we get

$$\sum_{\ell m} \frac{d\underset{\sim}{I}_{\ell m}(\tau)}{d\tau} \left[\alpha_{\ell, m} \, Y_{\ell-1, m} + \beta_{\ell, m} \, Y_{\ell+1, m} \right] =$$

$$\sum_{\ell m} \frac{d}{d\tau} \left[\underset{\sim}{I}_{\ell+1, m}(\tau) \, \alpha_{\ell+1, m} + \underset{\sim}{I}_{\ell-1, m}(\tau) \, \beta_{\ell-1, m} \right] \cdot Y_{\ell m}(\theta, \varphi)$$

Then the equation of transfer takes the final form:

$$\frac{d}{d\tau} \left[\underset{\sim}{I}_{\ell+1, m}(\tau) \, \alpha_{\ell+1, m} + \underset{\sim}{I}_{\ell-1, m}(\tau) \, \beta_{\ell-1, m} \right] =$$

$$\underset{\sim}{I}_{\ell m}(\tau) - \omega(\tau) \underset{\sim}{J}_{\ell, m}(\tau)$$

where

$$\underset{\sim}{J}_{\ell m}(\tau) = \frac{1}{4} \sum_{\ell' m'} \underset{\sim}{P}_{\ell m}^{\ell' m'}(\tau) \left[e^{-\tau/\mu_0} Y_{\ell' m'}(-\theta_0, \phi_0) \underset{\sim}{F} + \underset{\sim}{I}_{\ell' m'}(\tau) \right]$$

$$\underset{\sim}{F} = \begin{bmatrix} 1/2 \\ 1/2 \\ 0 \\ 0 \end{bmatrix}$$

$$\underset{\sim}{P}_{\ell m}^{\ell' m'}(\tau) = T(\tau) \underset{\sim}{M}_{\ell m}^{\ell' m'} + \left[1 - T(\tau) \right] R_{\ell m}^{\ell' m'}$$

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III Measurements of the Polarization Field

As pointed out in previous reports, the degree of polarization of light

from the sunlit sky has been found in the past to be a sensitive indicator of

the presence of dust, haze, and other types of particles in the atmosphere. The

magnitude and distribution of skylight polarization were both strongly affected

by volcanic ash injected into the atmosphere by the eruptions of Krakatao on

the island of Java in 1883 and the Alaskan volcano Mt. Katmai in 1912. More

recent measurements by Dorno (1919), Jensen (1942), Neuberger (1950), Sekera

et al (1955), Pyaskovskaya-Fesenkova (1960), Coulson (1971), and others have

verified the sensitivity of various parameters of the polarization field to

atmospheric turbidity. Such turbidity has a strong effect on remote sensing

by reflected solar radiation, both in degrading the contrast inherent in a

landscape or other scene as observed from a remotely located platform and in

increasing the background radiation against which the scene must be observed.

Thus the derivation of means of characterizing the turbidity conditions of the atmosphere is of considerable importance in remote sensing applications.

Two locations were chosen for making measurements of the polarization field of skylight. The first of these, the Mauna Loa Observatory on the Island of Hawaii, was mentioned in the previous report, and some preliminary results of the measurements were given. Further results, together with some analysis, are shown below. The rationale behind this choice is that Mauna Loa has a long record of measurements of atmospheric conditions, that multi-spectral measurements of the direct and diffuse solar radiation are available at the site, and that its location is not too remote from California. In addition, the altitude of the Observatory (approximately 11,200 feet MSL), assures that it is in the clear air above the trade wind inversion of the Hawaii area, and it is relatively far removed from any local sources of pollution. The second site of polarization measurements was the Davis Campus of the University of California. In addition to its convenience, the Davis area is well adapted to clear sky measurements because of the absence of significant cloudiness during the summer months. Typical data from the Davis measurements are included in the discussion which follows.

Instrumentation

The instrument used for the polarization measurements is the computer-controlled polarizing radiometer which was developed during the previous periods of this project. It has been briefly described in previous reports, and in somewhat more detail by Coulson and Walraven (1972) and Coulson et al (1974). Basically, the instrument measures the relative intensity, degree of linear polarization, and the orientation of the plane of polarization of the incident light. It is a two-channel device, the design of each of the channels being

as indicated in Fig. 1. Radiation confined to a 0.75° half-angle cone enters the collimator tube and is transmitted successively through the rotating polarizer (Glan-Thompson prism) an appropriate number of neutral density filters, and an interference color filter, and finally it impinges on the photocathode of a photomultiplier tube. The opaque shutter is normally out of the optical path, but it is inserted into position for obtaining a dark count at selected times during instrument operation.

Pertinent data on each of the two channels of the instrument are tabulated as follows:

	Channel A	Channel B
Wavelengths of peak transmission of interference filters (μm)	0.32,0.365,0.4,0.5	0.6,0.7,0.8,0.9
Type of photomultiplier tube	EMI6256A	EMI9559A
Central wavelength of quarter wave plate (μm)	0.40	0.70
Type of amplifier discriminator	SSRI Model 1120	SSRI Model 1120

A unique feature of the device is that it is controlled completely by means of a mini-computer, which is an integral part of the system. By appropriate computer programs, any type of scan pattern and any sequence of measurements can be achieved. This feature provides great flexibility and reliability in the operation, with minimal effort by a human operator. In addition, the signals from the instrument are processed and the required computations performed by the computer to give the output directly in terms of the physical variables of intensity, degree of polarization, and angle of the plane of polarization, all within one second after the measurement is made. Not only does this eliminate the slow and laborious step of data processing, but it also permits immediate inspection of the data to detect any possible malfunction of the system itself.
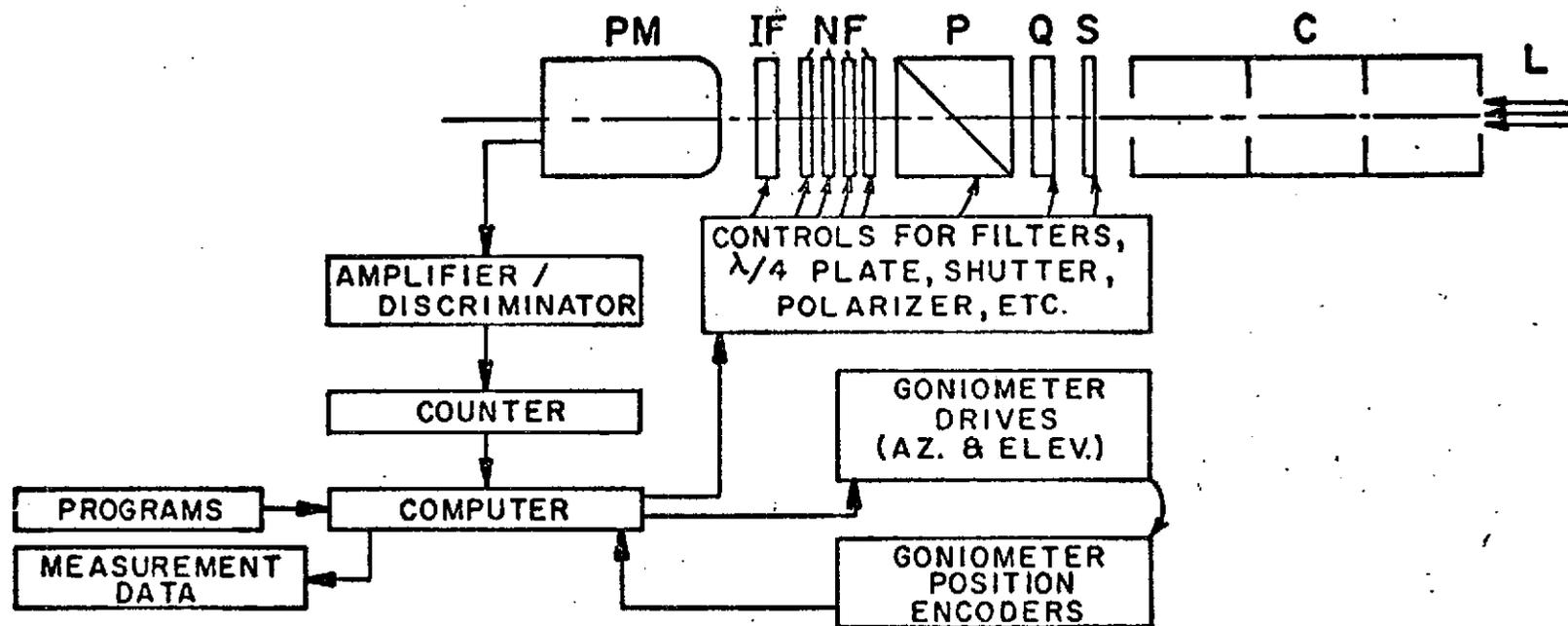
Fig. 1 Schematic diagram of one of the two channels of the photon-counting polarizing radiometer.

Skylight measurements were made on Mauna Loa mainly during February and March, 1973, and in Davis in July, 1973. The normal operational procedure for making the measurements was to scan the sky in the plane of the sun's vertical, beginning and ending the scan at 5° above the horizon in the solar and anti-solar azimuths. Data points were taken at regular intervals of sometimes 2° and sometimes 5° throughout the 170° scan, and the two channels of the instrument were operated simultaneously. Thus measurements of relative intensity, degree of polarization, and orientation of the plane of polarization were made in two wavelengths at either 35 or 86 angles in the plane during each scan of the sky. For points at 2° intervals, the scan required approximately 30 minutes, whereas about half of that time was required for 5° data points.

Results of Measurements

Measurements of skylight polarization were made only under conditions of essentially cloudless skies. This requirement presented no difficulty in the Davis measurements, as atmospheric subsidence in the anticyclone which prevails over California in summer minimizes the amount of cloudiness over the area. On Mauna Loa there were short periods of time when a few wisps of cloud appeared, but appreciable cloudiness in the upward hemisphere was sufficient to stop the measurements. Cumulus type clouds were very common, of course, over the ocean around the island, but these were mainly confined to levels below the trade wind inversion and generally remained below the observation site. There were occasions when the upslope wind brought significant cloud masses over the Observatory, but persistent cloud intrusions caused suspension of the measurements.

One additional difficulty with skylight measurements at Mauna Loa was occasioned by the several antennae and supporting wires projecting above the

observation platform. A considerable number of spurious data points resulted from such obstructions in the field of view of the instrument, and since the distribution of the obstructions is very irregular, it is impossible to determine just which of the data points are affected. This is perhaps more of an annoyance than a substantive deficiency in the data, but it is a feature to be considered in possible future measurements.

Since the total number of data obtained from the measurements is very large, it is not feasible to present an exhaustive discussion in this report. Consequently, a selection has been made to show typical results of complete scans of the sky at various wavelengths, the variations and some of the extremes of the polarization field, and the behavior of the polarization maximum. A method of parameterizing the data was discussed in the previous report (May, 1973), and although that discussion will not be repeated here, some further results of the method will be indicated. It is anticipated that a more complete discussion of both the data themselves and the parameterization method will be prepared for formal publication during the coming period of the project.

The general distribution of the degree of polarization in the plane of the sun's vertical is shown in Fig. 2. The points shown are the actual data points obtained from the measurements, and no smoothing of the data has been performed. The pattern is generally as expected from computations for a Rayleigh atmosphere (Sekera, 1956). The maximum is located at approximately 90° from the sun, the neutral points (points of P = 0) are located in roughly their normal positions, and the expected strong wavelength dependence is obvious in the curves. Indications that the atmosphere was not purely molecular are seen in the fine structure of the polarization curves and in the neutral
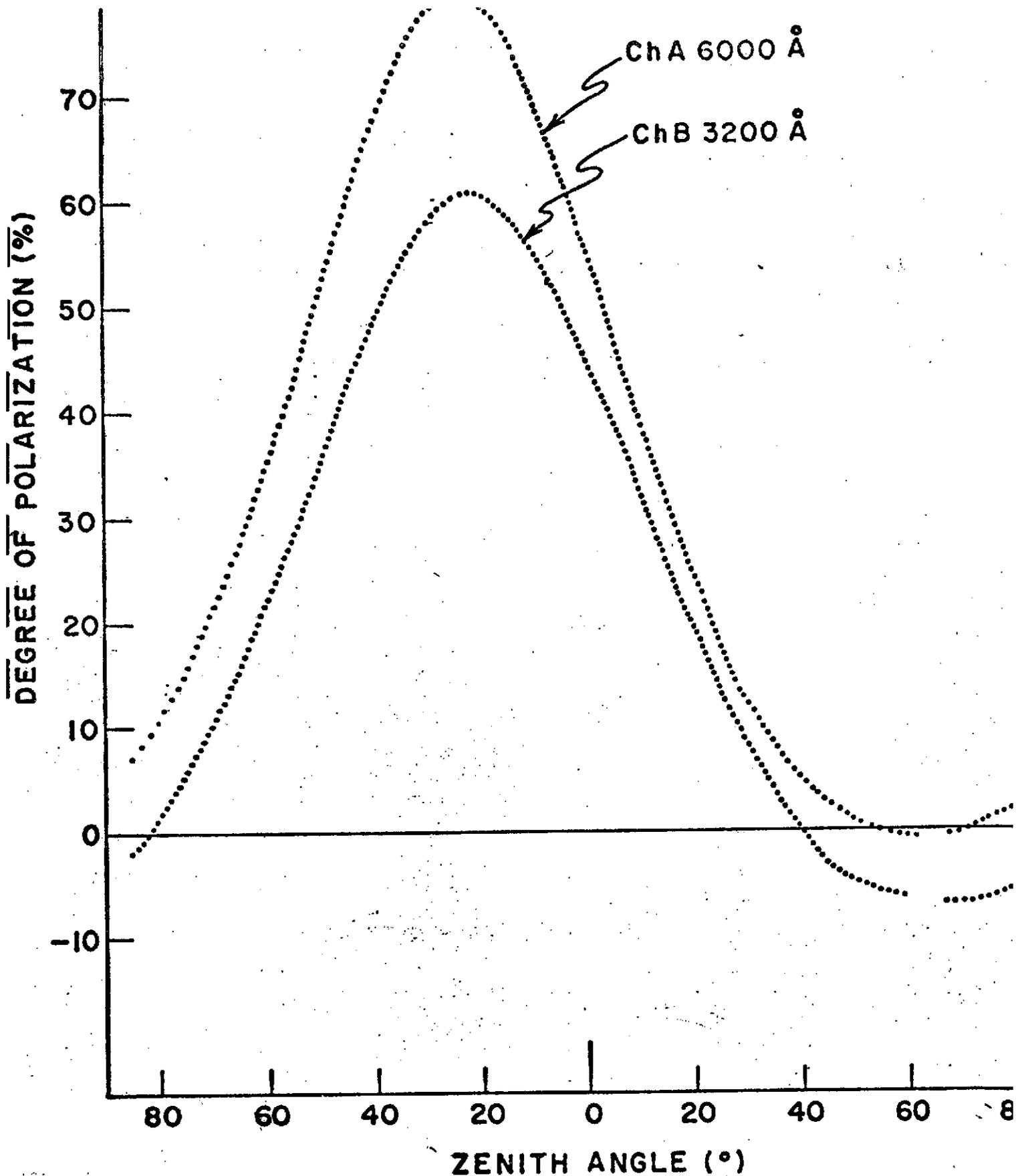
Fig. 2 Typical data on the degree of linear polarization of skylight, as measured by the photon-counting polarizing radiometer. The two channels of the instrument are operated simultaneously for measuring the intensity, degree of polarization, and angle of the incoming radiation. The curves shown are for wavelengths of 0.32 and 0.60 μm, and were obtained during a scan in the plane of the sun's vertical at the Mauna Loa Observatory on February 8, 1973.

points being very close to the sun at $\lambda = 0.60\mu m$.

The shift of the polarization field with changing sun elevations is shown in Fig. 3. Here also, the maximum of the curves is at about 90° from the sun, and the magnitude P_{max} of the maximum is slightly dependent on zenith angle 0_o of the sun, as expected from theory (Coulson, 1952). However, P_{max} for a Rayleigh atmosphere reaches a slight minimum at about $0_o = 50°$ to 60°, and no such minimum is seen here at $\lambda = 0.32\mu m$. There is a tendency for it at $\lambda = 0.60\mu m$, and it definitely occurs at this wavelength in some of the other Mauna Loa data.

The fact that atmospheric conditions were different on March 25 from those on February 8 can be seen by comparing the data of Figures 2 and 3, even though both were noted as being very clear days at Mauna Loa. For instance, P_{max} at $\lambda = 0.60\mu m$ is only 70% or less in Fig. 3, whereas it is 80% in Fig. 2. Similarly, P_{max} at $\lambda = 0.32\mu m$ is lower in Fig. 3 than in Fig. 2, although by a smaller absolute amount than for $\lambda = 0.60\mu m$. A similar difference in atmospheric conditions can be deduced from the disappearance of the neutral points at $\lambda = 0.60\mu m$ on March 25.

It is found throughout the data that the polarization field at the longer wavelengths at which measurements were made ($\lambda = 0.80$ and $0.90\mu m$) has a fundamentally different character in the region near the sun than that at the shorter wavelengths. This is shown in Fig. 4. Not only do the neutral points at $\lambda = 0.90\mu m$ disappear, but the minimum degree of polarization reached for the higher sun elevations is fully 5%. Thus the entire region of the solar aureole is positively polarized at the longer wavelengths. In addition, the magnitude of the polarization maximum is considerably less at $0.90\mu m$ than at $0.50\mu m$. In evaluating the significance of these points it should be remembered that for a pure Rayleigh atmosphere overlying a non-reflecting surface, the polarization maximum
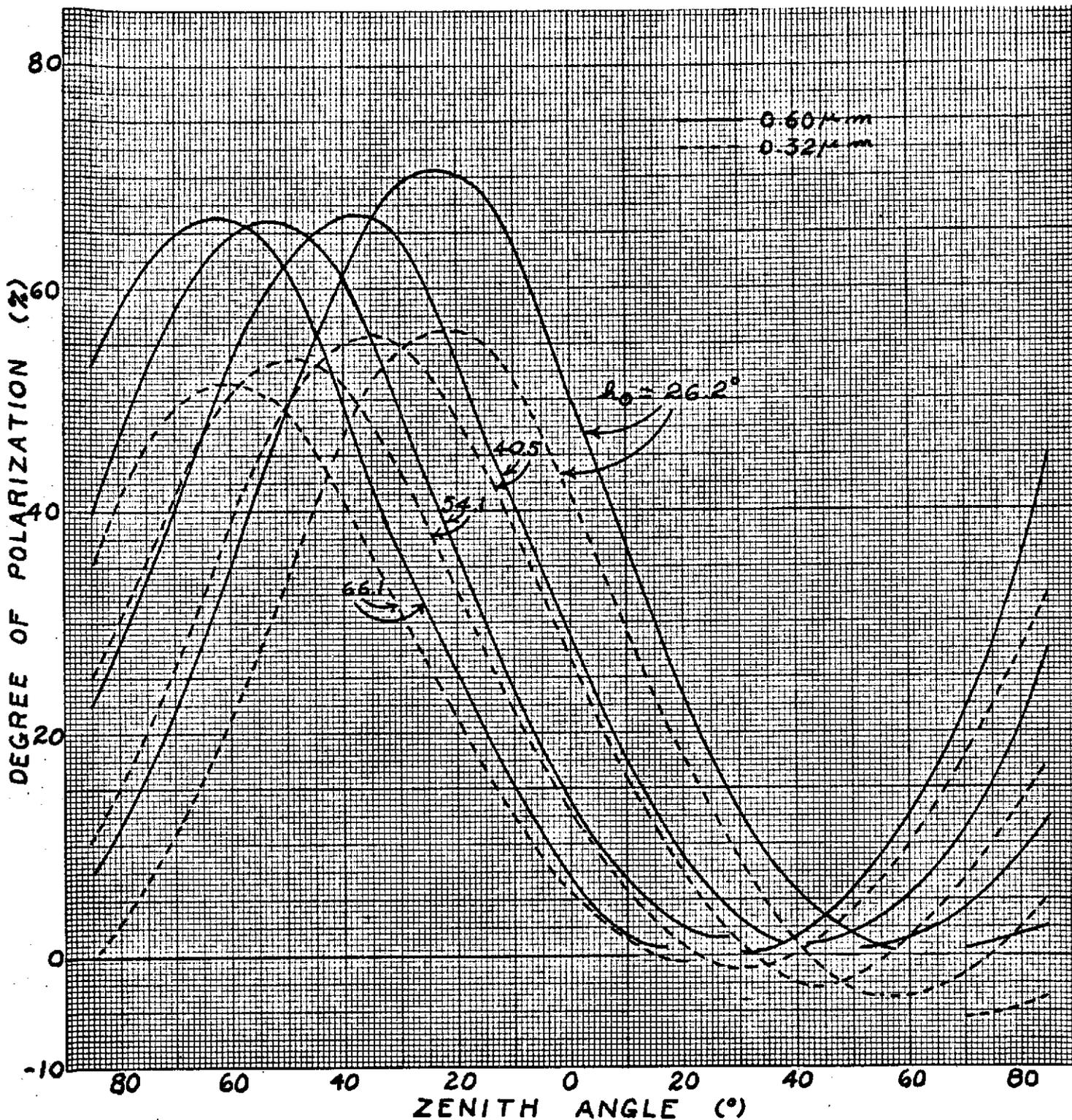
Fig. 3 Degree of polarization as a function of zenith angle in the principal plane as observed on Mauna Loa on March 25, 1973, during four different scans of the sky. The two sets of curves were obtained simultaneously with the two channels of the polarizing radiometer. The sun elevation for the mid-point of each scan is indicated.
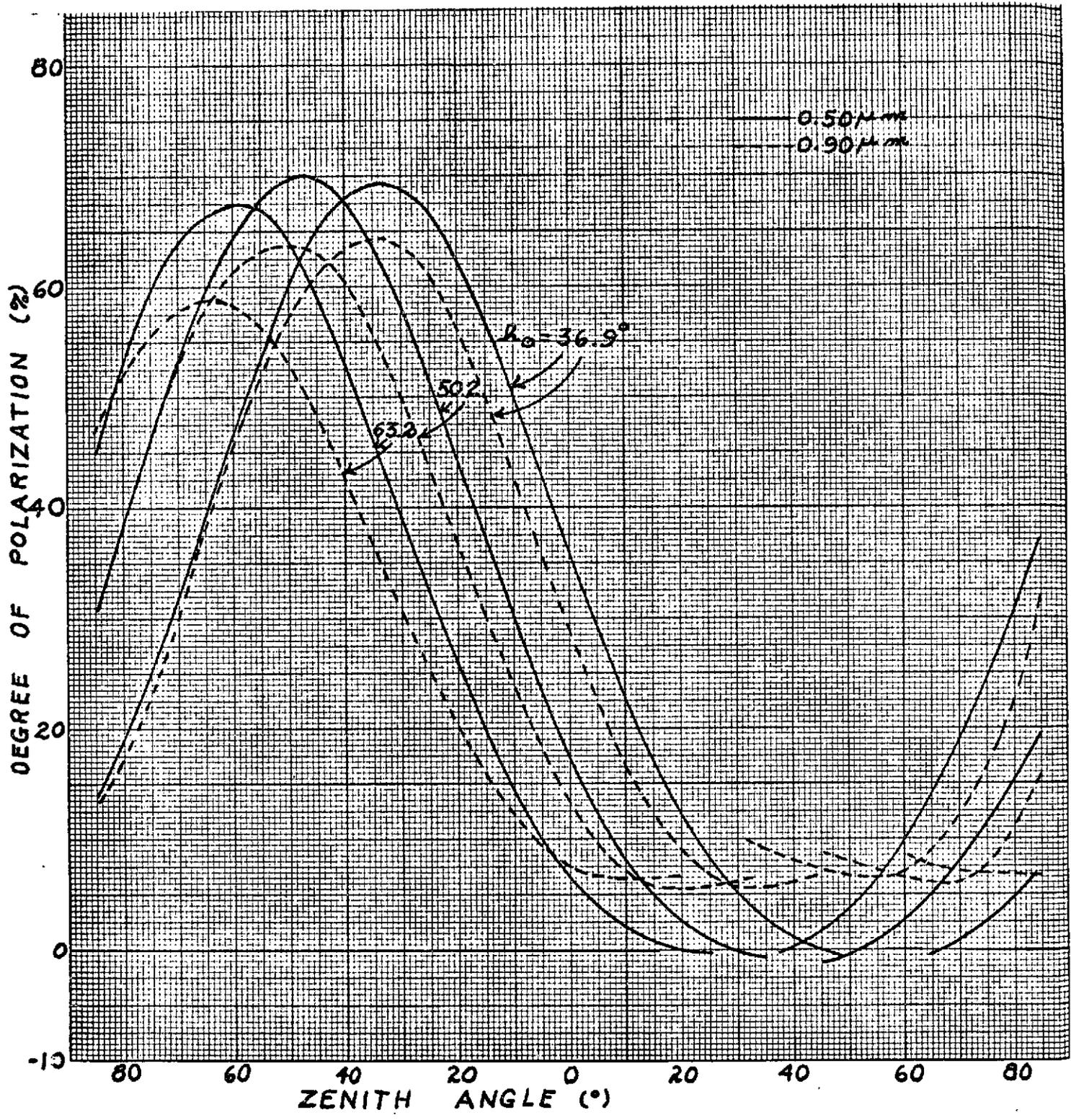
Fig. 4 Degree of polarization as a function of zenith angle in the principal plane as observed on Mauna Loa on March 25, 1973, during three different scans of the sky.

increases in magnitude with increasing wavelength and there is always at least one point at which the polarization is zero. Some possible explanations of the apparently anomalous behavior of the actual polarization field are suggested in a later section.

As indicated above, the magnitude P_{max} of the polarization maximum at Mauna Loa is a relatively strong function of wavelength. A summary of the dependence of P_{max} on wavelength as obtained on about 25 scans of the sky on March 25, 1973, is shown in Fig. 5. The two groups of data were taken by the two channels of the instrument, and the data points from each series of four successive scans of the sky are connected by straight lines. Data for two wavelengths were obtained on each scan, the wavelength pairs for the two channels being 0.32 and 0.60µm; 0.365 and 0.70µm; 0.40 and 0.80µm; and 0.50 and 9.90µm. Each series of four scans required about one hour to complete.

Although there is a considerable scatter in the data, it is evident from Fig. 5 that P_{max} reaches a maximum in the 0.50 to 0.60µm range. The lower values at shorter wavelengths are expected from computations for a molecular atmosphere, in which case the decrease of polarization values with decreasing wavelength is mainly a result of multiple scattering by the atmospheric gases. However, multiple scattering cannot explain the decrease of P_{max} with increasing wavelengths beyond $\lambda = 0.60$µm, and in fact progressively decreasing multiple scattering with increasing wavelength would indicate the opposite trend. Thus the explanation of the behavior of P_{max} in the longer wavelength range must be an increasing influence of non-Rayleigh effects, the most important being aerosol scattering, and surface reflection. The relative contributions of these two effects is difficult to estimate from present information.

The variations of the polarization field with time, on both hour-to-hour and day-to-day time scales, were found to be unexpectedly large on Mauna Loa.
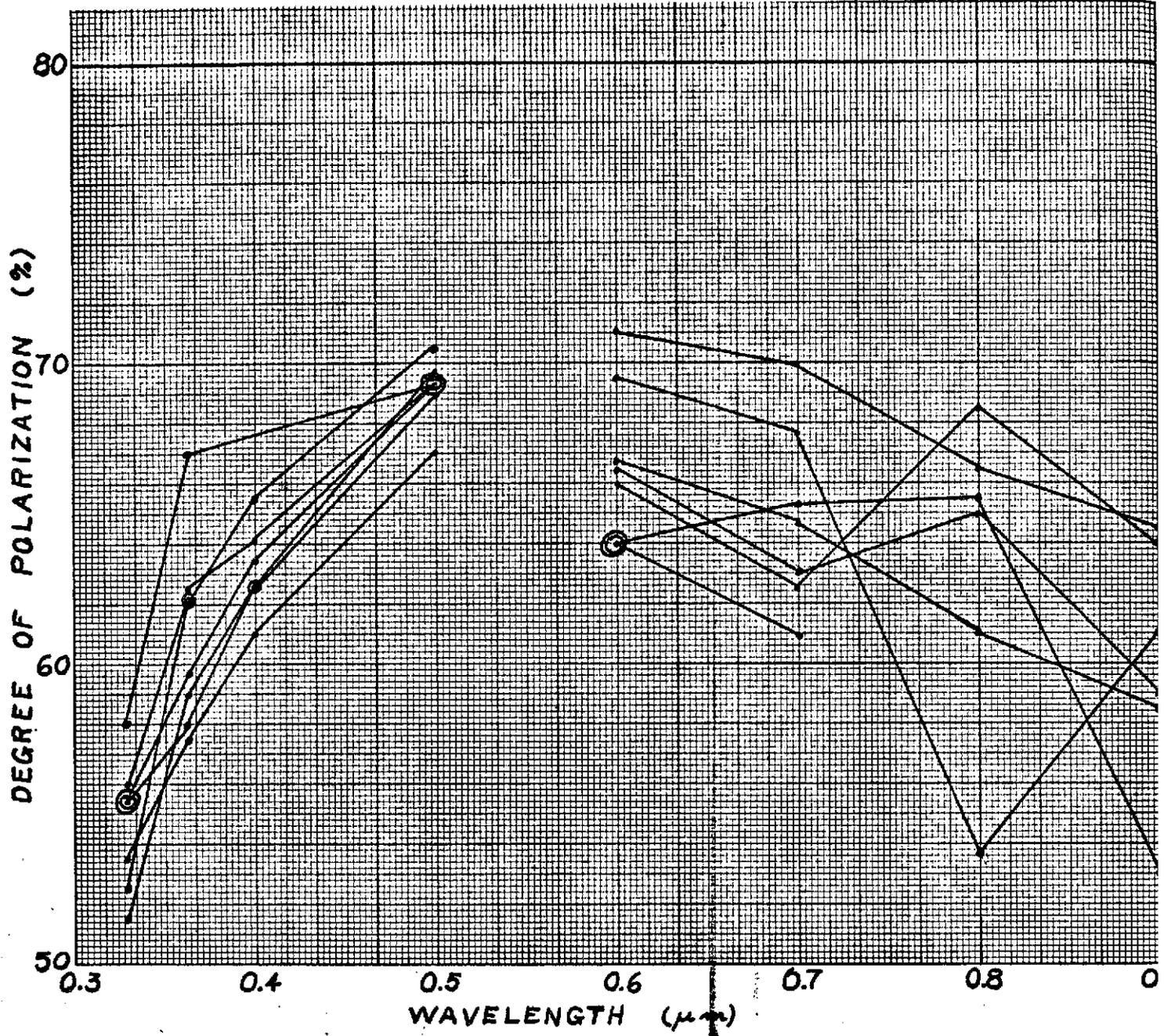
5-47

Fig. 5 Magnitude of the polarization maximum as a function of wavelength for approximately 25 scans of the sky on Mauna Loa on March 25, 1973.

The general magnitude of the variations can be seen perhaps best by means of the total amplitude of the polarization curve represented by the absolute difference between the maximum and minimum values obtained in one scan of the sky. As shown in a previous report, it is possible to represent most of the variation very well in terms of the scattering angle by means of the polynomial

$$P(\theta) = A + A_2 \left[-\sin^2\theta / (1 + \cos^2\theta) \right] + A_3 -\sin 2\theta + A_4 -\sin 4\theta$$

According to this relation, the amplitude of the polarization curve is given approximately by the magnitude of the coefficient A_2.

A summary of the variations of A_2 on all days for which Mauna Loa data are available is given for $\lambda = 0.60\mu m$ in Fig. 6 and for $\lambda = 0.32\mu m$ in Fig. 7 There appears to be some systematic variation in the data, the values in January, February, and the last days of March being relatively high, and the period March 12-25 showing generally lower values. To the extent that this variation is representative, it would indicate a period of increased turbidity of the atmosphere from the middle to near the end of March.

It is obvious, however, that the variations within the period of a single day are comparable in magnitude to those observed over longer time intervals. Since the time of observations was not consistent from day to day and more afternoon observations were taken in the March 22-25 period than at other times, it is possible that the apparent trends in P_{max} are due to biases in the time of measurement. For instance, the data of March 25, which are the most complete data taken, show lower values of P_{max} in the afternoon than in the forenoon. Presumably the afternoon decrease is caused by higher atmospheric turbidity brought to the top of the mountain by up-slope winds which developed in the afternoon. If this diurnal pattern was prevalent during other observational periods, then the apparent trends are probably the result of a time bias in the data.
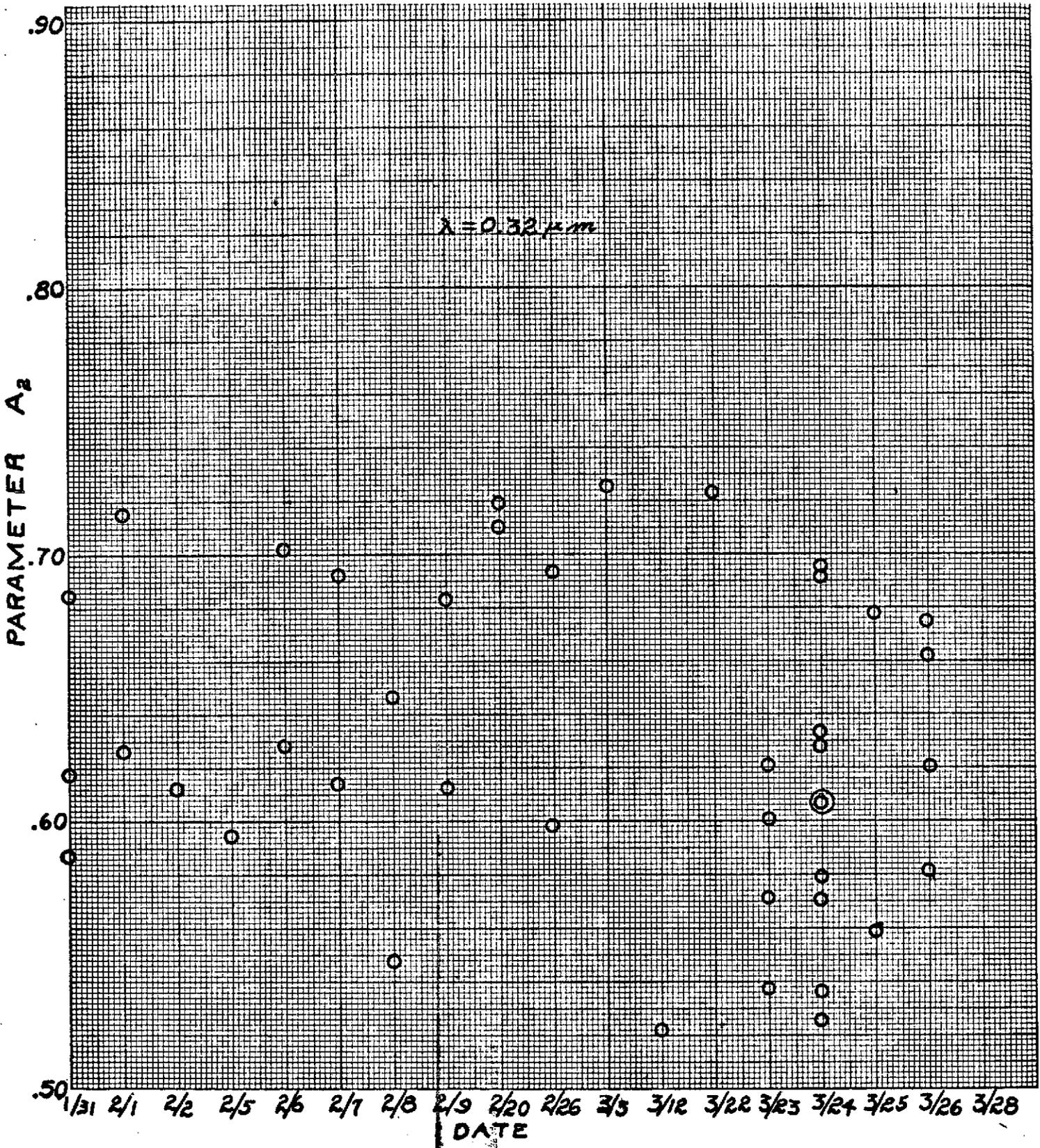
Fig. 6 Magnitude of the coefficient A_2 on different days as observed at $\lambda = 0.32\mu m$ on Mauna Loa during the period January-March, 1973.
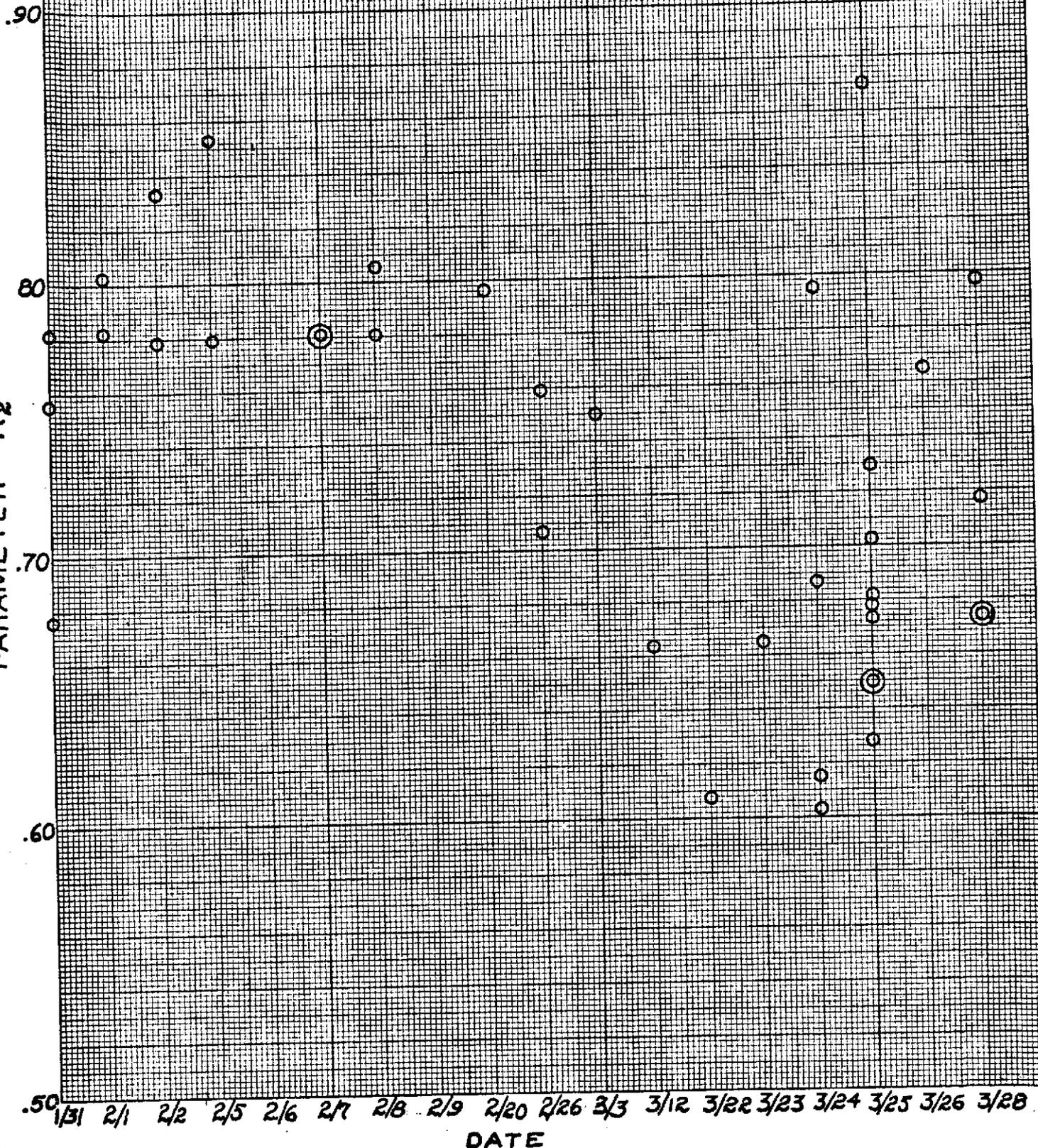
Fig. 7   Magnitude of the coefficient A_2 on different days as observed at
$\lambda = 0.60\mu m$ on Mauna Loa during the period January-March, 1973.

The large magnitude of the variations of P_{max} is one of the most puzzling

features of the Mauna Loa data. While it is known that the polarization field

is sensitive to atmospheric conditions, one would think that the atmosphere at

Mauna Loa would be stable enough to yield only small variations of the polariza-

tion field. An indication that this is not the case was already seen by Dr. R.

Hansen and his colleagues (private communication) in connection with their

Mauna Loa observations of the solar corona. Large variations of the polariza-

tion component introduced by scattering in the earth's atmosphere were fre-

quently observed to occur near the disk of the sun. These perturbations were

observed to cover periods ranging from minutes to hours, and did not appear

to be correlated with obvious atmospheric changes. Since Hansen's observa-

tions were confined to the region near the sun, no information on the variability

of the polarization field in other parts of the sky was available until the pre-

sent series of polarization measurements was initiated. In fact, the observa-

tions are still inadequate to establish a correlation between variations very

near the sun and those of other parts of the polarization field, although a

strong correlation would not be unexpected. It is likely that the entire

polarization field responds to whatever changes of atmospheric optical proper-

ties which occur on Mauna Loa, but as of the present writing the cause of the

observed variations is not well understood.

A series of polarization measurements was made also on the Campus of

the University of California, Davis, during July, 1973. Data typical of the

Davis measurements are shown for seven scans of the sky at λ = 0.60μm taken

during the forenoon of July 25, 1973. The sun elevation varied between -3.6°

(Figure 8)

and 69.4° during the period of the measurements. The atmosphere was quite

turbid with a visibility of approximately 20 miles throughout the day. This

condition is responsible for limiting the polarization maximum to generally
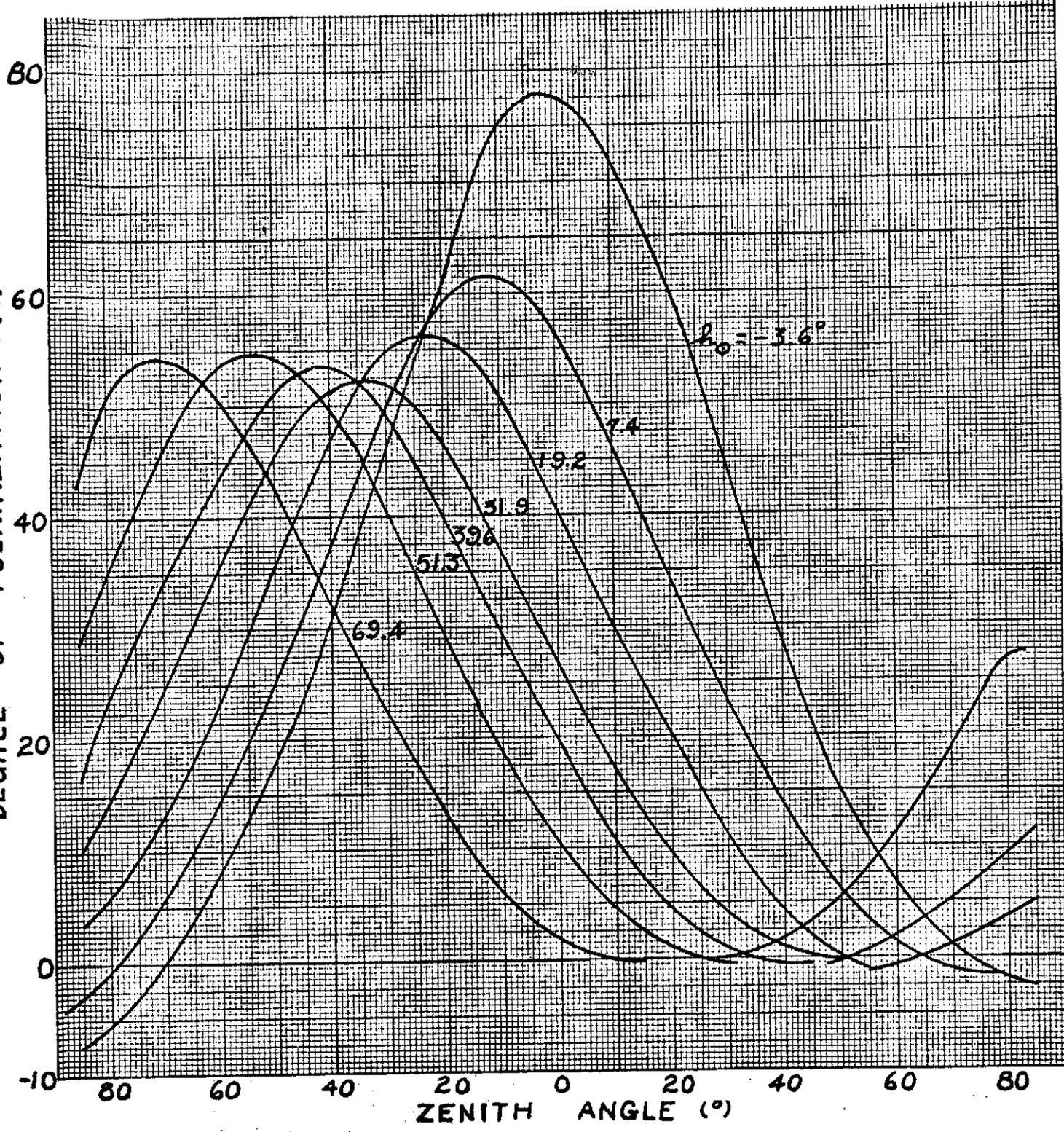
Fig. 8 Degree of polarization as a function of zenith angle in the principal plane as observed at Davis, California, on July 25, 1973, during seven different scans of the sky.

less than 60% for all of the curves except the two in the very early morning. A quite high value of 78% was observed during the period before sunrise, a feature which is frequently observed to occur when the sun is below the horizon. Presumably, the large difference between polarization maxima at positive and negative sun elevations is explained by the effects of surface reflection during periods when the surface is illuminated by direct sunlight, but the absolute magnitudes of the differences should be confirmed by further computations before this explanation is accepted as final.

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IV Instrumentation

A. Video-polarizer system

The possibility of displaying the polarization information of an entire scene in real time has led to the idea of the video polarizer: a black-and-white TV camera with a rotating polarizer in front, followed by a signal processor driving a color monitor which displays the intensity, degree of polarization, and phase angle of polarization of an entire scene in terms of the intensity, saturation of color and hue of color on the TV monitor. Many schemes were devised for constructing such a video polarizer, but requirements of simplicity and low cost have restricted the available techniques. The method finally adopted uses digital techniques to process the signal so that an existing PDP-11 mini-computer may be used and, to keep the cost down, degrades the image to a 64x64 grid of points.

A schematic diagram of the proposed video polarizer is shown in Fig. 9. A fast, 8-bit analog-to-digital converter (ADC) samples the video output from the TV camera. The digitized data are placed in a 64x64 array in the PDP-11 memory. In this manner four arrays corresponding to the image for four orientations of the polarizer are constructed in memory. From these arrays the intensity and the amplitude and phase of the polariza-tion for each point in the 64x64 array are calculated and sent to an ex-ternal image storage memory for the color monitor display.

A Panasonic WV-4KP TV camera and monitor has already been purchased and some initial experimentation with it has been performed which indicates

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┌─────────────┬─────────────┐                ┌──────────┐              ┌──────────────┐        ┌──────────────┐
│             │             │  Video         │          │              │              │        │              │
│  Polarizer  │   T.V.      │  Output        │  8-Bit   │              │  Computer    │        │   PDP-11     │
│             │   Camera    │───────────────▶│  ADC     │─────────────▶│              │◀──────▶│              │
│             │             │                │          │              │  Interface   │        │   Computer   │
└──────▲──────┴──────▲──────┘                └────┬─────┘              │              │        │              │
       │             │                            │  Start             │              │        │              │
       │             │                            │                    │              │        │              │
┌──────┴───┐  ┌───────┴──┐  ┌──────┐         ┌────┴──────┐            │              │        │              │
│  Driver  │  │  Sweep   │◀─│ DAC  │◀────────│  Digital  │───────────▶│              │        │              │
│          │  │ Circuitry│  └──────┘         │  Address  │            │              │        │              │
│          │  │          │◀─│ DAC  │◀────────│  Generator│◀───────────│              │        │              │
└──────────┘  └──────────┘  └──────┘         └───────────┘            └──────────────┘        └──────┬───────┘
                                                                                                     │
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┌────────────┐         ┌──────┐                              ┌──────────┐                    ┌───────┴──────┐
│            │◀────────│ DAC  │◀─────────────────────────────│          │                    │              │
│  Sony      │         └──────┘                              │  Ram     │                    │  Computer    │
│  Color     │◀────────│ DAC  │◀─────────────────────────────│  Image   │◀───────────────────│              │
│  Monitor   │         └──────┘                              │  Storage │                    │  Interface   │
│            │◀────────│ DAC  │◀─────────────────────────────│          │                    │              │
└────────────┘         └──────┘                              └──────────┘                    └──────────────┘
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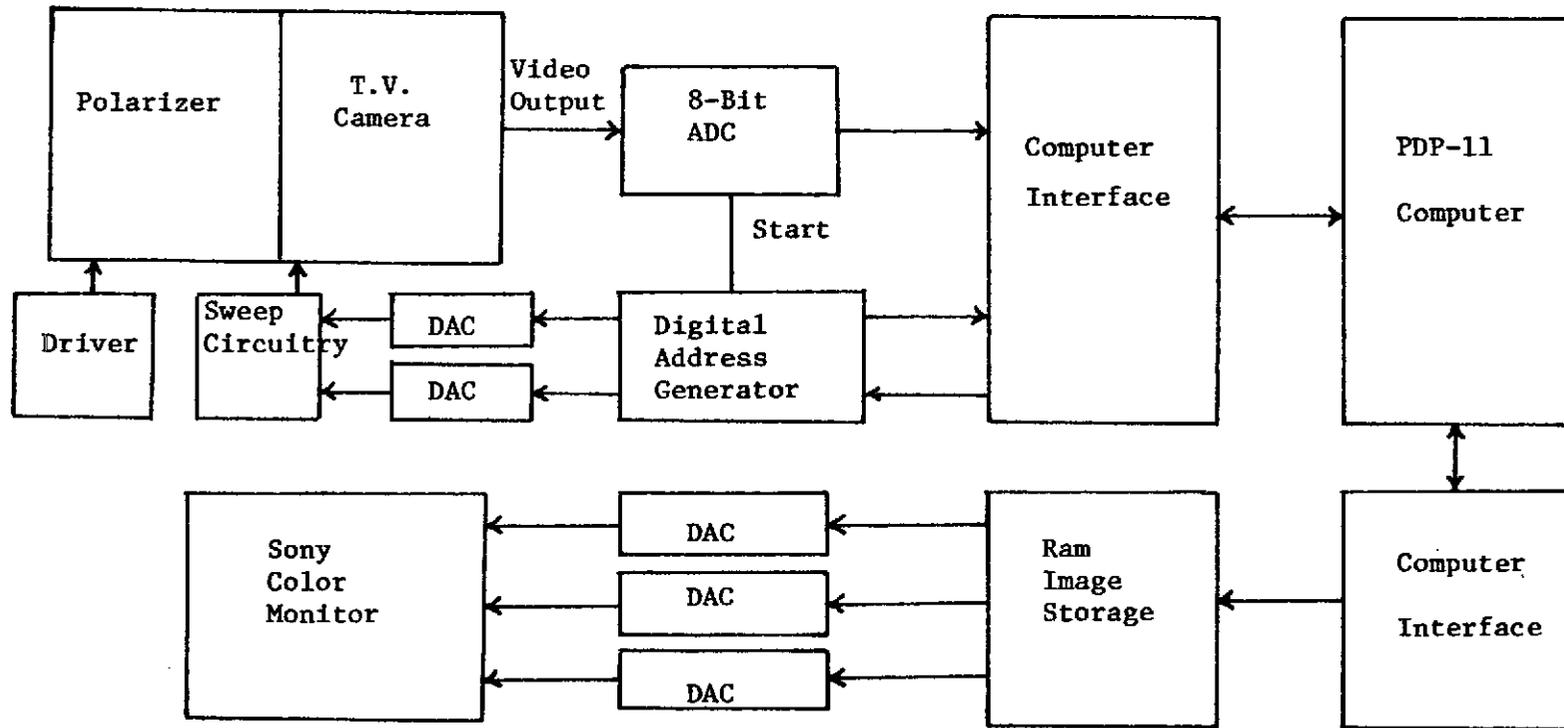
Figure 9.   Schematic Diagram of Video Polarizer

that the video polarizer is capable of measuring polarizations as small as 1%. The only other parts of the video polarizer system which exist so far are the PDP-11 computer and some components for the interfaces to the computer. The plan for acquisition of the remaining components necessary for implementing and checking out the method is discussed in the proposal section of this report.

B. Photographic Studies

In the last progress report the result of some photographic work obtained as a joint effort with Dr. V. Algazi was shown. This was a digitally processed image of two normal photographs which showed the polarization of the scene. We have just received a pair of matched Minolta Himatic 7A 35 mm cameras. These cameras will be mounted rigidly together and will be used for collecting pairs of photographs to be processed by Dr. Algazi. This will yield reconstructed images in polarization, as opposed to images in light intensity as in the ordinary photographic method. The routine implementation of the process is reserved for the coming period.

V Proposed Work for the Period May 1, 1974, to April 30, 1975

In planning the work for this part of the overall investigation, it is well to look at the specific goals toward which the investigation is oriented, and to see what contribution this particular aspect can make toward achieving the goals. At the request of NASA, the integrated study was recently reoriented, and a revised multi-campus proposal was submitted on September 30, 1973. Emphasis in that proposal, and presumably in future directions of the integrated study, is on the supply, demand, and impact relationships of the water resources of California. Since it is not clear how studies of atmospheric effects in image transfer can make significant contributions to achieving the revised goals of the integrated investigation, it is thought desirable

to phase out the atmospheric part of the investigation over a two-year period in accord with the established procedures for Y-type funding.

The activity proposed for the period May 1, 1974, to April 30, 1975, reflects this phase-out concept in both type of work and level of effort. Emphasis will be on bringing present activities to a logical conclusion, and no new types of investigation will be initiated. The work anticipated for the first and most important half of the phase-out period, as well as the proposed budget, is outlined below.

A. Theoretical work

The theoretical work will be in two main areas. The first of these is the computation of the radiation field in realistic atmospheric models to determine what effects are introduced by aerosol scattering and by aerosol and gaseous absorption. The programs for this work are almost completed, so the main effort and expense will be in running the programs and analyzing the results. Unlike most such studies which have been performed, the programs are designed to compute the complete vector equations, thereby permitting determinations of the state of polarization of the radiation field. Since the polarization is a sensitive indicator of atmospheric properties, it is expected that the results to be obtained will be particularly valuable for characterizing the state of the atmosphere.

The second theoretical aspect is oriented somewhat more directly toward remote sensing. As has been shown in previous reports of the present grant, the reflection properties of natural surfaces vary through wide ranges, and a proper utilization of such properties should provide an efficient method of discrimination among the surfaces. Because of

the wide variability of such surfaces, it is desirable to develop a theoretical model to predict not only the important parameters for determining reflection properties but also the reflection properties themselves for certain types of idealized surfaces.

In the progress report of May, 1973, a detailed description of an approach toward modeling of the reflection matrix of natural surfaces was presented. The method includes the effects of multiple scattering and surface roughness. In order to implement the method it is necessary to develop several computer programs for performing the necessary computations. This will be accomplished during the next period.

B. Observations and measurements

Here also the work will be divided into two aspects. First, the measurement program will be continued to provide data against which the theoretical work can be evaluated. The electronic instrumentation for polarization and intensity measurements has already been developed, so only minor items of equipment will be required. In the interest of economy it is anticipated that the radiation measurements will be confined to the Davis area.

A second aspect of polarization determinations, polarization by photography, has also been shown in the past reports to have great potential for surface characterization and discrimination in remote sensing applications. This technique will be developed further during the period. The camera equipment necessary for the work has already been purchased, and the necessary procedures are available. Thus it is expected that the method will be applied to some significant remote sensing problems during the coming year.

C. Instrument development

The only instrument development planned for the next year is that connected with the video-polarizer system described above. In the interests of economy, the first system will be of relatively low resolution (a 64x64 point grid). This system will be used to demonstrate the feasibility of the approach and to show the type of discrimination which can be achieved by the use of polarization. The more expensive components will, however, be adaptable to a higher resolution system if, as is expected, such a system proves to be a useful tool in remote sensing. The funds for the basic components are included in the proposed budget.

D. Proposed budget for period May 1, 1974, to April 30, 1975

The budget proposed for this part of the investigation for the period May 1, 1974, to April 30, 1975, is the following:

Personnel

Name	% Full Time	Rate	Cost
Dr. K. L. Coulson Professor of Meteorology	10	–	No cost
Dr. R. L. Walraven Development Engineer	50	$14,366/yr.	$7183
Grad. Res. Asst.	50	8,460/yr.	4230
Grad. Res. Asst.	25	8,460/yr.	2115
		Total salaries	$13528

Employee benefits (13% of salaries)   1759

Equipment and facilities

Components for video-polarizer system

   A-D converter (DATEL Model VH8B or equivalent) $1350

   TV color monitor (Sony Transitran or equivalent)   450

   Memory (INTEL MOS RAM or equivalent)   1000

Power supplies	300
Total E&F	$3100

Supplies and Expense

Repair of magnetic tape drive	$1000
Computer time (3 hrs. @ $500)	1500
Electronic components	250
Total S&E	$2750

Travel (domestic)	500

University overhead

(34.2% of modified direct costs)	$6340
Total budget	$27977

INTERCHANGE AND COOPERATION WITH USER AGENCIES

By

D. T. Lauer
Center for Remote Sensing Research, Berkeley Campus

INTRODUCTION

It is very apparent that the rate of remote sensing technique development is increasing at a much faster pace than is the rate at which these same techniques are being put to practical use. On the one hand, research scientists and engineers are actively engaged in sensor development and applications research, while on the other hand, earth resource managers and inventory specialists struggle to keep pace with new technology and to relate it to informational requirements within their own disciplines. Unfortunately, those burdened with the responsibility of managing earth resources often are unable to comprehend rapid advances in the field of remote sensing. This is particularly true for advances which employ high altitude aircraft and spacecraft sensor systems and automatic image classification and data processing techniques. Yet it is they who must ultimately decide whether the end product of this sophistication is meaningful.

Considering that as of the time of this writing, ERTS-1 and Skylab are in operation and that supporting underflights by U-2 and RB57 aircraft already have been implemented, it becomes increasingly important to bridge this widening communication gap between remote sensing specialists and potential "users", especially resource managers.

In the spring of 1970 when NASA saw fit to sponsor the Integrated Study of Earth Resources in the State of California Using Remote Sensing Techniques, it was recognized that the project's strongest contribution might be through interchange and coordination between university and user agency personnel. Not only is a university atmosphere conducive to such activities, but also most members of our team of scientists are professional educators experienced at giving lectures, seminars, workshops and short courses. Consequently, throughout the duration of the Integrated Study members of the team have participated in maintaining library facilities, disseminating research findings, training remote sensing specialists and interacting with resource managers.

LIBRARY FACILITIES

The documents library at Berkeley and film libraries at all five campuses of the University are being maintained and updated for use by staff, students, user agency personnel and other visitors. The remote sensing documents library at the Center for Remote Sensing Research (Berkeley campus) is, to our knowledge, the only one of its kind located in the far-western U.S. and now contains over 3400 items. Search techniques (by author and/or key word) can be employed to quickly and efficiently locate documents, and a loan file is maintained whereby

anyone interested in any particular items, including fully illustrated copies of the reports which we have prepared under the Integrated Study, may obtain them.

Likewise, the remote sensing imagery libraries, which are being maintained at the various campuses, are receiving heavy use. For example, we have found that the imagery library at the CRSR on the Berkeley campus, which contains data obtained from earth orbiting satellites (Tiros, Nimbus, Gemini, Apollo, ERTS-1 and Skylab), as well as from NASA Earth Resources Program aircraft (Convair 240, Lockheed P3A, Lockheed C130, RB57 and U2), government agencies (Agricultural Stabilization and Conservation Service, Geological Survey, Forest Service, etc.), and private contractors, can provide a means for review of imagery by scientists prior to requesting reproductions from NASA or other agencies. The imagery library at the CRSR employs an efficient indexing system, similar to that used for all NASA imagery at NASA/MSC (U.S. Army Map Service UTM grid system).

REPORTING

A major responsibility of each scientist participating in the Integrated Study is to disseminate the research findings derived from this project. This function is carried out by means of preparing and disseminating technical reports, special reports, briefing materials, information notes, professional papers, training syllabi and field tour guides. Fully illustrated copies of these materials are available in the loan files on the various campuses of the University. Furthermore, the semi-annual and annual progress reports for the Integrated Study are widely distributed to both national and international library facilities, research groups and user agencies.

Numerous formal oral presentations on research results have been given, by scientist participating in the Integrated Study, during the period covered by this report, several of which are listed below.

On June 12, 1973 at the AWRA International Symposium on Remote Sensing of Water Resources in Burlington, Ontario, Richard Lingenfelter and Gerald Schubert presented a paper entitled, "Remote Sensing of Stream Flow Rates: Correlation of Meander and Discharge Spectra".

On July 11, 1973 at the Fourth Biennial Workshop on Color Aerial Photography in the Plant Sciences, in Orono, Maine, Andrew Benson and Donald Lauer presented a paper entitled, "Testing Multiband ERTS-1 Imagery for the Classification of Commercial Conifer Forests".

On September 16, 1973 at the International Union of Forest Research Organizations Remote Sensing Symposium in Freiburg, Germany, Donald Lauer and Andrew Benson presented a paper entitled "Classification of Forest Lands with Ultra High Altitude Small Scale Infrared Photography".

Three papers were presented at the symposium entitled Management and Utilization of Remote Sensing Data held at Sioux Falls, South Dakota on October 29-November 1, 1973. The papers were (1) "ERTS-1 Analysis of Wildland Resources Using Manual and Automatic Techniques", by P. F. Krumpe, D. T. Lauer and J. D. Nichols, (2) "Combining Human and Computer Interpretation Capabilities to Analyze ERTS Imagery", by J. D. Nichols and W. M Senkus, and (3) "Operational Uses of Satellite Imagery in Agriculture", by A. S. Benson and W. C. Draeger.

On October 17, 1973 a paper was presented at the conference entitled "Machine Processing of Remotely Sensed Data" held at Purdue University, West Lafayette, Indiana, by William Senkus and was entitled "Complementary Role of Humans and Computers in the Analysis of Remotely Sensed Data".

Three papers were presented at the symposium on "The Application of Remote Sensing of Arid Land Resources and Environment" held at the University of Arizona, Tucson, Arizona on November 14, 15 and 16, 1973. The papers were (1) "Application of ERTS-1 Pre-Enhanced Imagery for Arid Land Recreation Planning", by Charles Hutchinson and James Huning, (2) "Remote Sensing of Arid Environments: Contrasts and Conflicts in Studying Baja and Alta California" by Leonard Bowden, and (3) "Estimates of Irrigated Water Demands from Remote Sensing" by Claude Johnson.

On December 5, 1973 at the Interdisciplinary Symposium on Advanced Concepts and Techniques in the Study of Snow and Ice Resources held at Asilomar, California, Donald Lauer and William Draeger presented a paper entitled "Techniques for Determining Areal Extent of Snow in the Sierra Nevada Mountains Using High Altitude Aircraft and Spacecraft Imagery".

Four papers were presented at the Third ERTS Symposium held in Washington, D. C., on December 10-14, 1973. The papers were (1) "Multispectral Combination and Display of ERTS-1 Data" by V. R. Algazi, (2) "Practical Applications of the Use of ERTS-1 Satellite Imagery for Land Use Mapping and Resource Inventories in the Central Coastal Region of California" by J. E. Estes, et al., (3) "Regional Agricultural Surveys Using ERTS-1 Data" by W. C. Draeger, et al., and (4) "A Timber Inventory Based Upon Manual and Automated Analysis of ERTS-1 and Supporting Aircraft Data Using Multistage Probability Sampling", by J. D. Nichols, et al.

The 15 papers listed above will be published as part of the proceedings of the respective conferences.

TRAINING

In reference to training, participants in the Integrated Study are pursuing a vigorous program involving lectures, short courses, workshops, guided field tours of NASA test sites and formal training

courses. We feel that virtually all remote sensing training programs currently being offered are merely "appreciation courses", i.e., those designed to convey to the attendee the fact that remote sensing techniques offer a powerful means of making accurate, timely, economical inventories of earth resources. While there may be a continuing need for these courses to be presented to various top-level "decision-makers", the major need is to thoroughly train the actual "doers". Mere appreciation courses definitely will not prepare them to accomplish the all-important task of making operational inventories. Instead, they need to receive rigorous training in how to produce, through an analysis of remote sensing data, a survey of earth resources of the type that will meet the specific informational needs of the resource manager.

As in the training exercises conducted thus far (the CRSR alone has presented more than 30 courses since the inception of the Integrated Study), all future programs will make maximum use of the concept of "learning by doing". Consistent with this concept, actual rather than hypothetical problems are emphasized. These problems are centered around the inventory of earth resources at NASA test sites, one of which (the San Pablo Reservoir Test Site) is only eight miles from the classroom facilities on the Berkeley campus. Training films, field tour manuals, and display boards based on this and other NASA test sites which the team of scientists have studied on the Integrated Study during the past three and a half years have been successfully used for training in the past and are available for future programs. These training materials illustrate various data acquisition and analysis techniques with emphasis on both the gathering of "ground truth" data and the extraction of information from remote sensing imagery. More specifically, during these training programs we attempt to disseminate information on the following subjects: (1) specific user requirements for earth resource information; (2) basic matter and energy relationships (3) remote sensing capabilities in various parts of the electromagnetic spectrum; (4) sampling techniques, including techniques for the acquisition of ground truth; (5) photo interpretation equipment and techniques; (6) image enhancement techniques; (7) automatic data processing techniques; and (8) techniques for optimizing the interaction between those who provide earth resource inventories and those who use such inventories in the management of earth resources.

A good example of where this approach to training was used can be found in a 2-day seminar conducted in September, 1973 by the CRSR staff. Ten representatives from the U.S. Forest Service Region V Headquarters and from various Region V field offices attended the session held on the Berkeley campus.

In addition, an information exchange seminar will soon be conducted by the CRSR with the California Division of Forestry. Twenty-six representatives from the CDF's Forest Management, Range Management, Watershed Management, and Fire Control sections at both the staff and field level will attend.

These seminars are conducted using information obtained from ERTS imagery and Skylab imagery with associated aircraft and ground data, to demonstrate what has been done in the recent past in areas of pure research and applications. After this presentation of the state of the art, much time is spent in obtaining feedback from the user groups in the present and possible future applications of such data. Much attention is paid to the problem of providing information to the user agencies in a form that can be used at the various levels within the agencies, depending upon their information requirements. To date, these information exchange sessions have been highly valuable to both the user, in educating him to the state of the art, and to the CRSR in defining user requirements.

The participants in the Integrated Study who have presented training programs, such as the two listed above, have learned a great deal about how training courses of this nature should be conducted. For example, we have learned that several of the many factors which govern the effectiveness of a training course are:

1. Familiarity of staff with attendees, both personally and professionally.

2. Staff's ability to communicate with attendees (lecturing vs. teaching).

3. Organization of course material (appreciation course vs. workshop course).

4. Balance in course material (lecture vs. laboratory vs. field excursions).

5. Staff's familiarity with field sites.

6. Staff's research experience at field sites.

7. Length of course (technical and personal factors).

8. Use of "free-time" for study and travel.

9. Course Syllabus (organization, quantity, and quality).

10. Logistical support.

USER INTERACTION

A primary effort has been made during the Integrated Study to determine the feasibility of providing resource managers who are operating within the State of California with operationally useful information through the use of remote sensing techniques. As a first step, therefore, records have been compiled of resource agencies active within the State and contacts have been made with land managers and resource specialists who are keenly interested in the results of the study.

Thus, through direct interaction with user agencies, resource management problems and information requirements have been well defined at the outset of the Integrated Study, and have been refined and updated throughout the duration of the project. A specific result from the interaction between the participating scientists and user groups was that detailed information has been obtained about operational resource inventory and management projects which are currently in progress or have been performed in the recent past within the State of California. Several of the operational projects dealing with water supply and demand problems have been cited in the previous chapters in this report.

The remaining pages of this section show a listing of key personnel from user agencies who are cooperating with the various campus groups on the Integrated Study.

BERKELEY CAMPUS -- Co-investigator Professor C. W. Churchman

User Agency Interaction

State of California

Agriculture and Services Agency

David Adams
Division of Plant Industry, Sacramento

Continuous contact with respect to Dr. Adams' dual roles:
(1) as a user of ERTS data, in his work on detection of
certain crop diseases and infestations, and (2) as member
of the staff of the State Coordinator for Remote Sensing.
With respect to the latter, there is a constant and mutual
exchange of information about all activities related to
ERTS, its technical development, its applications, and its
effects on resource management in the State.

Ward Henderson
Bureau of Agricultural Statistics, Sacramento

Continuous contact on (1) current activities of this Depart-
ment; (2) present information sources; (3) uses to which
information is put; (4) exploration of areas in which satel-
lite data might make significant contribution, e.g., statewide
agricultural surveys, land use categorization and stratifi-
cation; (5) inquiry into management decision-making processes
bearing on development and utilization of ERTS-related tech-
niques; and (6) investigations of factors (social, political,
economic, and bureaucratic) encouraging or impeding adoption
of the new techniques.

Carl W. Nichols
Division of Plant Industry, Sacramento

Continuous contact on Division's (1) current activities;
(2) present methods of acquiring information; (3) decision-
making processes, especially the factors (social, economic,
and political) impinging on delineation of objections, i.e.,
mainly, whose interests are to be served by certain measures,
and in what time frame; (4) responsibilities vis-a-vis detec-
tion, evaluation, and control of pests and diseases, and
(5) potential impacts of ERTS technology in identification

and control, specifically of the pink boll worm and sugar
beet leaf virus.

Vernon L. Shahbazian
Division of Marketing Services, Sacramento

Continuous contact on (1) functions of the Bureau of
Marketing; (2) its present information sources; (3) uses
of information, especially with respect to marketing
orders; (4) possible uses of ERTS data, particularly as
they become more accessible and available, and (5) potential
impacts of improved information (i.e., more accurate, more
timely) on Bureau's service to public.

Dr. Gordon F. Snow
Special Assistant to the Director

Continuous contact on developments throughout the State of
California on environmental and ecological matters. Consi-
deration of possibilities for use of ERTS data to improve
decision-making processes; review of current practices
among the various agencies involved; exploration of the
potential pro's and con's of satellite imagery.

Department of Conservation

Robert Weaver
Department of Conservation, Division of Forestry, Sacramento

Continuous contact on functions of the Division, information
sources, management decisions, and responsibilities. Review
of current experimentation with ERTS imagery in various
of the Division's activities. Of special interest is the
research being carried out in cooperation with the U.C.
Remote Sensing Laboratory.

Other User Agency Interaction

Ralph B. Bunje
California Canning Peach Association, San Francisco

At a meeting with the top-level Production Committee of the
Board, Prof. Robert N. Colwell and Dr. Ida Hoos gave pre-
sentations and discussed the potential uses of remote sensing.
As soon as the techniques are adequately developed, the
Peach Association is anxious to investigate possible utiliza-
tion for specific purposes.

Harold Bissell
Jones and Stokes Associates, Sacramento

This consulting firm made up of 30 former officials of the
State Fish and Game Department, specializes in natural
resource planning and in environmental impact studies.
The potential for remote sensing in their activity seems
to be very great and further contact and exploration are
warranted.

Jack Schoop
California Coastal Commission, San Francisco

Investigation of the progress being made to implement Propo-
sition 20, which created the Commission. Information gathered
on the organization of the Commission, the location of the
six regional subdivisions, and the key personnel in each.

Revan Tranter
Association of Bay Area Governments, Berkeley

ABAG is undergoing considerable reorganization under the direc-
tion of Mr. Tranter, its new director. Through informal
discussion, it has been learned that Mr. Tranter utilized
remote sensing as a source of information in his previous
position, which was in the Washington, D. C. regional organi-
zation. As soon as organizational and procedural matters
are under control, steps will be taken to investigate the likeli-
hood of ABAG's utilization of remote sensing information.

Milton L. Levy
Apricot Producers of California   )
California Green Lima Bean Grocers)   Berkeley
California Christmas Tree Growers)

Exploratory talks with Mr. Levy, who, besides being execu-
tive secretary of three grower associations, maintains
considerable contact with a considerable spectrum of agri-
cultural organizations, have opened the way for exciting
possibilities for exploration of remote sensing utilization.
The California Farm Bureau Federation, of which Mr. Allan
Grant, a member, ex officio of the Board of Regents of the
University of California, is president, coordinates the
activities of close to 1000 agricultural associations,
covering some 200 crops.

All of these associations have as their ultimate objective improved production of their particular crops, and the ways in which more timely and more complete information could benefit their operations have yet to be explored. It is anticipated that specific tasks, such as crop estimating, or particular problems, such as the location and movement of the Nantucket tip moth, which has invaded California's cash crop of Christmas trees, might be selected. Or, in connection with the U. C. Forestry Remote Sensing Laboratory's work on California's range land, special projects could be developed in cooperation with the Brush Range Association and the California Cattle and Livestock Associations. If the proper mechanism can be established, Mr. Levy, through the Farm Bureau Federation, could be the prime link in the communications chain between ERTS or other remote sensors and the user community.

Cameron Girton
California Canning Pear Association, San Francisco

Preliminary talks about possible utilization of ERTS imagery especially in crop estimation. Although not as large as the peach industry, the pear industry is substantial and has a history of receptivity toward innovative techniques, plus a sophistication in production that, as with the Peach Growers, would provide ground truth useful in investigating possible uses of remote sensing.

Mr. Almendinger
Wine Institute, San Francisco

Informal talks about the possibility of utilizing remote sensing in this industry. With California wines gaining prominence and importance nationally and internationally, considerable interest is being generated in the extent and condition of vineyards. This is an area in which remote sensing may be of service. It is very likely that the grower associations would be receptive to specific projects.

BERKELEY CAMPUS -- Co-Investigator Dr. William C. Draeger

User Agency Interaction

State of California

Agriculture and Services Agency

David Adams
Division of Plant Industry, Sacramento

Manual and automated analysis for detection and evaluation
of citrus decline in southern California.

Ward Henderson
Bureau of Agricultural Statistics, Sacramento

Development of operational agricultural inventory techniques;
determinatión of cost effectiveness and accuracy of remote
sensing based inventory systems.

Department of Water Resources

Barry Brown
Division of Resources Development, Sacramento

Technique for performing statewide irrigated land inventories;
compilation of land use inventory requirements of the DWR.

Van H. Lemons
Snow Surveys and Water Supply Forecasting Section, Sacramento

Measurement of snowpack parameters in Feather River test
site.

Arthur deRutte
Central District, Sacramento

Specifications for operational water quality monitoring
systems in the Sacramento-San Joaquin delta

Department of Conservation

William Ennis
Division of Forestry, Sacramento

Use of ERTS data collection systems for fire weather monitoring.

Clint Phillips
Division of Forestry, Sacramento

Wildland fuel mapping in the State of California.

C. Hoyt Thornton
Division of Forestry, St. Helena

Use of ERTS-1 data for fire mapping and damage assessment.

Bill Weaver
Division of Forestry, Sacramento

Definition of research needs of CDF.

Department of Parks and Recreation

Sandy Rabinowitch
Student Intern, Sacramento

Preparation of vegetation maps of park lands adjacent to
Oroville Reservoir.

Norman Hongola
Sacramento

Urban land use change detection.

Water Resources Control Board

Gilbert Fraga
Division of Planning and Research, Sacramento

Aerial photo reconnaissance systems for evaluating impact of
prospective logging and land use conversion operation on
water quality.

Department of Navigation and Ocean Development*

Glenn Twitchell
Comprehensive Ocean Area Plan, Sacramento

Selection of mapping categories and aerial photo techniques
for land use mapping in coastal zone of California.

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*Program now carried out by the California Coastal Zone Conservation
Commission.

Governor's Office

John Passerelo
Office of Planning and Research, Sacramento

General resource planning applications of remote sensing.

Federal Government

U.S. Department of Agriculture

Harold Huddelston
Statistical Reporting Service, Washington, D. C.

Use of remote sensing techniques in nationwide crop inventory systems.

William Kibler
Statistical Reporting Service, Washington, D. C.

Use of ERTS data for crop identification, land use classification.

James Cook
Forest Service, Pacific Southwest Forest and Range
Experiment Station, Berkeley, California

Use of remote sensing techniques for producing California
Comprehensive Framework Study data.

Richard S. Driscoll
Forest Service, Rocky Mountain Forest and Range
Experiment Station, Ft. Collins, Colorado

Cooperation on large scale color and color-infrared aerial
photo studies of rangeland environments.

Donald Duncan
Forest Service, San Joaquin Experiment Range, O'Neals, California

Collects supplementary ground information regarding climate
and forage production at local test site for ERTS forage
production study.

Neil McDougald
Forest Service, Sequoia National Forest, California
Hot Springs, California

Provides climatic and forage production data from local
test site for ERTS range monitoring study.

James McLaughlin
Forest Service, Plumas National Forest, Quincy, California

Soil and vegetation mapping using high altitude aerial
photography.

Walter Bunter
Soil Conservation Service, Berkeley, California

Use of ERTS and high flight data for regional land use
mapping.

U.S. Department of the Interior

Gordon Bentley
Bureau of Land Management, Riverside, California

Determine usefulness of satellite and aircraft data for
monitoring range resources.

Dean Bibles
Bureau of Land Management, Susanville District, Susanville,
California

Cooperative remote sensing studies of aircraft and spacecraft
data to determine usefulness for integrated resource
analysis for Unit Resource Analysis and Planning.

Grover Torbert
Bureau of Land Management, Washington, D. C.

Uses of satellite and high flight imagery for inventorying
and monitoring BLM lands.

Richard Brown
National Park Service, Point Reyes National Seashore,
Point Reyes, California

Vegetation and terrain mapping of National Seashore.

Ted Hatzimanolis
National Park Service, Redwood National Park, Crescent City,
California

Cooperative agreement to analyze U-2 and ERTS imagery to
determine usefulness for resource management purposes.

Richard Janda
Geological Survey, Menlo Park, California

Cooperative studies of U-2 and ERTS imagery of Redwood
National Park resource management problems.

James Mills
Bureau of Outdoor Recreation, San Francisco, California

Assessment of recreation areas using remote sensing tech-
niques.

U.S. Army

George Lukes
Corps of Engineers, Topographic Laboratory, Ft. Belvoir,
Virginia

Crop inventory techniques using satellite and high flight
imagery.

Michael C. Stroud
Natural Resource Conservation Office, Hunter Liggett
Military Reservation, Jolon, California

Provides climatic data and forage production from local
test site for monitoring forage development on rangeland
in California.

Other User Interaction

Medhi Bahadori
University of Tehran, Tehran, Iran

General resource mapping problems in Iran.

John C. Baker
Jones and Stokes, Inc., Sacramento, California

Evaluation of effects of logging activities on water quality.

Alan Black
Association of Bay Area Governments, Berkeley, California

Use of high flight imagery for regional planning in San
Francisco Bay Area

James Bruner
Tahoe Regional Planning Agency, South Lake Tahoe, California

Potential use of remote sensing in regional planning.

William Hartman
East Bay Municipal Utility District, Oakland, California

Range vegetation and plant stress studies at San Pablo
Reservoir test site.

Bernard Herrera
National School of Agriculture; Chapingo, Mexico

Uses of ERTS for forestry and agricultural purposes in
Mexico.

Raymond McAllister
Sonoma County Planning Department, Santa Rosa, California

Detailed land use mapping using aerial photographs.

Darrell Payne
Plumas County Planning Department, Quincy, California

Land use mapping in Plumas County.

Alan Stevenson
Aerospace Corporation, El Segundo, California

Automated wildland fuel mapping using ERTS and high flight
imagery.

Gary Tate
East Bay Regional Park District, Oakland, California

Evaluation of eucalyptus frost damage.

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Ray A. Perry
Rangeland Research Unit, Commonwealth Scientific and
Industrial Research Organization, Canberra, A.C.T., Australia

Cooperative study of the usefulness of ERTS and supporting
aircraft data for evaluating rangeland condition in Australia.

Jesus Veruete
National Forest Inventory, Coyoacan, Mexico

Uses of ERTS for forestry and agricultural purposes in Mexico.

A. Westerland
University of Washington, Seattle, Washington

Urban change analysis surrounding the Seattle Airport.

DAVIS CAMPUS -- Co-investigator Professor R. Burgy

User Agency Interaction

State of California

Department of Water Resources

Barry Brown
Division of Resources Development, Sacramento

Definition of user needs for determination of water consumption.

Charles McCullough
Division of Resource Planning, Sacramento

Planning applications of remote sensing in water resources.

Eugene F. Serr
Northern District

Water quality and quantity in upper Sacramento River Valley.

A. deRutte
Central District, Sacramento

Delta region water quality monitoring and flood delineation.

Water Quality Control Board

Gilbert Fraga
Division of Planning Research, Sacramento

Use of remote sensing for water quality determination.

Federal Government

U.S. Department of the Interior

Dominic Pastir
Bureau of Reclamation, Sacramento

Use of remote sensing for water quality, hydrobiological, and environmental applications.

Stuart Porter
Bureau of Land Management, Sacramento

Use of remote sensing for water quality, hydrobiological,
and environmental applications.

DAVIS CAMPUS -- Co-Investigator Dr. W. Wildman

User Agency Interaction

State of California

Department of Water Resources

Barry Brown
Division of Resources Development, Sacramento

Assistance in making a color print map of state of California
using 9 x 9 transparencies prepared at Davis.

County of Plumas

Darrell Payne
Planning Department, Quincy

A training session was prepared for Mr. Payne and his assistant,
followed by a meeting at the Forestry Remote Sensing Laboratory
to apprise them of the Feather River Test Site information.
The Farm Advisor in the Plumas area has ordered color infrared
composites of ERTS images to use with the planning director in
revising the county general plan.

SANTA BARBARA CAMPUS -- Co-investigator Prof. J. E. Estes

User Agency Interaction

State of California

Department of Water Resources

Barry Brown
Division of Resources Development, Sacramento

Close communication is maintained concerning the nature and
scope of investigations in the Central Valley and Central
Coastal Zone. Strong interest has been expressed in work
dealing with land use and agricultural data, since these are
important planning inputs to water resource management.
Information is regularly exchanged.

Department of Transportation

Robert Meyer
Division of Highways, Community and Environmental Factors
Unit, Sacramento

Discussions and land use information have been exchanged to
determine possible uses of remote sensing for assessing
environmental impacts from highway projects.

Stephen Oliva
Division of Highways, Environmental Planning Department,
San Francisco

Close cooperation is being extended, through discussions and
distribution of reports, in setting up a remote sensing
capability for environmental analysis in this office of the
Division of Highways.

Department of Conservation

Fred Frank
Division of Forestry, Sacramento

Reports are sent to indicate potential feasibility of ERTS-1
data for mapping forest fire burn areas and inventorying
coastal vegetation.

Governor's Office

John Paserellq
Office of Planning and Research, Sacramento

Periodic reports are provided on the status of ERTS-1
investigations at the Santa Barbara campus for purposes of
information, dissemination and coordination of research
activities.

Other User Agency Interaction

Robert Gin
Kings County Planning Agency, Hanford

Discussions have been held concerning our possible partici-
pation in the construction of a uniform land use data base
for the southern Central Valley. This would involve
several county planning agencies and rely heavily upon
remote sensing techniques and computer data processing.

David Loomis
Ventura County Planning Department, Ventura

The Planning Department would like to obtain the results
of the Central Coastal Zone data base study that apply to
Ventura County, since the county is almost totally lacking
in this information. There is also interest in the tech-
nique for intercensal population estimation which is being
developed under the NASA grant.

Michael Rector
Kern County Water Agency, Bakersfield

Close cooperation is maintained to determine the potential
of remote sensing data as a source of information for
accurate estimates of cultivated acreages. Data are being
supplied to Kern County Water Agency to establish accuracy
levels and to use in models for projecting future agri-
cultural water demands.

Ned Rogoway
San Luis Obispo County Planning Department, San Luis Obispo

The Planning Department is interested in keeping informed about
new techniques for gathering environmental information.
They would like to obtain the results of the Central Coastal

Zone data base study for San Luis Obispo County; Interest
has also been expressed in obtaining cooperation for a study
of the Morro Bay Watershed area to determine the limits of
development which can be allowed to occur.

Jim Staples
Santa Barbara County Planning Department, Santa Barbara

Mr. Staples has toured our facility and would be interested
in cooperating on a project to predict flood hazard areas.

RIVERSIDE CAMPUS -- Co-investigator Professor L. W. Bowden

User Agency Interaction

State of California

Department of Water Resources

Barry P. Brown
Division of Resources Development, Sacramento

Discussion of ERTS-1 projects. Discuss feasibility of
possible state agricultural land use map (irrigated vs.
dry farming).

Richard Koch
Los Angeles District, Los Angeles

Interested in land use mapping for the desert area high
altitude imagery; Mojave River agricultural land use
mapping.

Charles Perchard
Redding District, Redding

Use of imagery for extracting land use data for input to
State Resources and Planning Department project.

Robert Smith
Los Angeles District, Los Angeles

Worked with U-2 (RC-10) imagery; did land use mapping of
Southern California (2 month project).

Department of Transportation

Don Grey
Division of Highways, San Diego

Interested in availability and coverage of San Diego County;
for use in environmental impact of highway construction.

Department of Parks and Recreation

Jerry Henderson
Mt. San Jacinto Station, Palm Springs

Interested in available imagery of the San Jacinto environs.
Needs management technique and vegetation studies of area.

Norman Kucala
Sacramento

Evaluating imagery for development of a Perris Lake Recreation Area plan.

Roderick Meade
County of Los Angeles, Los Angeles

Introduction to imagery for use in determining potential
park sites.

George Rackelmann
Sacramento

Required all available imagery of Tijuana Estuary.

Governor's Office

John B. Passarello
Office of Planning & Research, Sacramento

Land resources and use program.

Federal Government

U.S. Department of Agriculture

Bill Ryan
Forest Service, Fire Laboratory, Riverside

Evaluation of results obtained and methodologies incor-
porated in mapping montane vegetation from imagery.

John Sawer
Newcastle Disease Headquarters, Riverside

Used imagery to map areal extent of recent outbreak of
Newcastle disease

U.S. Department of the Interior

Mr. Hagihara
Bureau of Land Management, Riverside

Many discussions concerning long-term evaluation of
off-road-vehicle operation in the California desert.
Extensive use of both ERTS-1 and U-2 underflight imagery
for comprehensive planning of varied subjects concerning
BLM land.

Mr. Cushman
Bureau of Land Reclamation, San Bernardino

Used U-2 imagery in order to define the southern shoreline
of the Salton Sea for an irrigation study.

U.S. Bureau of Census

Robert Durland
Geography Division, Washington, D. C.

Discussion of techniques and availability of assistance with
NASA sponsored project in Afghanistan to perform census
counts within the country from remotely sensed imagery.

U.S. Department of State

Mr. Acker (Dr. Ominde, University of Nairobi)
Washington, D. C.

Evaluate ERTS-1 imagery and U-2 underflight imagery and
obtain techniques for performing agricultural land use
mapping by computer.

Other User Agency Interaction

Jean McKnight
County Planning Department, Los Angeles

Exchange of land use data for regional land use planning
and open space planning. Published joint UCR/NASA Technical
Report on Use of Remote Sensing in County Planning Agencies.

William Livingstone
County Planning Department, Riverside

Use of interpreted data and raw film for land use planning.

Emphasis on open space planning.

Ken Topping
County Planning Agency, San Bernardino

Prepared pilot study of Agricultural land use in Victor Valley
for land use planning. Present emphasis is use of data and
film to prepare open space planning in the desert area.

Ken Pyle
County Planning Agency, San Diego

Use of data in land use planning. Cooperated in project of
automating county soils map for an Information Overlay
System.

Kevin Barrett
County Planning Agency, Orange

Preparation of vegetation map and data for open space
planning.

Charles W. Reither, Richard Alexander, and Elmer Swanson
Parks Department, Cities of Beverly Hills, Culver City,
and Inglewood

Use of U-2 imagery to provide inventory of parkway trees
and assist in detection and control of disease within these
trees.

Steve Whyld
Planning Department, City of Riverside

Data and imagery of West Riverside/Norco area for use in
developing common park facilities.

Chapter 6

SUMMARY

R. N. Colwell

Some Basic Considerations

This summarizing chapter is purposely a rather lengthy one for the following combination of reasons:

1. As requested by NASA there has been a dramatic reorientation of our study since the last previous reporting period. Consequently a rather complete summary is needed to indicate the new direction in which our efforts now are oriented.

2. The nature of this new orientation is such that it has been necessary for us at the outset to compile a large number of seemingly isolated facts. While these facts are documented in the previous chapters their interrelationships and their overall impact can be better appreciated by our summarizing them, voluminous though they are, as in the present chapter.

3. Although some readers of this summarizing chapter would be satisfied with a much less complete summary than is provided here, others, including our own co-investigators and other participants, need a rather detailed and systematic tabulation of the relevant facts that have been uncovered by their colleagues during the period since reorientation of the study. By that means it should be possible for each participant to better appreciate how his part in the integrated study relates to the whole. Such comprehension by each participant is certain to result in better integration of the overall study. It is partly for the benefit of our fellow participants, then, that this summary has been made quite detailed.

4. Whenever a major reorientation is given to a study such as ours, it is important to appreciate not only the new direction that it has been given, but the extent to which the old direction has been abandoned. Furthermore, it is important to realize the extent to which work presently being done builds upon work previously done under the project. In order for such information to be conveyed adequately, a summary having approximately the degree of detail that is presented in the remainder of this chapter would seem to be needed.

Detailed though this summary is, one should not infer that it represents a definitive state of completion of our preliminary data collecting phase. Rather it should be regarded as a status report that is written even while we are in the midst of that phase and while we are at the same time progressing with our work on certain other phases of the integrated study.

If, as one reads the following detailed summary, he makes occasional reference to Figures 1.1 and 1.2 (in Chapter 1) of this report, he will acquire an increased appreciation of how the various parts relate to the whole and to the eventual objective of assessing the Impact of remote sensing on the management of California's water resources.

A reading of the preceding chapters will document the fact that there is a mix of many problems relating to the proper management of California's water resources, ranging from ecological and technological, through political and social, and including several economic, legal and enforcement aspects. Adding to the complexity of this multifaceted problem is the fact that California's water resources are in a rapidly changing state. All of these factors contribute to the need for resource inventories that are related to water resource management in California and that can be made with increased frequency and accuracy, but with little or no increase in cost. As the preceding chapters have indicated, remote sensing from high altitude aircraft and/or from spacecraft such as ERTS-1 or Skylab can do much to facilitate the management of California's water resources by improving our ability to make the necessary inventories.

In the sections which follow, a brief summary is given of work done and conclusions arrived at by our multi-campus group during the period covered by this report. In each case a fuller treatment will be found in the pertinent preceding chapter.

1. SUMMARY OF STUDIES RELATIVE TO WATER SUPPLY

A. With respect to the California Water Project we have established that;

1. Fully operational use has been made of that project for flood control purposes for a number of years.

2. Flood control operations have already been highly beneficial to Northern California, the most notable instance to date being the prevention of an estimated 30 million dollars of flood damage in the Winter of 1964-65.

3. In addition to the obvious economic impact of preventing flood damage, flood control operations set definite limits on water storage by setting requirements on flood control space, and also by setting release requirements related to precipitation and conditions of the watersheds.

4. Three aspects that are especially important relative to management of the California Water Project are the development of adequate water supply and conservation facilities, the development of a realistic schedule of contracted water deliveries, and the establishment of a suitable basis for charging water users.

5. By 1968 the California Water Project annual delivery capability of 4.23 million acre-feet of water had been fully contracted for.

6. Long-term water supply contracts with 31 local agencies currently are in force. Each contract is for a period of at least 75 years and sets a schedule of annual water amounts which the agencies are entitled to receive.

7. For the present, the maximization of the amount of water that can be made available to water user agencies by the supply area definitely is not a "driver" because it plays a role secondary to flood control, power generation, control of water quality, and even to fish and wildlife management in the operation of the water supply area.

8. Power costs are the largest single annual operating expense of the Project. Under ultimate water delivery conditions, power costs are presently estimated at $73 million annually, including costs of transmission service.

9. Project pumping energy requirements will continue to increase over the next 20 years at an average rate of about 350 million kilowatt-hours annually, ultimately reaching 13 billion kilowatt-hours by the year 2020.

10. The long-term outlook in the electric power industry continues to reflect a rising trend in electric power costs. Higher power costs can be expected in the future due to (a) environmental factors resulting in siting problems and construction delays, (b) more stringent licensing and safety requirements, (c) escalation of labor and materials costs, and (4) rising fuel costs associated with the increasingly acute energy crisis.

11. By the Oroville-Thermalito Power sale contract, the Department of Water Resources has contracted the power generating capacity of the power plants, rather than the energy actually generated. Thus, the economic benefit to the State of increased energy generation is comparatively small under present conditions.

12. The management of the California Water Project is greatly affected by water quality considerations in that allowance must be made for release of enough water to maintain certain flow rates through the Sacramento-San Joaquin Delta to San Francisco Bay. These minimum flow rates are necessary to prevent salt water intrusion into the Delta and to provide "flushing" action through the Delta and Bay system to prevent water pollution and destruction of fish and wildlife habitat in the area.

13. At the present time, however, there is considerable disagreement among the experts as to what minimum flows are actually necessary to prevent environmental degradation, what steps need to be taken to assure compliance with water quality standards; and whether the steps required by the Water Resources Control Board are reasonable.

B. With respect to current operation of the Oroville facility we have established that:

1. At the present time, the primary constraint imposed on the Oroville Reservoir facility is that pertaining to flood control. During the winter months a certain storage capacity must be maintained to provide a margin of safety in the event of high runoff.

2. There is not, however, any significant constraint imposed for water supply purposes, due to the staged schedule of water deliveries by the California Water Project.

3. While eventually over 3 million acre feet per year will be required by users in the San Joaquin Valley and the Los Angeles area, at the present time only about 1 million acre feet are being delivered. Thus demand pressures at the present time are not great and there is no problem in supplying enough water to fulfill current water and power contracts.

4. By the mid 1980's, however, the amount of water available at any given time will become much more critical and a greater emphasis will probably be placed on water conservation practices than at present.

5. Even before then, efforts to solve the state's energy crisis may place increased emphasis on the possibility of producing more hydro-electric power from the Oroville Dam facility.

6. Water releases from Oroville Dam to achieve flood control are based on an analysis of present and projected reservoir inflow, reservoir storage capacity, and constraints on outflow.

7. Before construction of the Oroville Reservoir, damages from a single flood along the Feather River in the lowlands downstream from the dam site went as high as $82 million dollars (during December, 1955).

8. Flood protection is provided up to the magnitude of the standard project flood, which has been calculated for the dam site as an inflow of 440,000 cubic feet per second (cfs). This value is approximately 1.8 times the largest peak flow ever determined for that location.

9. Releases from Oroville Reservoir must never be increased by more than 10,000 cfs nor decreased by more than 5,000 cfs in any 2-hour period. These release change limits prevent damage to structures or boating traffic on or near the river that might result from sudden changes in water level.

10. Reserved flood storage volume at Oroville Reservoir is a function of the potential for a standard project storm and a calculated watershed ground wetness index.

11. The potential for a standard project storm is based on a seasonal precipitation distribution analysis for the Feather River

Project Area. Releases from Oroville Reservoir must be based in part on stream gage measurements or forecasts of the Yuba River flow rate, because flood damage might otherwise result in areas that are below the confluence of these two rivers.

12. When the rate of rise of the Oroville Reservoir for a given elevation of the reservoir indicates a necessary exceedence of the normal maximum release capacity of 150,000 cfs, then use of the spillway is initiated. The spillway outflow rate is increased each hour, (at a rate not to exceed the 5,000 cfs limit) so that reservoir inflow is eventually matched by reservoir outflow.

13. In relating the foregoing to possible benefits to be derived through remote sensing, one consideration seems paramount. At the time when a major storm seems imminent, the very large "safety factor" which must be employed (through drawdown at the Oroville Reservoir) results primarily from very large uncertainties as to the maximum strength which that storm might achieve. Secondarily it results from similar uncertainties as to the "wetness factor" that prevails at that particular time, area-by-area, throughout the watershed. Just as some of our other research has indicated that a combination of meterological satellite data and ERTS data can permit the best crop forecast to be made, so it would seem that a similar combination would permit the best flood forecast to be made, and with equally dramatic cost effectiveness. We hope to perform research relative to this important possibility in the very near future.

C. With respect to the potential value of remote sensing information in estimating water supply we can now state that:

1. Potential applications are presently being considered under two major contexts. The first involves a direct remote sensing input into present "state-of-the-art" streamflow prediction, and the second context involves future-period applications.

2. Within the state of California, prediction of streamflow or runoff (i.e., water supply through time) is officially the responsibility of the Joint Federal-State River Forecast Center and the California Cooperative Snow Surveys.

3. Information on water yield provided by the Snow Surveys' publications is utilized by 50 cooperating agencies. These include 25 irrigation and water districts, along with major private organizations, public utilities, municipalities, and state and federal organizations.

4. The Joint Federal-State River Forecast Center has as its primary responsibility the issuing of six, twelve and twenty-four hour river state forecasts during rain floods and snow floods for watersheds throughout the state.

5. One way in which to differentiate between the water yield modeling responsibilities of the RFC and of the CCSS is in terms of the time period for which predictions are made. The River Forecast Center is primarily involved in issuing six hour to several day forecasts. Its modeling function is therefore real-time or what may be termed "dynamic" water yield prediction. The Snow Survey's state-wide forecasts, however, deal basically with monthly mean runoff amounts and therefore are commonly known as "volumetric" water yield estimation. Dynamic estimation is most useful in providing data for day-to-day regulation of reservoir levels and for real-time flood forecasting. Volumetric runoff estimates allow longer term water management planning.

6. The distinction that is indicated above, (between dynamic and volumetric yield prediction) is an important one from the standpoint of the application of remote sensing. The difference in time interval of yield estimation will affect the potential use of remotely sensed data in the respective predictive models.

7. Two basic approaches to water yield modeling are exhibited by the above organizations.

(a) The Joint Federal-State River Forecast Center (RFC) employs a technique known as system "synthesis." In this case the system is considered to be known in terms of a set of mathematical equations, the objective being to determine the characteristics of the output for a given class of input. Moreover, since most components of the current RFC model are strictly arithmetic transformations of data or variable values, their simulation system can be classified as largely "deterministic."

(b) The California Cooperative Snow Surveys' (CCSS) approach may be classified as that of systems "analysis." Here watershed input data (e.g., precipitation, temperature, snow water content, snow depth) are related to watershed output (water runoff past a gaging station) by a response function that, in a statistical sense, best describes the input-output pair.

8. The CCSS model does not explicitly describe subsystems processes with mathematical equations as in the RFC model. Instead, it treats the watershed as a "black box," choosing to derive water supply output through a single relationship or series of relation- ships relating watershed input directly to output. Since these relationships are determined by statistical line fitting techniques, a given amount of uncertainty, or alternatively a statement of con- fidence concerning numerical exactness, can be attached to a given output value. Thus the Snow Surveys' model may be said to be "stochastic" or "probabilistic."

9. The three basic inputs to the River Forecast Center hydro- logic model are (a) effective basin (watershed) precipitation,

(b) basin evapotranspiration, and (c) basin characteristics affecting streamflow.

10. Streamflow prediction based on the RFC model is the result of processing effective precipitation data through an algorithm describing water movement in the soil mantle. This algorithm gives rise to runoff estimates in five basic forms: (a) direct runoff from permanently impervious areas, (b) surface runoff due to precipitation occurring at a rate faster than percolation and interflow can take place when both upper zone storages are full, (c) interflow resulting from the lateral drainage of a temporary upper zone free water storage, (d) baseflow from lower zone supplementary free water storage, and (e) baseflow from lower zone primary free water storage. Together the estimates of these runoff components give rise to the predicted water yield at a given gaging station. The prediction assumes that no moisture escapes from the watershed through deep bedrock aquifers below the stream channel.

11. In order to determine the effective precipitation input to the River Forecast Center's hydrologic model when precipitation occurs in both liquid and solid forms, the RFC has developed a snow melt submodel. This computerized simulation procedure calculates the amount of melt and determines what portion of the melt plus rain will be retained by the snow pack. The resulting pack water output is utilized on a daily basis as the effective precipitation input to the RFC water yield prediction model.

12. Remote sensing information could potentially be a very useful input into the River Forecast Center snow melt submodel, since accurate determination of effective precipitation is especially critical to accurate water yield estimation by the RFC hydrologic model.

13. An important property of snow in relation to both its photo-graphic appearance and its melt rate is "albedo", i.e. the reflec-tivity of the snow surface. This property is determined, when using the RFC hydrologic model, by reference to published curves according to age of surface snow layer (time since last storm) and depth of snow (determined from on the ground snow course measurements during tuning of the model and from topographic and vegetation cover moderated transforms of this value to other areas in the watershed lacking ground data).

14. Two hydrologic models for water yield are employed by personnel of the California Cooperative Snow Surveys. The first of these is "volumetric" and the second is "dynamic", i.e. it involves real-time water yield forecasts, and is based on probabilistic relationships.

15. The CCSS dynamic model is composed of five basic submodels as indicated below. Each submodel produces its own hydrograph (water yield versus time) and the sum of these hydrographs over time gives rise to an estimate of total water yield from the basin in question.

(a)   The first submodel consists of a determination of summer base flow. This flow is defined as the minimum daily discharge expected near the end of the water year after snow melt and recession flow (stream flow arising from water emerging from temporary natural storage) have been depleted.

(b)   The second submodel is a derivation of the minimum daily discharge during the winter known as winter base flow. Precipitation, snow melt, and temperature affect the size of this flow.

(c)   Computation of recession flow comprises the third submodel. This value is defined as discharge arising from snow melt or precipitation which passes through temporary natural storage in the watershed and runs off at a variable but derivable rate. This temporary storage consists of lakes, river channels, snow pack, and soil mantle zones such as conceptualized in the River Forecast Center hydrologic model. The effect of these storages is to delay runoff from precipitation and spread it out over a longer period of time.

(d)   The fourth submodel is a determination of direct precipitation runoff resulting from rainfall over the watershed. This non-delayed form of runoff is a function of the overall basin wetness, the freezing level, and the volume of water in recession storage.

(e)   The fifth and final submodel estimates snow melt. Maximum and minimum temperatures are used to index both the priming of the snow pack for melt and the rate of melt from the pack. These relation-ships are developed from historical temperature -- runoff data. The maximum potential and actual melt rates are determined from the amount of priming, the energy input into the pack, and the volume and area of the pack. The priming and energy components are indexed by temperature, and the pack volume and areal extent are estimated from snow course data.

16.   The primary limitation affecting the River Forecast Center streamflow simulation model is limited data for input parameters and some model components. For example,

(a)   Mean effective precipitation is computed presently from a maximum of only five point recording station values.

(b)   Evapotranspiration, an important loss mechanism for basin water, is not measured directly but only approximated from either a limited number of pan evaporation stations throughout the watershed or by using average evapotranspiration values from other basins.

(c)   The fraction of the watershed covered by streams, lakes, and riparian vegetation is obtained by noting the difference between permanently impervious areas (found by hydrograph analysis) and paved surfaces draining directly into water bodies (as indicated on maps).

17. The limitations of the two <u>California Cooperative Snow Surveys' water yield models</u> are similar to those of the RFC model. Again the basic problem is limited data for input parameters. Specifically:

(a) For both the primary (volumetric) and dynamic CCSS models, the density of precipitation recording stations throughout most monitored watersheds is low. In addition, many of these stations are concentrated at lower elevations below much of the snow pack region in most basins. Consequently, estimates of total precipitation received at various watershed locations based on adjusted station values are potentially subject to significant error.

(b) The same situation exists for temperature estimation. Precise and accurate estimates of this parameter are important throughout the watershed in determining the rain-to-snow ratio and snow melt rates. Both of the CCSS water yield models could utilize improved estimates of snow areal extent throughout the hydrologic year. Such data would provide additional information on snow accumulation, melt rate, and antecedent indexes. Moreover, snow areal extent data, when combined with other remotely sensed ground characteristics, could be used to develop more specific relationships between snow behavior and vegetation, soil, geologic, and topographic features.

D. Work done in relation to the Remote Sensing of <u>Water Supply</u> during the period covered by this report includes the following:

1. <u>Snow Survey Study</u>

(a) A snow survey study was carried out in the following three steps:

(1) sequential ERTS-1 imagery, U-2 high flight photography and ground data were used to develop a suitable reference document, in the form of an image interpretation key, which could effectively be used as training material for the determination of areal extent of snow in forested areas;

(2) an efficient manual analysis technique was developed for estimating acreages of snow. This technique capitalizes on the human's ability to integrate information on the appearance of snow, as seen on satellite photos, with information obtained from aerial photos regarding the type, density and distribution of the vegetation/terrain within which the snow occurs and which greatly influences the appearance of snow;

(3) within the Feather River watershed in northern California an estimate of areal extent of snow was made over a 2.1 million acre (850,000 ha) area using ERTS-1 imagery. The level of accuracy of the estimate was verified through the use of sample vertical aerial photos, taken from a light aircraft, showing in detail the actual snow cover conditions.

(b)   It was found in developing the interpretation key that four environmental factors greatly influence the appearance of snow as seen on aerial photographs, viz., elevation, slope, aspect and vegetation/terrain type.

(c)   In this study it was found that the presence or absence of snow was:

(1)   easily detectable in meadows and bare areas,

(2)   sometimes, but not always, detectable in sparse coniferous forest, and

(3)   nearly impossible to detect in dense coniferous forest.

(d)   An interpretation technique was developed which allows a trained interpreter to accurately estimate areal extent of snow, is suitable for the interpretation of very large, complex forested regions on very small scale ERTS-type imagery, and is fast and inexpensive to implement. By examining two images simultaneously, one taken during a snow free period and the other during the melt season, an interpreter can concentrate on both the appearance of snow, and on the vegetation/terrain condition. Thus reliable estimates of areal extent of snow can be derived.

(e)   To evaluate the accuracy associated with this estimate, the interpretation results for 80 of the cells were compared with estimates made on relatively large scale (1:45,000) color aerial photos. The overall "correctness" obtained was 83.7 percent, based on number of cells, and 98.4 percent based on acreage.

2.   ERTS-1 Map Using Generalized (Framework Study) Classification

Scheme

(a)   Regional mapping of the entire Feather River watershed from ERTS-1 color composites (bands 4-5-7) was done utilizing three dates of imagery in combination. The dates were July 26, 1972, August 13, 1972 and October 24, 1972.

(b)   A regional vegetation/terrain type map was produced by projecting and enlarging the ERTS-1 color composite transparencies to a scale of 1:250,000.

(c)   An evaluation of the level of accuracy associated with the generalized ERTS-1 map was done by comparing the ERTS-1 map with a map made from high flight photography. The average percent correct, (assuming that the higher flight map is "correct"), was 81 percent. The interpreter was able to proficiently map conifer forest, hardwood forest, grasslands, cultivated and pasture lands, desert shrub lands, water bodies and urban lands. The types that were most difficult to map were chaparral lands and barren lands.

3. ERTS-1 Map Using Detailed Classification Scheme

(a) Regional mapping was done of the entire Feather River water-shed from ERTS-1 color composites (July 26, 1972, August 13, 1972 and October 24, 1972) with an objective of mapping vegetation/terrain types in maximum detail.

(b) The techniques used by the interpreter were similar to those used when preparing the generalized ERTS-1 map; however, a much more detailed classification scheme was employed in this case.

(c) A point-by-point evaluation was made of the detailed ERTS-1 map shown in Figure 2.21 by comparing it with the high flight map.

(d) The overall agreement between the two maps (i.e., the average percent "correct" of the ERTS-1 interpretation was 66 percent).

4. Timing and Cost Factors Associated with Preparing the

Generalized and Detailed ERTS-1 Maps

(a) The total time required to map the entire Feather River watershed varied from 11.5 hours for generalized mapping, and 17.5 hours for detailed mapping from the ERTS-1 imagery, to 182.0 hours for mapping from the high flight photos.

(b) Costs associated with these time figures give cost ratios of 16:1 and 10:1, respectively, between high flight and ERTS-1, depending on the level of mapping detail required from the ERTS-1 images.

5. Multistage Sampling as an Aid to Wildland Resource Inventory

(a) The total volume of timber on the Quincy Ranger District of the Plumas National Forest was estimated by means of a multistage sampling scheme which employed ERTS-1 imagery, high and low altitude aerial photography, and direct on-site measurement.

(b) By this means the timber volume was found to be 407 million cubic feet (approximately 2.44 billion board feet) based on eight selected photo plots located within four primary sampling units.

(c) The sampling error associated with this estimate was 8.2 percent, which falls well below the acceptable S.E. of 20 percent for the District.

(d) These preliminary results indicate that the procedures employed in the multistage sampling design are valid and substantially reduce both the costs and the amount of time required to perform a timber inventory of acceptable accuracy for a large area.

(e)   This study also demonstrates the value of ERTS-1 data for accurately correlating picture elements with timber volume estimates as a fundamental first step in selecting primary sampling units in the first stage of the inventory.

(f)   The inventory procedures utilized here will be applied for the remaining districts of the Plumas National Forest in an effort to estimate the total timber volume on the forest. Based on the preliminary results it is felt that the sampling error will be well below the ten percent specified at the beginning of the study.

6.   Work Done Relative to the Handling and Processing of

Remote Sensing Data

(a)   The progress which we have made in this general area during the présent reporting period can be divided into the following broad categories:

(1)   minor hardware modifications and improvements in the digital image processing facility which is central to our work;

(2)   development of a systematic image enhancement procedure applicable to a variety of problems as well as to remote sensing;

(3)   preliminary work on the combining of multispectral data for the study of Earth Resources;

(4)   application of the procedures of (2) and (3) in enhancing ERTS-1 data and imagery of interest to several participants of our integrated study; and

(5)   articulation and investigation of some of the basic issues which underlie the interactive processing of remote sensing data by digital computers.

(b)   Because of the high correlation both spectrally and spatially in the ERTS-1 data it seems possible to achieve at the same time several of the following objectives through the combining of multi-spectral data:

(1)   improvement of the quality of the data by reduction of the noise due to errors and coarse quantization.

(2), efficient representation of the data either for transmission (encoding) or for further processing.

(3)   presentation of the information provided by sensors in a more interpretable form.

(4)   significant increase in the speed of processing for enhancement or classification.

(c) We have conducted and are continuing to conduct work on the following application areas:

(1) delineation and mapping of snow cover. Some preliminary work has been done and we are quite encouraged both by our results and those obtained by Dr. Martin Taylor of the Canadian Center for Remote Sensing Research on the use of image enhancement for this problem.

(2) mapping and enhancement of salt affected soils. This work, carried out by a Ph.D. student, Mr. Samulon, is nearing completion and will be reported later on. It deals with a significant problem related to irrigation and, to our knowledge, no other work relative to this problem using digital processing techniques is being pursued elsewhere.

(d) We plan to examine and incorporate into our software packages some of the algorithms developed elsewhere which seem most useful to our continuing work. Among the possibilities which we intend to examine are:

(1) geometric correction.

(2) radiometric correction.

(3) preprocessing and interactive processing of remote sensing data to increase efficiency and interpretability.

(4) subpixel processing.

(5) incorporating all available data, including ground truth in the form of radiometric values, atmospheric modeling, sun angle correction, and sensor characteristics, into a unified discussion of the radiometric value recorded by a satellite.

E. Work done in relation to socio-economic and political considerations:

1. During the months just past, the Integrated Study of Earth Resources has conducted research on the decision-making processes pertaining to water. Effort has been directed to ascertaining who are the decision makers, what are their areas of responsibility, what kinds of information do they need, who are their publics, what are the objectives, how are these identified, and how do officials go about achieving them.

2. It is clear that the California State Water Project has now completed a number of the goals set for it. The Commissioner's Annual Progress Review lists some of them:

(a) Conservation and delivery of water from Plumas County to Los Angeles County; water service in the San Francisco Bay Area;

(b) Provision or facilities for family recreation and sport fishing in northern, central, and southern California;

(c) Smog-free generation of electric power;

(d) Maintenance of flood control and of water quality control.

3. The foregoing items, although covering a broad range of activity, only begin to suggest the degree of involvement of water with the total social, political, and economic pattern of life in California.

4. The availability of water in California as elsewhere is proving to be a prime factor in the intrusion of man into the desert, often with irreversible ecological results. Specifically, the growth and spread of population in the Los Angeles area have served as a very unfavorable example to other parts of California according to some authorities.

5. With water for domestic consumption commanding a much higher price than is paid by agricultural users, there are unmistakable economic forces at work influencing policy with respect to supply.

6. Metropolitan and industrial uses of water are growing steadily, and not only do they pay two to three times as much for water, but they also are gaining representation as reapportionment reflects the shifting urban-rural ratio. In the current calculus, cities may appear to be more cost-effective than rural areas.

7. In view of the foregoing, water management policy could precipitate a headlong collision between farmers and the bulldozers of the subdividers and developers in the near future.

8. The recreation benefits of the Project are best determined, according to some authorities, by deducting the number of visitor-days of use expected <u>without</u> the Project and <u>without</u> additional recreational facilities, from the number of visitor-days of use anticipated <u>with</u> the Project. The net economic worth or benefit of recreation use, they say, is then derived by multiplying visitor-days of use by the assigned value of a visitor day of use.

9. Using "recreation days" as a basis for computing benefits is, however, not a universally accepted notion. A review of the literature reveals large areas of disagreement among economists and between economists and resource planners on how benefits of recreational services can be assessed. Since they fall into the category of "nonmarket, intangible, or incommensurable", they elude the usual monetary measures.

10. One limitation in making estimates as described in (8) above is that such gross-use estimates do not reveal who receives the direct recreational benefits of the facilities. To be a "beneficiary" one must want the particular kind of outdoor recreation and must have "the psychosomatic and financial wherewithal to go get it.

11. Another limitation is that no allowance is made in the recreation-day benefit calculations for social costs, such as road traffic to the sites, or environment damage wrought by intensive usage.

12. Still another limitation is that, in the method described in (8), above, there is no recognition of prior or substitute recreational uses of the area without development. For example, the substitution of slack water recreation does not necessarily compensate for the loss of the many recreational services of a free-flowing stream-white water canoeing, float-trip boating, fishing from the bank, wading, and the like.

13. The same difficulties of assigning values of costs and benefits arise in connection with the controversy over the preserva- tion of "wild rivers" in their pristine state. The battle lines are drawn between conservationists and developers and many are the legal suits. The value-preference structure of one set of advocates as against others is imposed on the total population.

14. Perhaps nowhere in the entire spectrum of California water is there so much divergence of position between the Commission and other sectors of the "water establishment" (and certain public groups as well) as on the issue of whether the Peripheral Canal should be built. Controversial and fraught with political overtones, special interest pressures, clouded issues and intentional and unintentional obfuscation, the Peripheral Canal looms as the key point in the supply aspects of the California Water Plan.

15. The primary purpose of the proposed Peripheral Canal are: (1) improved water quality; (2) improved flow conditions in the channel; (3) enhancement of quality in the east end of the Delta; and (4) correct flow direction.

16. Opponents to construction of the $220 million Peripheral Canal contend that it would result in enormous degradation and irreparable devastation in and to the Bay-Delta System and its water resources. They assert that neither its authorization nor designing nor construc- tion should be further considered until the many scientific investi- gations and studies of its impact upon the Bay-Delta System are first completed and thoroughly evaluated.

17. While it is generally agreed that the beneficial uses of the water in the Delta must be protected by law, there remains an important legal question as to which level of authority, the U.S., through the Bureau of Reclamation, or the State should bear the legal responsi- bility of protecting the Delta against increased salinity.

18. The Environmental Protection Agency report, prepared by a scientific and engineering team, has recommended that the 43-mile-long canal not be built and, further, that all water resource development under the State Water Project be halted until the plan can be subjected

to a thorough re-evaluation. This position has received strong endorsement from conservationists, as well as from the Contra Costa Water Agency, many civic groups and Representative Jerome R. Waldie.

19. The EPA task force also has asserted that the building of the canal would only work to the benefit of the Southern California water buyers because it would postpone their need for water reclamation and compensate for the decline of Colorado River Water quality. They have stressed the point that "export of the Delta water raises the risk of harm to the ecology of the Delta and San Francisco Bay, which depends on the flushing action of the river water." On the other hand, the California Water Commission has urged immediate action on construction of the canal. It maintains that sufficient information has been gathered and that the plea for more evaluation is really a delaying tactic.

20. For the Commission, the main item of concern still appears to be how recreational aspects of the California Water Project should be paid for. Perhaps, to the extent that benefits can be quantified, the user should pay; where indefinite, then the public would have to.

21. In summary, the Social Sciences Group currently is attempting to convey the magnitude and intricacy of the web of forces that enter into managing the Water resource so as eventually to learn how, where, and when remote sensing data acquired by ERTS and other vehicles can best be incorporated into the decision-making processes with respect to supply.

II. SUMMARY OF STUDIES RELATIVE TO WATER DEMAND

A. Work Performed by the Geography Remote Sensing Unit, Santa Barbara Campus

   1. Completion of Land Use and Vegetation Maps

   (a) Our work to date clearly shows that information on land use and vegetation types is essential as input for a water demand model.

   (b) GRSU has demonstrated that it is possible to map land use and vegetation within its primary study areas to an acceptable level of accuracy utilizing both ERTS-1 satellite imagery, and high altitude color infrared photography.

   2. Determination of Critical Inputs to Water Demand Models

   (a) Before remote sensing techniques can be used to generate meaningful inputs for water demand models, one must determine exactly what types of input are likely to be useful. We have engaged in the following tasks:

(1) Agency contact:

In the GRSU's test region, which is predominantly agricultural, the agencies contacted were the Kern County Water Agency (KCWA) responsible for 15 Kern County water districts, and the California Department of Water Resources San Joaquin Valley District Office (DWR-SJD), responsible for the greater San Joaquin Valley.

(2) The Making of an Agricultural Lands Inventory

(a) The principle objective of this study was to determine the utility of small scale high flight and satellite imagery for mapping agricultural cropland in Kern County.

(b) Special emphasis was given to determining the total acreage of agricultural cropland in this area, where water for irrigation is of utmost importance.

(c) Acreages obtained by using high flight and satellite imagery agreed very closely with those obtained through conventional on-the-ground surveys. For example, there was a difference of only 0.29% between the figures obtained from the September ERTS 1972 imagery and that obtained from the Kern County 1972 Crop Survey; similarly, an estimated difference of only 0.13% was the case for the March ERTS imagery.

(d) The cost of making an acreage survey of agricultural lands for Kern County without the use of remote sensing techniques (according to the KCWA) was between $10,000 and $12,000, whereas the completion of the maps based on ERTS-1 and high altitude conventional photography (including interpretation, mapping and measurement) only required about 15 to 20 man-hours, and cost only a little more than $100.

(e) Data being generated as a result of this study are being sent to, and used on an operational basis by, the Kern County Water Agency, as an important input to their hydrology model.

3. The Study of Perched Water and Soil Salinity-Soil Moisture Problems

(a) The importation of water to sustain and expand croplands in Kern County has brought about new problems associated with water drainage.

(b) A great many of these drainage problems are related to the existence of "perched water tables" resulting from impermeable clay layers such as those which underlie most of Kern County. The high salinity of perched water and the associated soil salinity problems decrease both the variety and yield of crops that can be grown in a given area.

(c) With large areas of croplands at stake, it is important for the KCWA to be able to both monitor and assess the extent, variability and severity of this problem.

(d) The major objective of this study was to examine the operational use of high flight and satellite imagery for the mapping and evaluation of perched water tables, as indicated by high soil moisture and salinity.

(e) GRSU found that:

(1) high flight photography (1:120,000 scale CIR) and satellite imagery are very useful and accurate in detecting and delineating the areal extent of saline deposits that are difficult to measure from field surveys;

(2) although such delineations can generally be done on ERTS-1 images (band 5 tends to yield the most information), the additional resolution afforded by Skylab color photography makes possible a mapping accuracy approaching that obtained using high altitude, 1:120,000 scale photography;

(3) ERTS-1 and Skylab imagery and especially high altitude, 1:120,000 scale NASA photographs are useful for detecting and delineating areas of perched water, as evidenced by those areas with high soil moisture and salinity problems.

(4) ERTS-1 imagery is very useful because repetitive coverage is required for accurately assigning drainage characteristics to different areas.

B. Work Performed by the Geography Department, University of California, Riverside

1. The Riverside campus has concentrated much of its study effort during the present reporting period on the Upper Santa Ana River Basin and the methods utilized by the California State Water Resources Board (DWR) for estimating long-term water demands.

2. Within this study area a general trend still exists, in which urban development is increasing rapidly within the basin at the expense of prime agricultural acreage.

3. With respect to the hydrologic significance of this trend, the effects on runoff, groundwater storage, and water quality are three important considerations for water resource management within the basin summarized in Chapter 3 of this report.

4. In a separate study the Riverside Group has been engaged in the evaluation and testing of remote sensing techniques for the production of water demand data in a controlled environment.

(a) The development of water demand models utilizing remote sensing data as a major input for either short term or long term water demands can be facilitated if model testing occurs in a controlled environment.

(b) Fortunately, a truly controlled environment in terms of total water importation does exist within southern California, viz. the Imperial Valley.

(c) Creating a false color infrared composite image from three black-and-white multispectral ERTS images provided us with a ready means for distinguishing growing crops, as indicated by the red return of vegetative growth.

(d) A second obvious surrogate of the condition of the fields was the white barren look of dry fallow ground.

(e) An attempt was made to identify such conditions on each image and then to verify the findings by relating the condition of each individual field over a sequence of four 36-day cycles. To take advantage of the sequential imagery it became necessary to record the field condition for each specific field for each of the four 36-day periods.

(f) It was found that, for each growing season, several specific patterns of field condition were both detectable on the photography and of diagnostic value as indicated by the crop calendar. By comparing each sequence of field conditions to the crop calendar the specific crop contained in each field usually could be identified.

(g) A computer program to perform the identifications was developed and it is anticipated that a 90 percent identification accuracy of specific crop types soon can be achieved with that program through the use of six 36-day cycles of ERTS imagery.

III. WATER IMPACT STUDIES

A. An analysis of water impact stems directly from an analysis of water supply and demand factors. For this reason much of what we do in analyzing water impact in relation to the California Water Project must follow the completion of some of the steps which we currently are performing relative to various water supply and water demand factors.

B. We soon will begin to investigate the potential impact of using modern remote sensing techniques as an aid in managing, even on a day-to-day basis, the storage, flow and delivery of water made available through the California Water Project. Obviously, the amount of this impact depends upon the extent to which remote sensing is proven to be useful in improving predictions of both the amount of water that will be available and the amount that will be needed. Such information can best be obtained through the research which we currently are conducting as described in Chapters 2 and 3 of this progress report.

C. Much of the work which we currently are performing is permitting us to determine the nature and magnitude of changes induced in our central and southern California test sites as a result of the California Water Project. Such work will also permit us to determine the usefulness of modern remote sensing techniques in monitoring such changes.

D. Among the indicators which we propose to study, with the aid of remote sensing relative to the impact of increased water availability on the landscape are the following:

1. The conversion of non-agricultural and non-irrigated agricultural land to irrigated agricultural land.

2. The increase in industrial, extractive, and other manufacturing processes.

3. The increase in income-generating recreation land development (e.g., water and land projects, including lakes, parks, golf courses, etc.) or tertiary activities such as service stations, restaurants, motels, etc.

E. We also propose to make an analysis of the individual and aggregate (total) land use changes in a sociocultural context. This study would closely parallel our economic impact study but also would be concerned with evaluating:

1. Population shifts (e.g., by using remote sensing techniques to determine increased urban extent and residential densities).

2. Commercial growth (as related to population growth).

3. Industrial and related development (as it effects the total population resources and cultural orientation of the area).

F. In addition we propose to study various indirect or subtle environmental effects, such as:

1. Increased land, water, atmospheric, and noise pollution, as a result of the growth of industry and urban extent (due to increased water availability).

2. Modifications to the physical environment.

G. By means of the studies just described, we plan to analyze the overall impact of a changing water resource base and to use such data in constructing and testing a water impact model.