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EARTH RESOURCES IN THE STATE OF
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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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Annual Progress Report
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UNIVERSITY OF CALIFORNIA, BERKELEY

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Chapter 1

INTRODUCTION

Principal Investigator: Robert N. Colwell

I. BASIC CONSIDERATIONS

Scientists on several campuses of the University of California are 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 of our integrated study in May, 1970 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. (See Figure 1.1)

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 information needed in managing California's water resources, we realize the importance of benefit-cost studies and therefore 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 and we soon will put that analysis to a test.

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

1. 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,
2. an analysis of the legal and regulatory provisions relative to the California Water Plan,
3. an analysis of present commitment restraints (based on promises already made to supply specific amounts of water to various users),
4. an analysis of the public policy factors which are related to the California Water Plan, and
5. 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:

1. the model that is applicable or in operation today, and
2. 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:

1. an account of how the items of information currently used in managing California's water resources are measured and how they presently interrelate.
2. 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.
3. 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.
4. 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

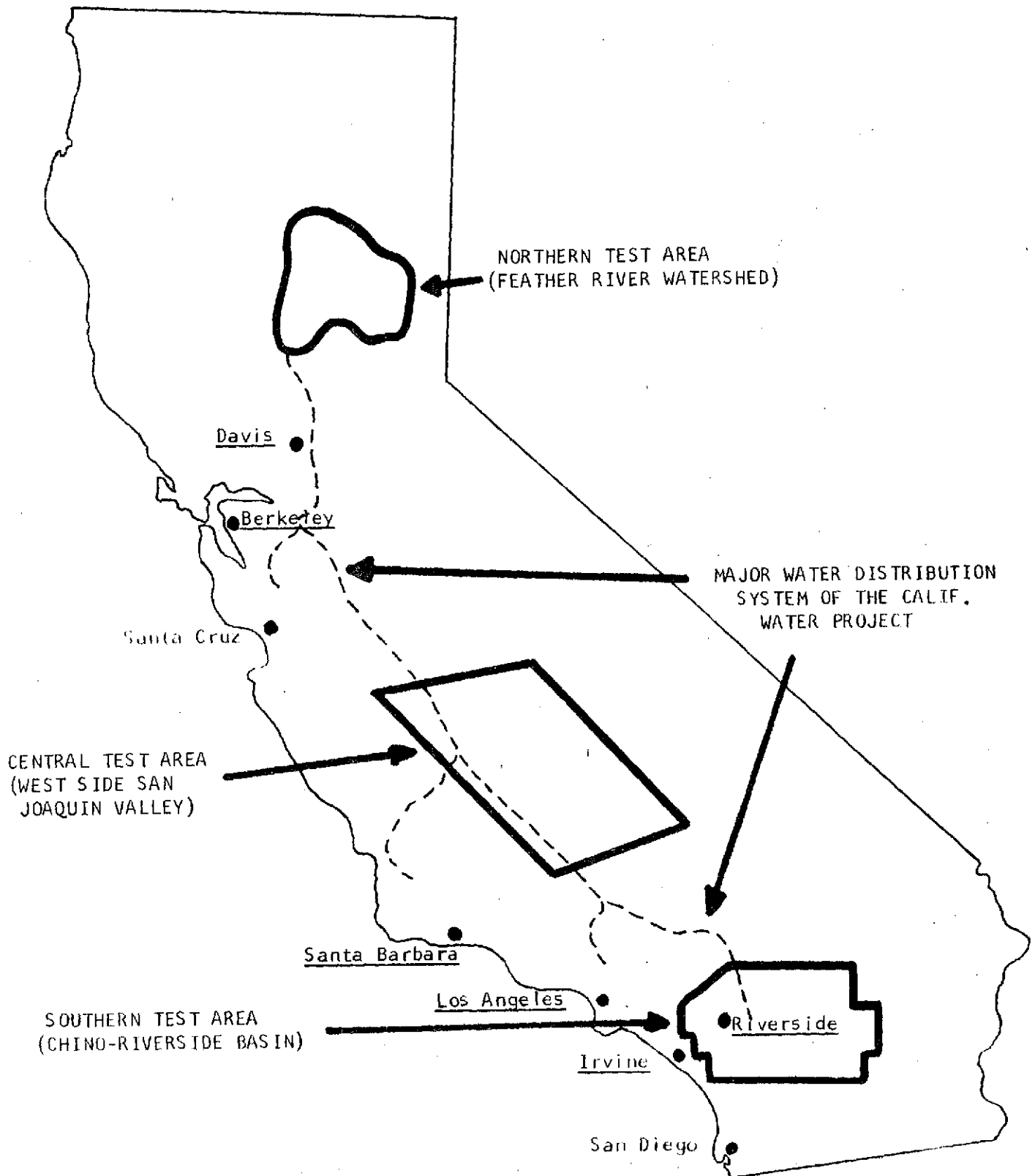


Figure 1.1. Location of campuses of the University of California that have been involved (underlined) in our Integrated Study, and their relation to the California Water Project. Also shown are the three test areas dealt with in this report.

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 overdraft and the intrusion of sea water. On the other hand, it raises and contributes to still other problems such as inadequate drainage, disputed water rights, water pricing policies of agencies such as the MWD, 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, dealing with water supply factors,

and Chapters 3 and 4, dealing with water demand factors. 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, 3 and 4 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.

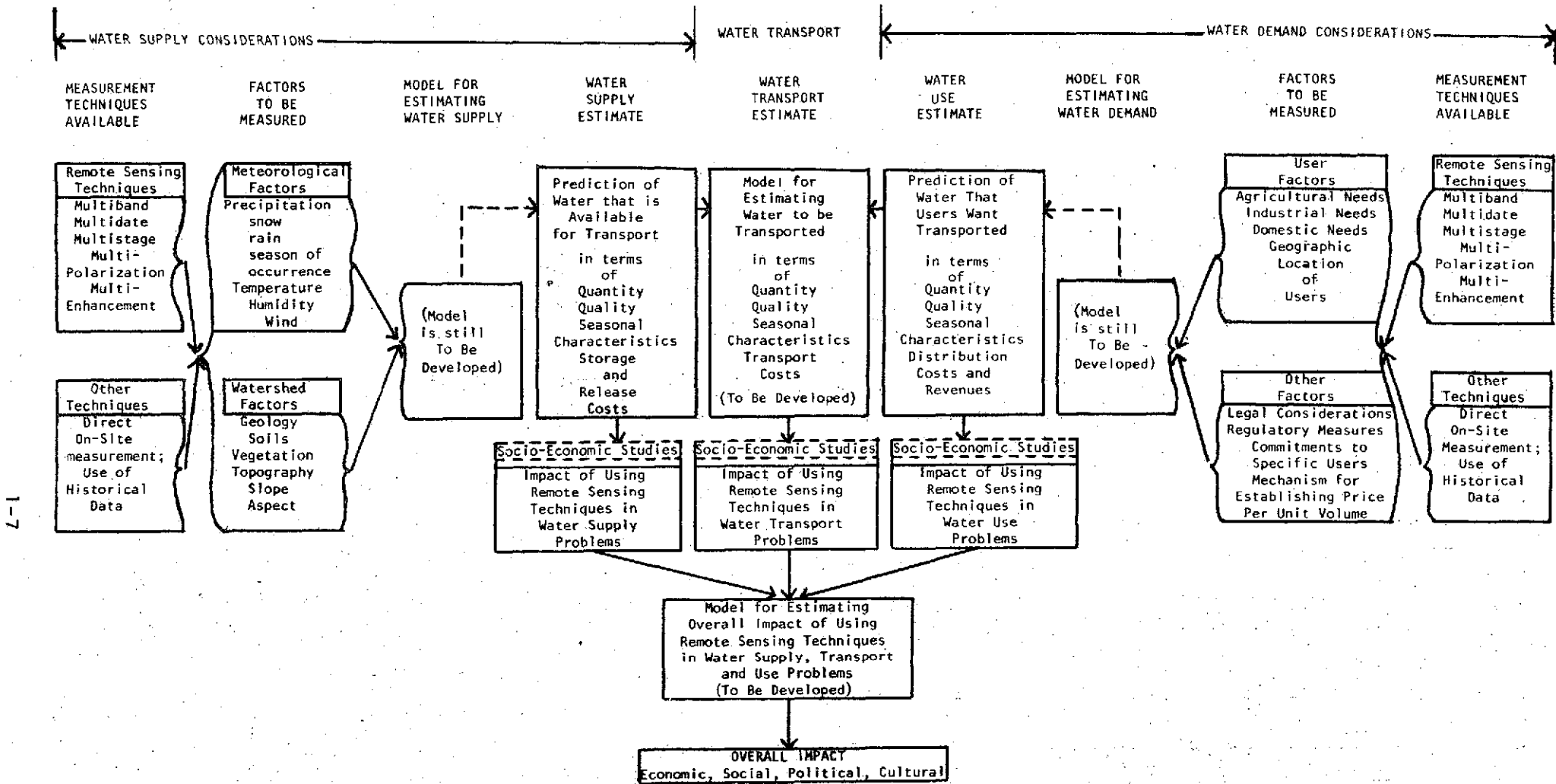


Figure 1.2. Block diagram indicating the factors which relate to water supply, water transport, water use and water impact. For a discussion of the proposed remote sensing studies in relation to this diagram, see text.

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Chapter 2

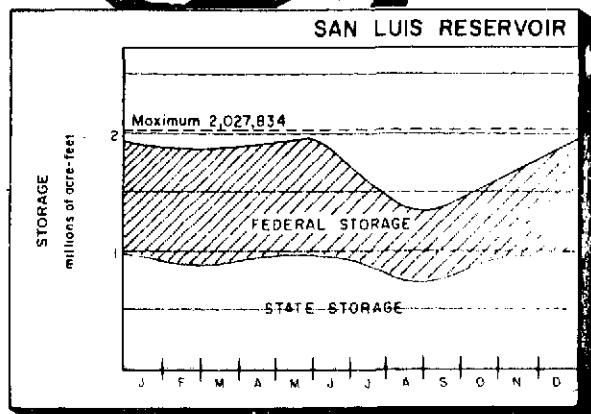
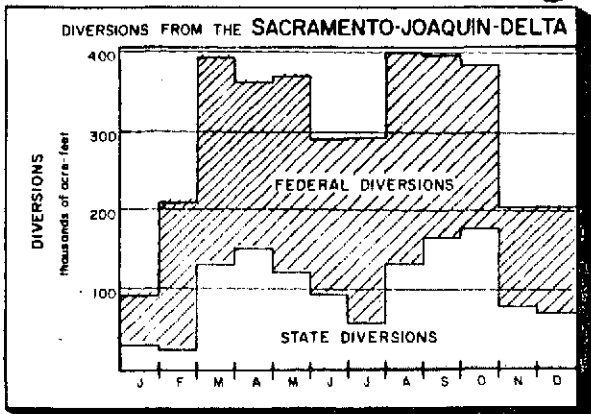
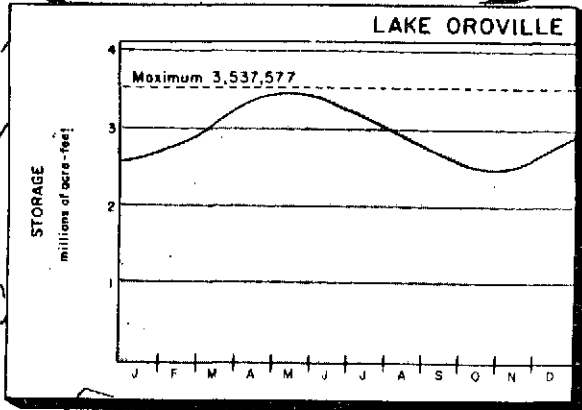
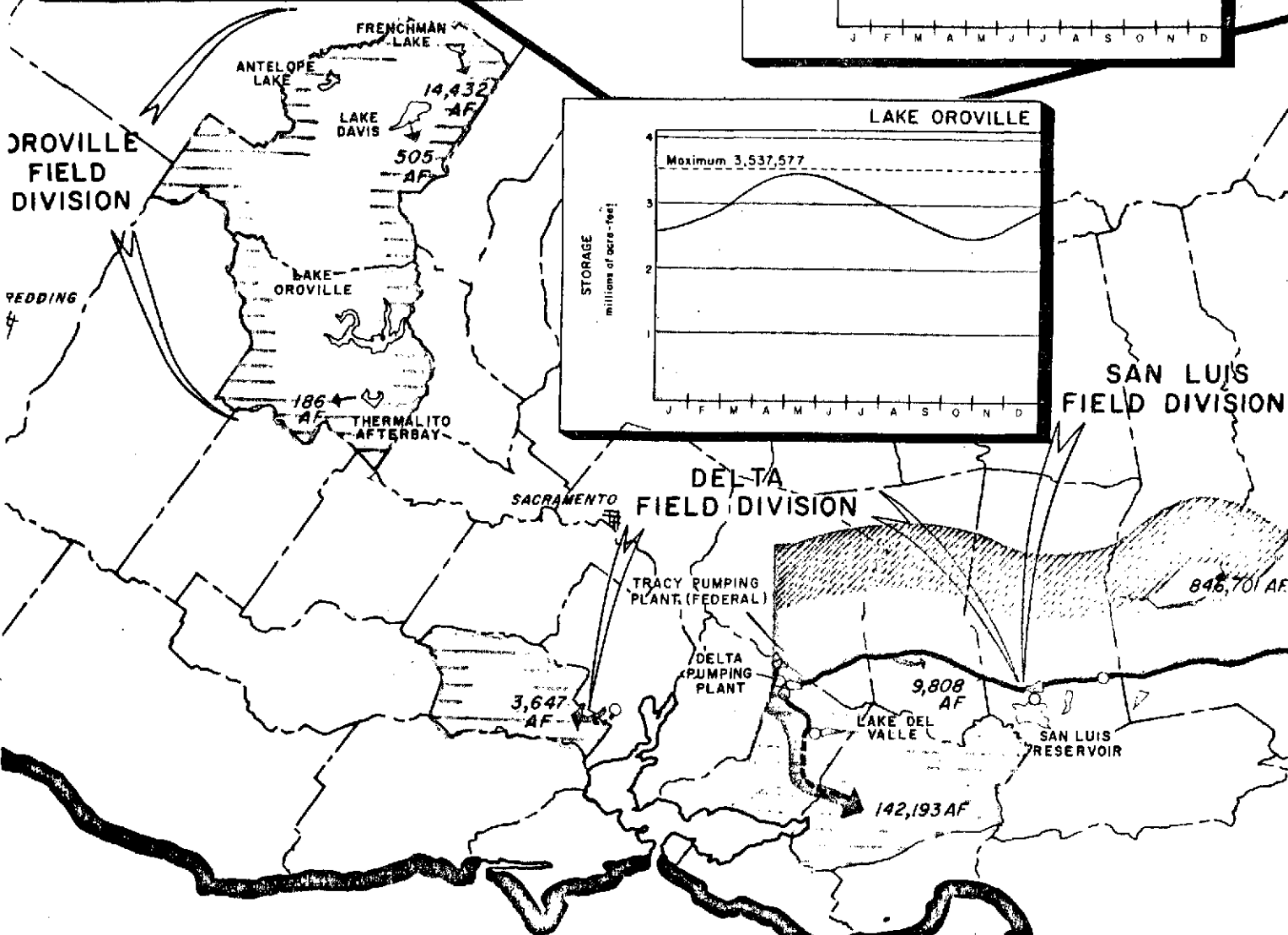
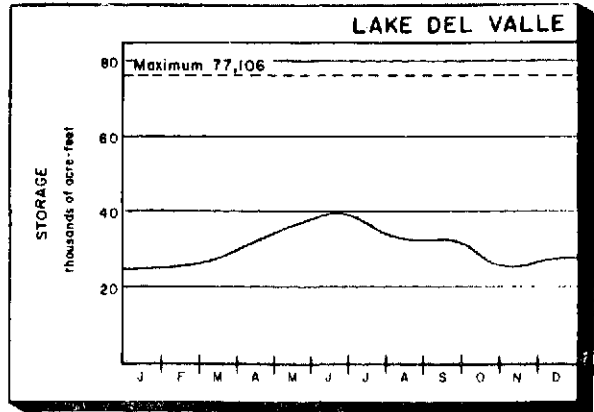
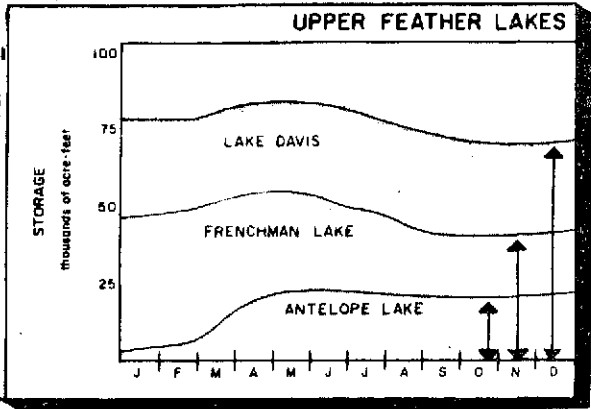
WATER SUPPLY STUDIES

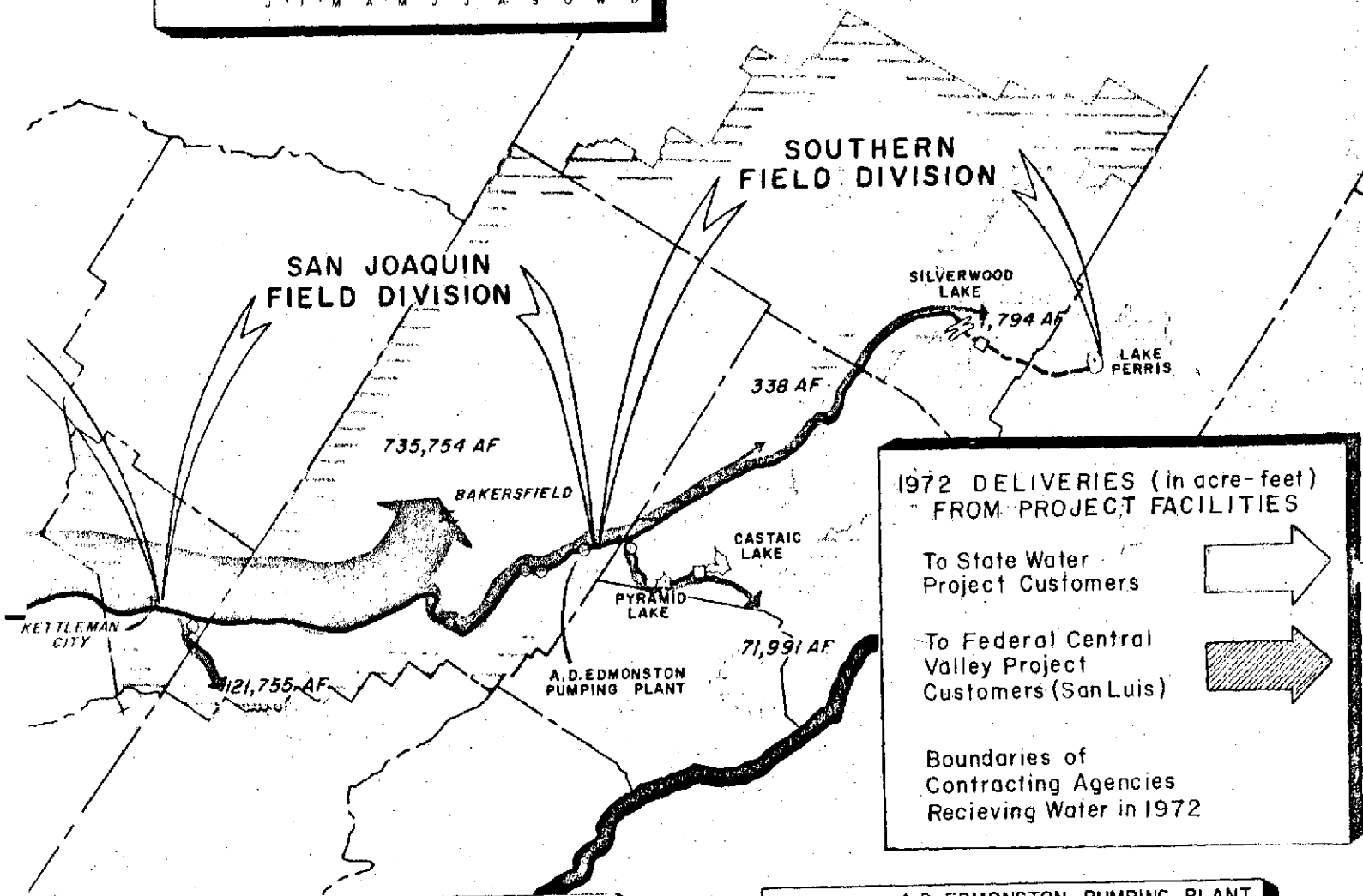
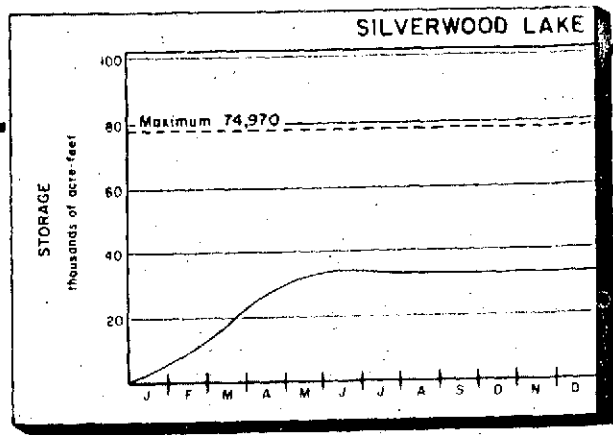
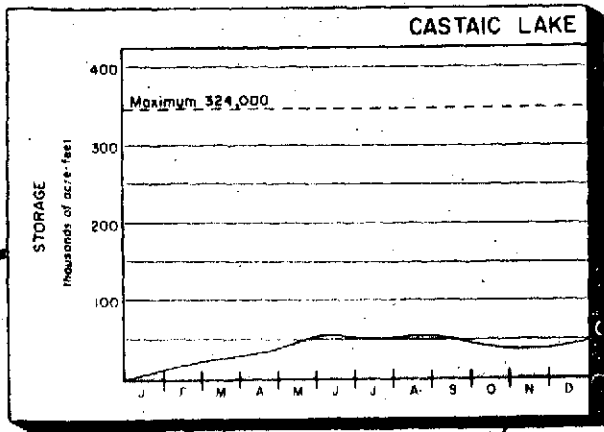
Co-Investigators: Robert H. Burgy, Davis Campus
Vidal R. Algazi, Davis Campus
William C. Draeger, Berkeley Campus
Contributors: Randall W. Thomas, Donald T. Lauer,
Paul F. Krumpke, James D. Nichols, Michael J. Gialdini,

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 Feather River watershed and the Oroville Dam have a central position in the California Water Project since most of the water available to the Project is impounded by the Oroville Dam. A map of the California Water Project is shown in Figure 2.1 (reproduced from Bulletin No. 132-73 of the Department of Water Resources, p. 44-45). The first objective 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 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.





1972 DELIVERIES (in acre-feet) FROM PROJECT FACILITIES

To State Water Project Customers

To Federal Central Valley Project Customers (San Luis)

Boundaries of Contracting Agencies Receiving Water in 1972

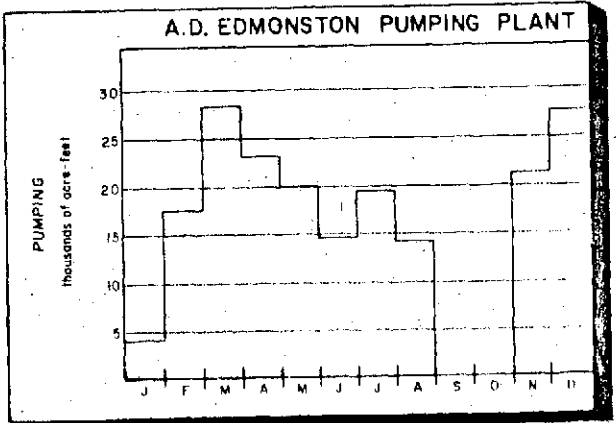
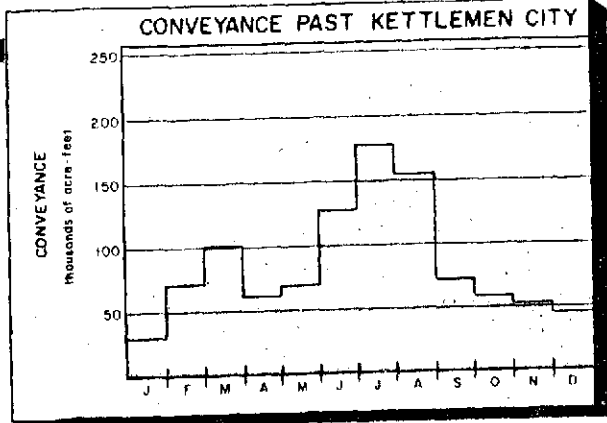


Figure 2.1

B. Investigation Tasks

The specific tasks which are to be undertaken will now be 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.

1. An extensive review of existing projects and management policies relative to the Feather River area. 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. These include the U.S. Forest Service, the Bureau of Land Management, the Pacific Gas and Electric Company, and the Flood Control Forecast Center.

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 match the increased intensity of water resource management in California.

2. Study and 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. Whenever 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 work is being carried out by existing groups (CRSR, Algazi, Burgy, Churchman). An economist, to be added soon to our team, will be active in this task. Much of the work involved in this phase involves consultation with persons currently involved in the water management process here in California.

Doubts are often expressed that it is 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 Special Study No. 3 in Chapter 5 of the present report.

3. Through use of the information acquired in (1) and (2) above, a study 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.

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.

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.

4. Given the background work 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 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 nearly culminated 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 probably 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 net benefit of the system exceed 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.

C. Work Plan

Figure 2.2 shows in diagrammatic form the relationships among the tasks just described.

Figure 2.3 provides a listing of these tasks, along with the investigators who are involved in performing them, and the periods of time when they will be performing them.

Referring to figure 2.3, it can be seen that during the current funding year the bulk of the effort has been 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.

Figure 2.2 Block diagram showing sequence of steps involved in the study of water supply problems as discussed in the accompanying text.

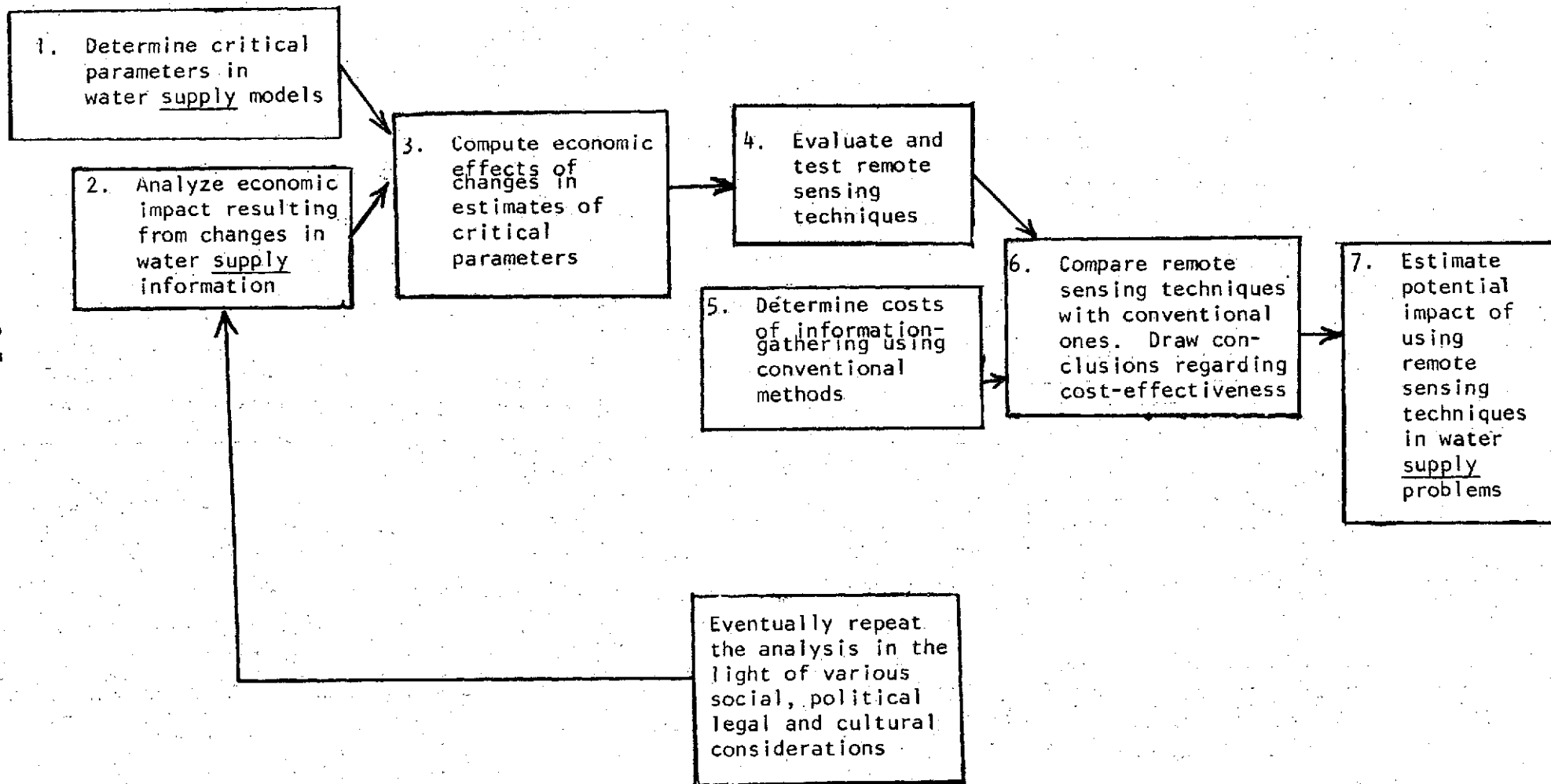


Figure 2.3 Chronological Plan for the Performance of Water Supply Studies

Work Item	Investigators	Period of Performance	
		Past Funding Year	Next Funding Year
		M J J A S O N D J F M A	M J J A S O N D J F M A
1. Determine critical parameters in water <u>supply</u> models	Burgy-Algazi CRSR	→ →	→ →
2. Analyze economic impact resulting from changes in water <u>supply</u> information	Churchman Economist Burgy Lawyer Public Policy	→ → →	→ → →
3. Compute economic effects of <u>changes</u> 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 <u>supply</u> problems	CRSR Burgy Economist Churchman		→ → → →

2-8

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. 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 2.4 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 conservation facilities are defined as those facilities which conserve water, including Lake Oroville, Delta Facilities, additional conservation facilities 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 allocated 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.

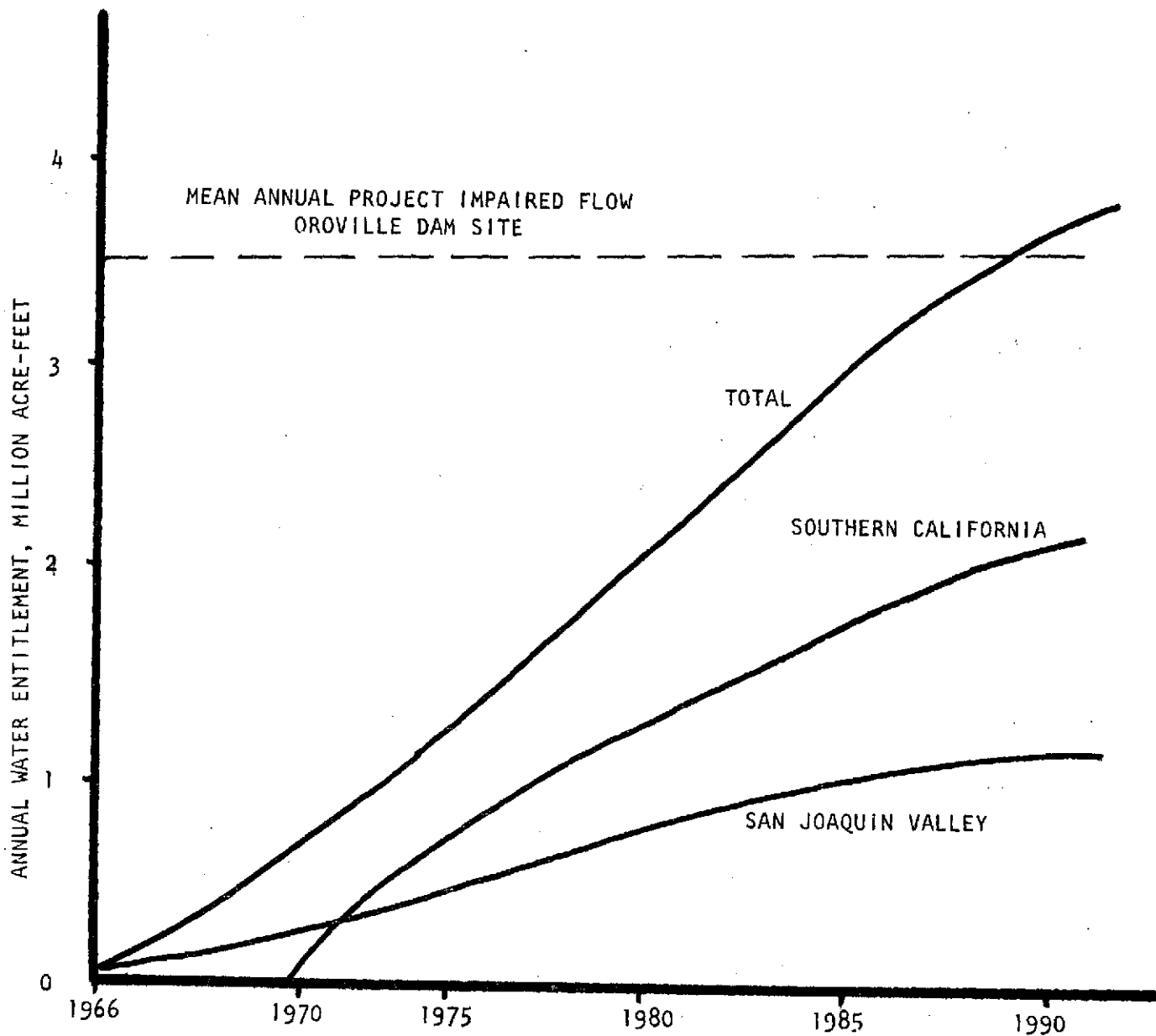


Figure 2.4

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 2.5 illustrates the transitional period represented by the 1970's.

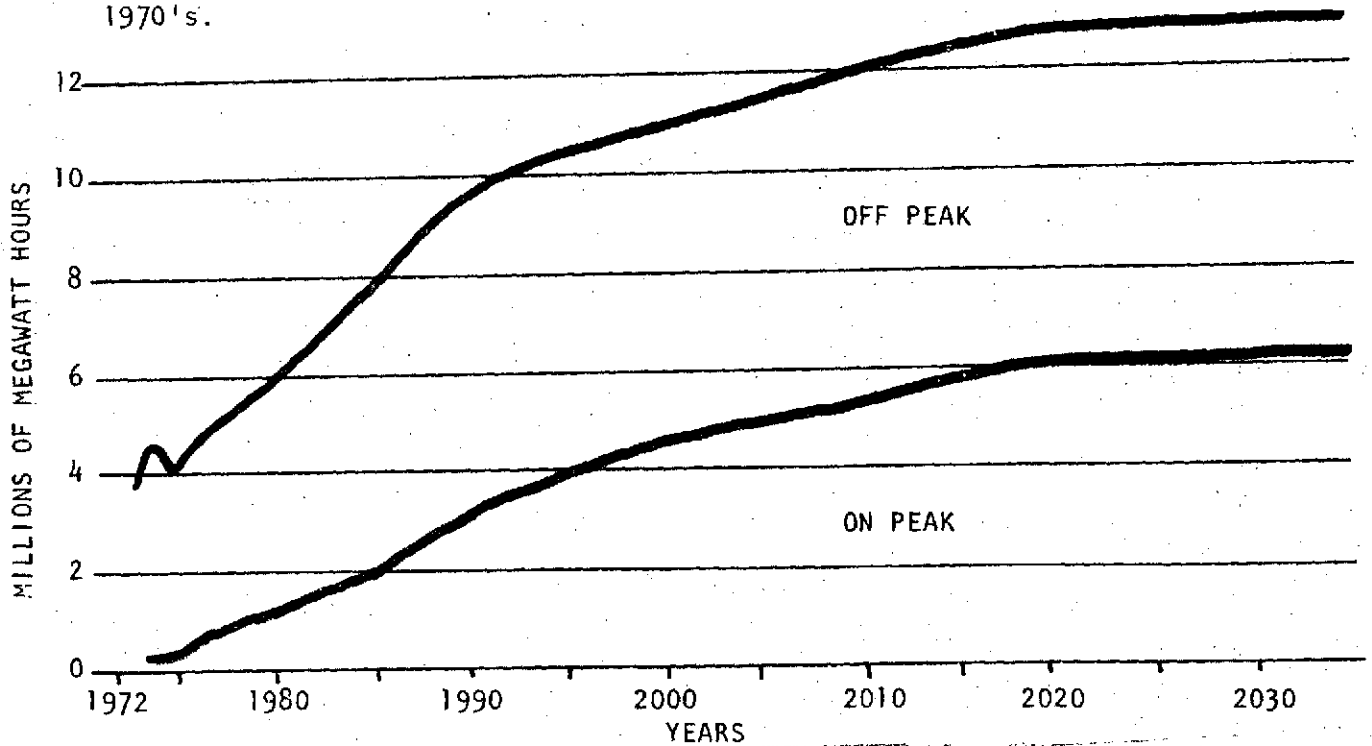


Figure 2.5. Projected Pumping Energy Requirements Associated With The California Water Project

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 Dam 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 facilities 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.

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.

III. POTENTIAL VALUE OF REMOTE SENSING DATA IN MODELS FOR ESTIMATING WATER YIELD

A. Approach

Potential applications for remote sensing techniques in water supply estimation are presently being considered in this study 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 operation nature. Relative cost-efficiency comparisons for this situation would then be related either to improved accuracies in present model predictions resulting from remote sensing inputs, or to lower costs for obtaining similar information.

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.

B. State Water Supply Modeling Responsibility

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 included 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.

The RFC has as its primary responsibility the issuing of six, twelve, and twenty-four hour river stage forecasts during rain floods and snow floods for watersheds throughout the state. A secondary function is to provide daily water inflow forecasts to the 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 occasions, forecasts are made for river stages downstream from dam sites to provide information on the maximum allowable releases from reservoirs.

The RFC 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 the respective water supply model applications are in order. A check in water supply forecasting as it relates to snowmelt yield is therefore provided by these two organizations.

The California Cooperative Snow Survey (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 publications. 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 through 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 River Forecast Center is primarily involved in issuing six-hour to several-day forecasts. Its modeling function is therefore real-time or "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.

C. Types of Water Supply Prediction Models

Two basic approaches to water yield modeling are utilized in the Feather River watershed and throughout California.

The RFC employs a techniques know 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 three basic inputs to the RFC hydrologic model (Burnash et al., 1973) are (1) effective basin (watershed) precipitation, (2) basin evapotranspiration, and (3) basic 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.

The 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 simple 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 major inputs in the CCSS 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 runoff 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.

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 being used for estimating water supply currently 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 currently used hydrologic models. An expanded discussion of the various types of models used by both the RFC and the CCSS is given in Appendix II to this chapter.

D. Some Limitations of the Current Water Yield Models

1. The RFC Model

The primary limitation affecting the River Forecast Center stream-flow simulation model is limited data for input parameters and some model components. For example, mean effective precipitation is computed presently from values obtained at a maximum of only five point recording stations. 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 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 about a given mean, 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.

An 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 assess 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 evapotranspiration will have higher coefficients of variation and higher potentials for bias than 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 to be the optimal path.

2. 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.

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

1. 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 2.1 for possible remote sensing applications in the RFC model.

It should be noted that the proposed avenues of investigation listed here represent the results of the analysis of the DWR models carried out to date. This analysis will continue, particularly along the line of a sensitivity analysis intended to determine the relative importance of changes in accuracy timelines or greater sampling density of the various input parameters on the overall accuracy of the prediction models. This information would be of particular value in assessing the possible benefits derived from the use of remote sensing technology. In the meantime, however, it is felt that the work to date is sufficient to provide direction to the concurrent development and tests of remote sensing techniques being conducted by the various co-investigators in the supply area.

Table 2.1 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	

*including both those currently under investigation by our group and those which might be the subject of future studies

Table 2.1 (continued)

Remote Sensing Application to be Investigated	Potential Implementation Period
(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 snow ablation model - specifically determination of the rain to snow ratio and as temperature input values for melt equations.	Intermediate and particularly the Long Run
(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

Table 2.1 (continued)

Remote Sensing Application to be Investigated	Potential Implementation Period
(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.
(i) 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

Table 2.1 (continued)

Remote Sensing Application to be Investigated	Potential Implementation Period
(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 design) 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

2. 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 (see Appendix ii) 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 2.2.

Table 2.2 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 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 2.2 (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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IV. EVALUATION AND TESTING OF REMOTE SENSING TECHNIQUES

A. Report By Remote Sensing Research Program, Berkeley Campus

During the period covered by this report three studies were carried out 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.

The snow survey project, which has the most direct applicability to the water supply study is reported here, while the vegetation/terrain mapping and multistage sampling projects are reported in Appendix III of this chapter.

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; Barnes and Bowley, 1960; Baker, 1971; Leaf and Haeffner, 1971; Tarble and Burnash, 1971). However, this parameter has rarely been used because it has been nearly impossible to economically 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) 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 entailed 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 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; and (3) within the Feather River watershed 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.

Procedures and Results

During the 1970-71 melt season, high flight aircraft obtain 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 flew four missions, each of which covered the entire Feather River watershed. In addition, during the 1972-73 melt season, ERTS-1 imagery was acquired over the watershed every 18 days with clear weather prevailing on April 4, April 22, May 10 and May 28. Consequently, 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 snowshoes 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 meaningless 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, (negative scale 1:140,000, print scale 1:40,000). Coincident with each ERTS overpass our own personnel took as many as 150 35 mm photos from a light aircraft at an altitude of 17,500 feet above sea level along pre-selected 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.

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 was prepared for use in evaluating snow pack conditions as seen on small scale synoptic view imagery. The primary value of the key was that it documented 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

vegetation/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 category, examples of different conditions of elevation, steepness of slope and direction of slope (aspect) were chosen. For example, within dense conifer forests, snowpack conditions were 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 represented an entire page in the key and consisted of five illustrations -- one before the snow season, two at the height of the snow accumulation and two during the depletion period. In the completed version of the key the eight vegetation/terrain type categories were illustrated with a total of twenty-two specific examples.

Possibly the most important value of the image interpretation key was that it allowed 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 occurs within a dense coniferous forest in which a deep snowpack can be completely obscured by the crown canopy. It was 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 adjacent 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 appear 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 coniferous forest, and (3) nearly impossible to detect in dense coniferous forest. However, it was hypothesized that, 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, 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-1.

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:

<u>Code</u>	<u>Snow Cover Class</u>
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.

Testing the Interpretation 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 2.6), were used, with a grid size of approximately 980 acres (392 ha) per cell. In addition, vertical 35 mm color aerial photos (scale 1:40,000) 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), he estimated 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, and in future surveys, it often would be highly useful to do so.

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. Table 2.3a 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 these 13 cells were misclassified by only one class. In addition, when the areal extent of snow was calculated on an 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.

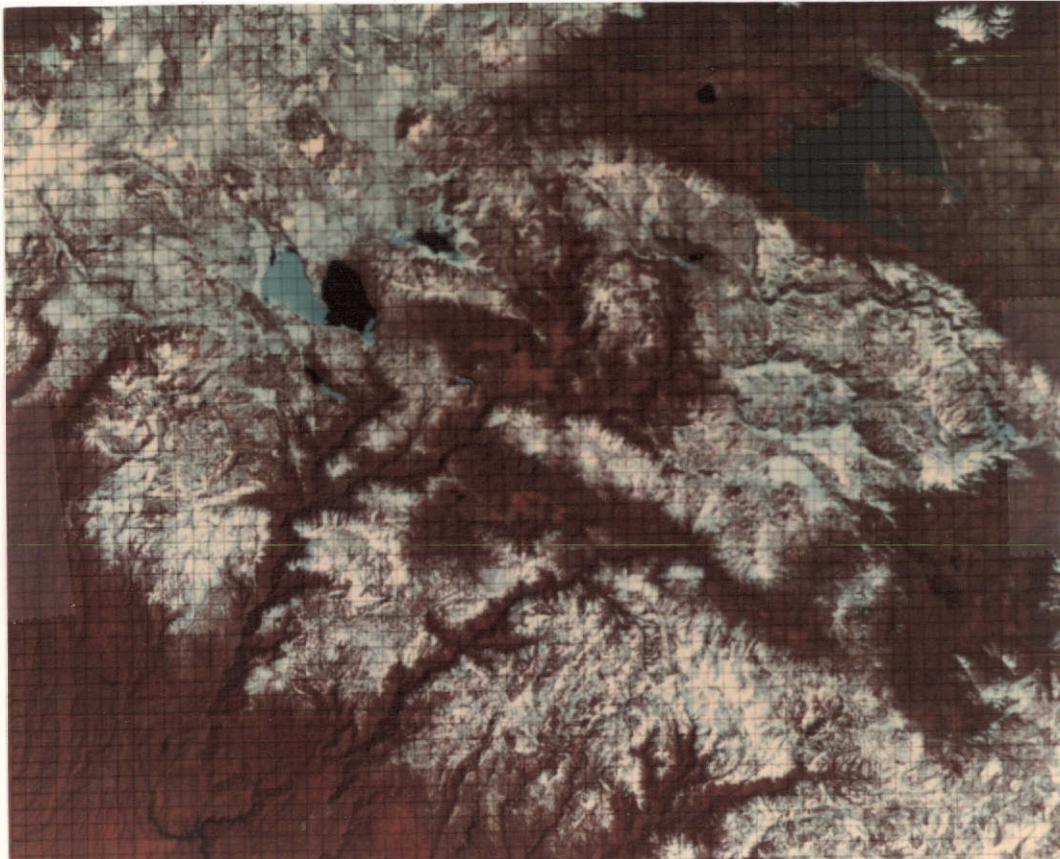


Figure 2.6a ERTS-1 image 1255-18174. April 4, 1973

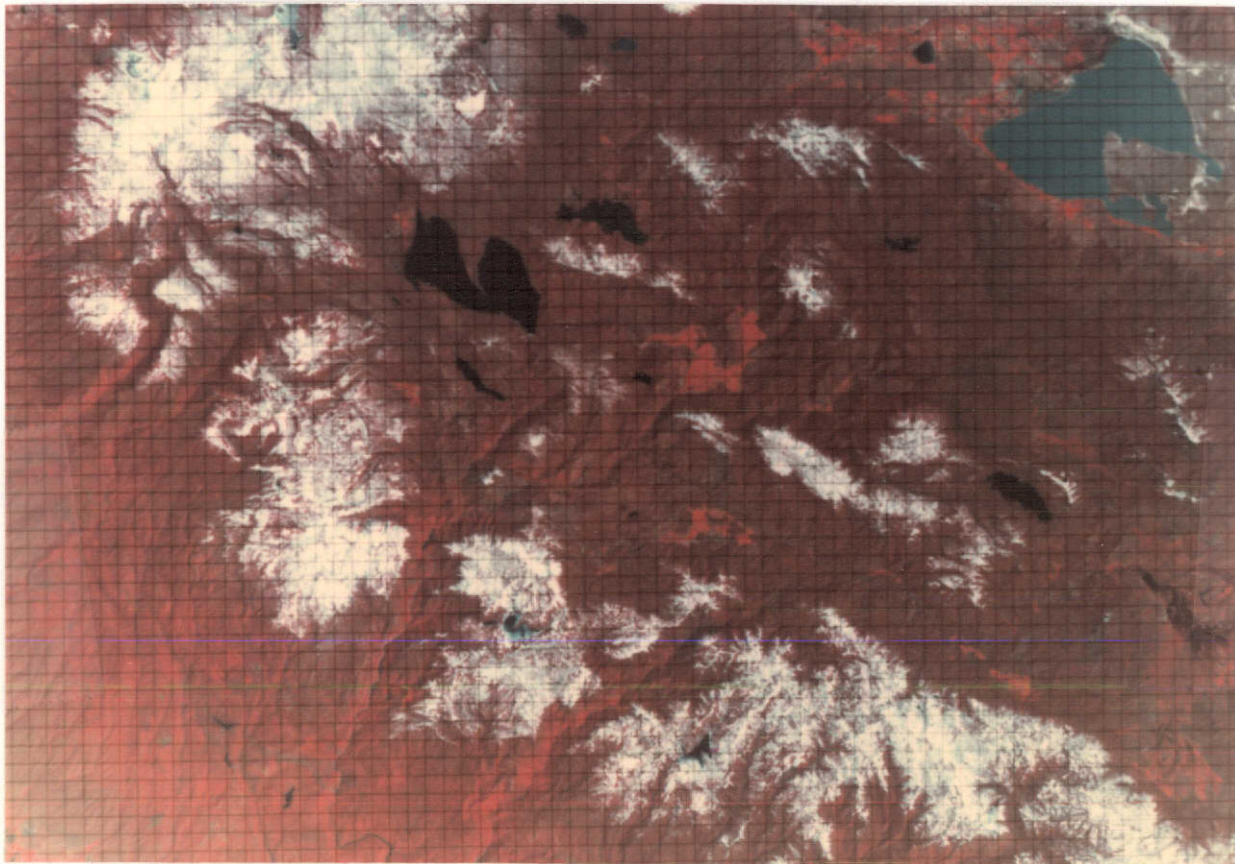


Figure 2.6b ERTS-1 image 1291-18173. May 10, 1973

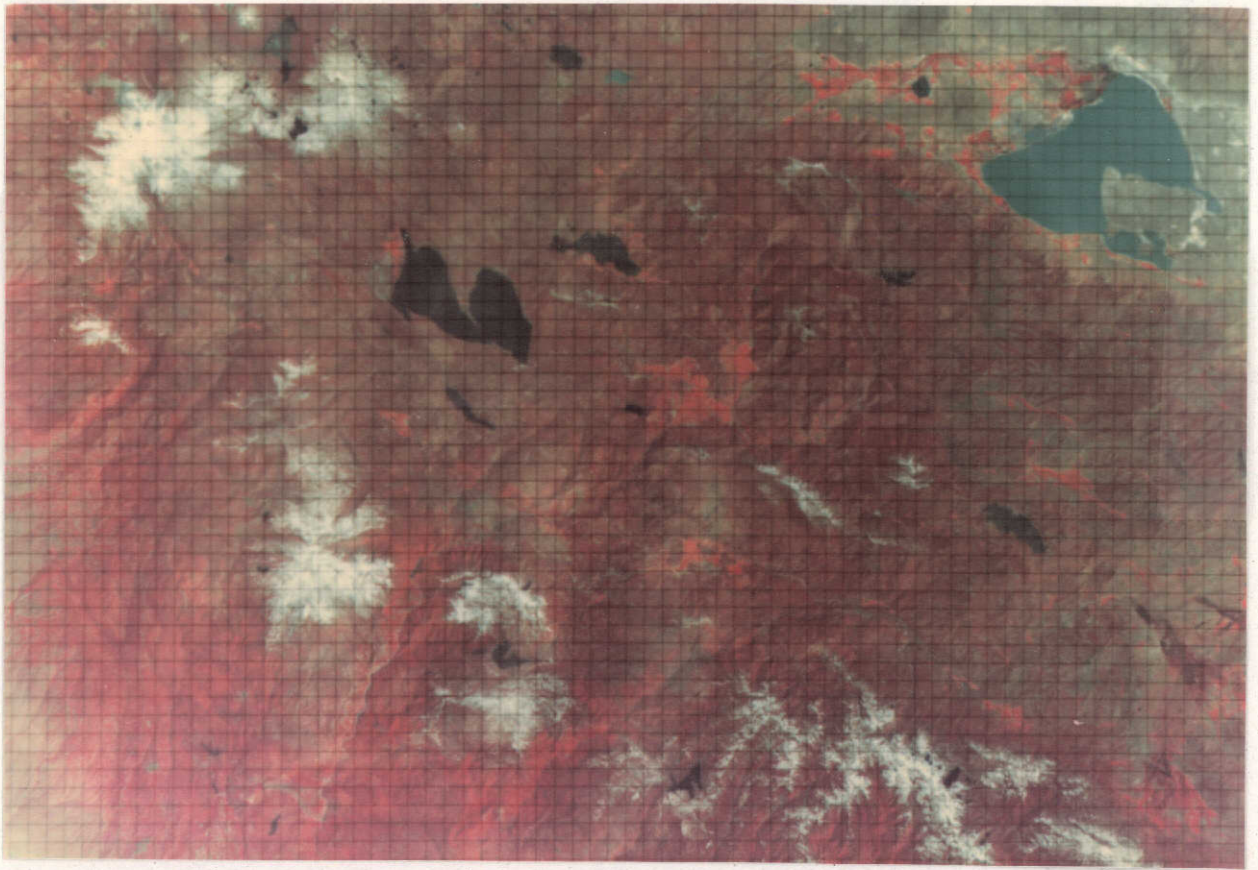


Figure 2.6c ERTS-1 image 1309-18172. May 28. 1973

These three photographs illustrate the three dates of ERTS imagery interpreted for the snow cover study. The color composite images were produced using a simple photographic additive process, with the grid being overlaid during that process. The interpreters actually viewed enlargements of these images on which each cell grid measured approximately one-quarter inch on a side. Each of the cells represents an area of 980 acres on the ground, the grid internal ground equivalent being 1.23 miles. These images include over two-thirds of the Feather River watershed, and nearly all of that portion of the watershed which receives snow cover.

TABLE 2.3a APRIL 6 SNOW COVER INTERPRETATION RESULTS

		LARGE SCALE PHOTO DATA							
		Snow Cover Classes					Total # Cells	Total Acreage	Total Acreage of Snow
		1	2	3	4	5			
E R T S IMAGE DATA	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	33	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

TABLE 2.3b MAY 11 SNOW COVER INTERPRETATION RESULTS

		LARGE SCALE PHOTO DATA							
		Snow Cover Classes					Total # Cells	Total Acreage	Total Acreage of Snow
		1	2	3	4	5			
E R T S IMAGE DATA	1	4	4				8	7,840	0
	2		13	2			15	14,700	1,470
	3		1	9	1		11	10,780	3,773
	4			2	3		5	4,900	3,626
	5				5	8	13	12,740	12,613
	Total # Cells	4	18	13	9	8	52		21,482
	Total Acreage	3,920	17,640	12,740	8,820	7,840		50,960	
	Total Acreage of Snow	0	1,640	4,459	6,527	7,762	20,512		

Overall percent "correct" (based on cell count) = 71.2 percent
 Overall percent "correct" (based on acreage count) = 95.5 percent

TABLE 2.3c MAY 28 SNOW COVER INTERPRETATION RESULTS

			LARGE SCALE PHOTO DATA								
			Snow Cover Classes					Total # Cells	Total Acreage	Total Acreage of Snow	
			1	2	3	4	5				
E R T S PHASE DATA		1	3	4					7	6,860	0
		2	1	16	1				18	17,640	1,764
		3		2	9	3			14	13,720	4,802
		4			2	4			6	5,880	4,351
		5				4			4	3,920	3,881
		Total # Cells		4	22	12	11	0	39		14,790
		Total Acreage		3,920	21,560	11,760	10,780	0		48,020	
		Total Acreage of Snow		0	2,156	4,116	7,977	0	14,249		

Overall percent "correct" (based on cell count) = 65.3 percent
 Overall percent "correct" (based on acreage count) = 96.3 percent

TABLE 2.4 SUMMARY OF INTERPRETATION RESULTS

	<u>April 6</u>	<u>May 11</u>	<u>May 28</u>
Total Acres Inventoried	2,173,640	2,009,000	1,972,740
Estimated Acres Snow	1,263,642	508,463	149,539
% Correct (# Cells)	83.8	71.2	65.3
% Correct (acreage)	98.4	95.5	96.3
# Test Plots	80	52	49

Following this initial test, the procedure was repeated using ERTS and aerial imagery acquired on May 11 and May 29, 1974. The time required for interpretation of the entire watershed declined to 6 hours for May 11 data and 3 hours for the May 28 data. This decrease was a result of both increased interpreter experience and the leaner amount of snow-covered area on the later dates. The percent correct based on number of cells declined to 71 percent on May 11 and 65 percent for May 28, however the percent correct based on snow acreage remained above 95 percent on both of the later dates (see Tables 2.3a through 2.3c for detailed breakdown of interpretation results). Thus, while it seemed to become increasingly difficult to correctly classify each cell, due primarily to the increase in partial snow covered areas as the melt season progressed, compensating interpretation errors continued to keep the overall acreage estimates quite accurate.

The continued good results on the two later dates of imagery tends to support conclusions drawn earlier that the technique described does in fact represent a reasonably accurate and efficient means of obtaining regional snow cover data in mountainous regions. Further studies will include the replication of the experiment using spring 1974 ERTS data, and a study of the relative efficiency of deriving similar information using automated discriminant analysis techniques with less human interpreter input.

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B. Report by the Algazi Group, Davis Campus

During the period covered by this 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 "Multi-spectral Combination and Display of ERTS-1 Data".

This symposium afforded an excellent opportunity to take stock of the results achieved by others and by us in using remote sensing data. Thus, our efforts in the specific technical field of digital processing have followed two parallel goals: to pursue vigorously the specific areas of work in which we feel we can make a valuable contribution and to incorporate into our facility and software the algorithms and techniques developed by others which seem to have most merit in applications. We shall divide our comments on progress into the following broad categories: (1) minor hardware modifications and improvements in the digital 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 procedure of (2) and (3) in enhancing ERTS-1 data and imagery of interest to several participants in our study; and (5) articulation and investigation of some of the basic issues which underly the interactive processing of remote sensing data by digital computers.

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. Examples of the photographic product which can be obtained with the precision CRT are shown later in this report.

2. Developments 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) Improvements 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 probably 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 combination with fast algorithms.

This work on linear transformation of multispectral data has greatly benefited from the temporary assistance of Dr. Bernard Fino, who completed a Ph.D. thesis in the same technical area--on the fundamentals of fast unitary transforms. The following papers have been completed, with partial support from the grant:

B. J. Fino and V. R. Algazi, "Slant Haar Transform", correspondence to be published in the Proceedings of the IEEE. (See Appendix IIIc of this chapter)

B. J. Fino and V. R. Algazi, "Unified Matrix Treatment of the Fast Walsh-Hadamard Transform", submitted to the IEEE Transactions on Computers.

Work is actively continuing in a) and b) above and results will be reported or submitted for publication by the next reporting period.

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

We have followed our previous contract 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 Remote Sensing Research on the use of image enhancement for this problem. A new approach, which combines enhancement with semi-automatic classification, is illustrated in the photographs of Figure 2.7. The image of Fig. 2.7b has been enhanced and displayed in such a way that the differentiation of snow with respect to surrounding areas is eased. This is

a new approach to interactive classification which will be more fully discussed and described in later reports.

(b) Mapping and enhancement of salt affected soils. This work, carried out by a Ph.D. student, Mr. Samulon, is nearing completion. 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. A short discussion of his work is presented as a special study in this report and a paper has been submitted for publication in the Special Issue on Image Processing and Digital Filtering of the IEEE Society on Circuits and Systems.

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.

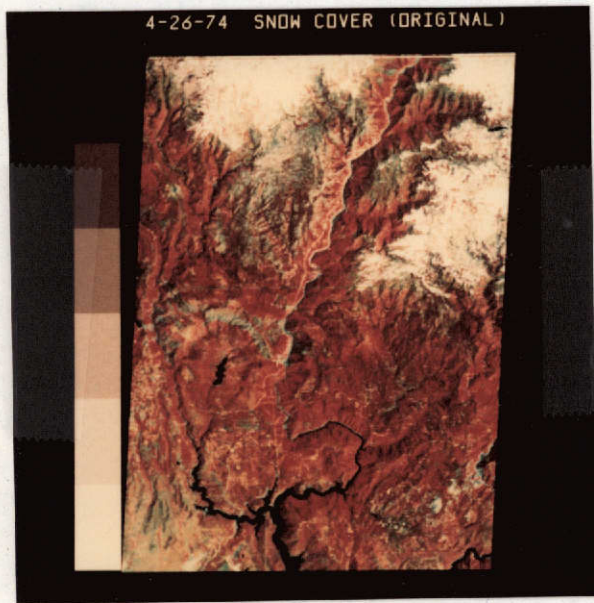
(a) Geometric correction: Various algorithms will allow us to generate images with one of several possible levels of geometric accuracy. Figures a and b include two geometric corrections. They have not been tested as to mapping accuracy. Since these corrections are very simple to do, we hope that they will be adequate for most applications.

(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.

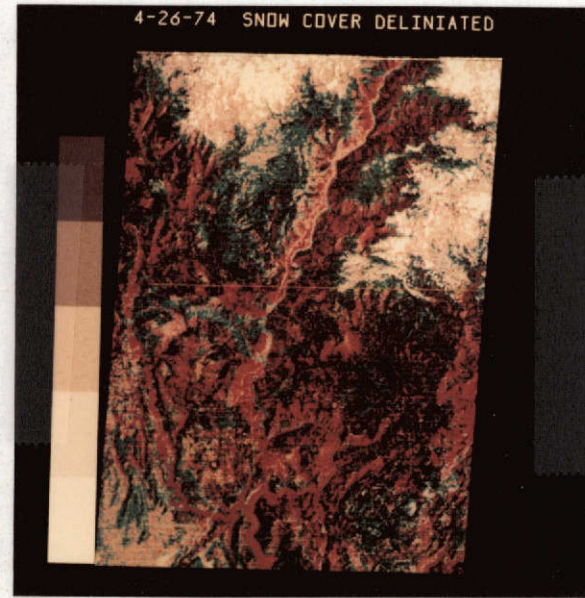
(c) Preprocessing and interactive processing of remote sensing data to increase efficiency and interpretability: Some of this work falls along the lines described earlier, since it requires linear combinations of multi-spectral data. This is a procedure which combines image enhancement and subsequent classification and may be an attractive alternative to automatic classification. One example of such an approach is given in Figure 2.7.

(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.

2-46



A



B

Figure 2.7

(e) Subpixel processing: In some applications, notably the quantitative determination of water surfaces, it is desirable to incorporate subpixel information. For advanced geometric correction, it is also desirable to interpolate between pixels. A systematic approach to the design of efficient filters and algorithms for that problem has been undertaken by a Ph.D. student, Minsoo Suk, with partial support of the grant. A paper on basic design considerations has been submitted for publication to the Special Issue on Picture Processing and Digital Filtering of the IEEE Society on Circuits and Signals. Both fundamental and applied work in this area will be continued.

(f) Bibliographic and Library Research: As part of our assessment of useful results and algorithms in remote sensing, a substantial bibliography of titles, abstracts or full papers has been generated. The major descriptors of references are:

1. Geometric Correction
2. Atmospheric Effects
3. New Sensors and Methods in Remote Sensing
4. Interpretation Techniques
5. Rainfall and Precipitation Forecasting
6. Water Quality
7. Hydrology and Watershed monitoring
8. Snow Monitoring

A very large amount of work in remote sensing techniques and applications is directly useful to our project and a continuing effort to keep abreast of new results is crucial to our project.

V. FUTURE DIRECTIONS OF THE STUDY

The work accomplished during the past several months and described in earlier sections of this report builds upon our previous results and sets directions for the future. Some general objectives as well as some specific goals will be discussed briefly.

Our continuing broad objective is to show practical utilization of Remote Sensing in the California Water Project. Thus, a substantial effort has already been devoted to the elucidation of the long range plans and of the present and near term operations of the project. This effort, being done with the extremely valuable assistance of the California Department of Water Resources, reveals a dynamic project, in full development and evolution. The project benefits in its current operation and future planning through the efforts, expertise and experience of the dedicated personnel of the DWR. Given the scope, dynamism of the project and of the State of California, it has become evident that we are not dealing with a tight logical structure to be elucidated once and for all. The DWR welcomes and encourages our work as possible valuable input to improved operation and as an aid in planning and analysis. This fairly open-ended, continuing, and evolving interaction with State Operating and Planning Agencies is among the most significant directions that we shall follow in the future.

In the immediate future we see a continuing need for a clarification of the physical basis and a better understanding of the actual use and accuracy of the predictive models of the DWR and other state water agencies. For some of this short term effort we are grateful of the helpful comments and suggestions of Dr. Peter Castruccio in response to our semi-annual report. This part of our work will enlarge upon the general factual basis presented in this report. 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.

From our work to date, we have firmly established the usefulness of remote sensing in supplying information on specific parameters in actual use by the DWR in planning and operations. Thus, we shall have a continuing determination of those areas in which remote sensing techniques will be explored, forming a foundation for the planned final phase of this study, namely an economic analysis of the worth of remote sensing in water supply problems.

As was discussed earlier, we listed a number of avenues of investigation for possible remote sensing applications (see Tables 2.2 and 2.3). This listing was an outgrowth of the numerous discussions that have been carried out with personnel of the Department of Water Resources as well as an analysis of the various predictive models used by the DWR in their current program. Using that listing as a starting point, an attempt was made to rank the various remote sensing applications. The ranking, while somewhat subjective, was based on the probability of successful remote sensing use, the importance of the parameter to the DWR models, current expertise of the project staff, and the immediacy of the potential implementation period.

As a result of this ranking, work has begun on several of the listed potential applications.

In regard to the estimation of the area extent of snow, work will proceed on a second year of data using the manual interpretation techniques already reported. It is also planned to initiate a study of the feasibility of the application of automated discriminant analysis procedures to the same problem. This work will first involve relatively simple multivariate analysis of summer and winter image data, but it is hoped soon to be able to include topographic information (slope, aspect, and elevation) in the classification procedure. If the snow mapping proves successful, this study will progress into an analysis of melt rates over time during the spring and correlation of snow accumulation and retention with vegetation and terrain type. At least the preliminary phase of the automated snow mapping project will be carried out in the Spanish Creek watershed, upstream from the gaging station at Keddie.

A second study which has recently been initiated is concerned with the mapping of impervious surfaces, surface water, and riparian vegetation in the watershed. These categories are particularly important in that precipitation falling on them immediately enters the surface runoff phase as opposed to that which, falling on areas with soil cover, enters the subsurface hydrologic cycle.

Finally, work has begun on the classification of watershed areas on the basis of potential evapo-transpiration. This information would form the basic input, along with climatic data, to the derivation of weighted basin evaporative indices.

Each of the three studies outlined above involves the use of ERTS or aircraft data to ascertain certain physical attributes of the watershed itself. Most of these data are of obvious but somewhat limited use in the solution of hydrologic problems. It is anticipated that as these studies proceed, the concurrent study and sensitivity analysis of the DWR models will allow us to assess the usefulness of these parameters acquired by remote sensing.

It seems clear that a significantly greater use of the parameters can be realized if they can be combined with meteorological or climatological information. For this reason it is planned to carry out a preliminary study of the possible use of meteorological satellite and ERTS data in providing fairly localized precipitation and temperature information to supplement that currently acquired from terrestrial stations. Depending on the success of this study it is possible that later work will be concerned with the development of hydrologic models incorporating as inputs remotely sensed information concerning both physical attributes of the watershed and meteorological parameters.

All our work involving the use of Remote Sensing Data in Applications, is built on the foundations of the techniques for the acquisition, handling and processing of remote sensing data. Thus, we shall continue to study the techniques and methodologies fundamental to any remote sensing applications. We shall also keep abreast of the advances of the state of the art, both in fundamental techniques and in applications. Some of our ongoing and future work in these areas has been described earlier.

As our work progresses in this coming year on the several interrelated areas described, these being identification of models and information requirements, scientific analysis, and acquisition of parameters by remote sensing, we shall continuously assess the related findings from an economic standpoint.

Thus, using such results as may be available we shall attempt to enumerate benefits or economic worth which can legitimately be ascribed to various types of information and to ascertain the costs of acquiring information using currently available methodology.

APPENDIX I 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 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 reservoir 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

*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 the drainage 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:

$$\text{Par} = (0.97)(\text{Par}') + \text{Precip}$$

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 I.1.

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.

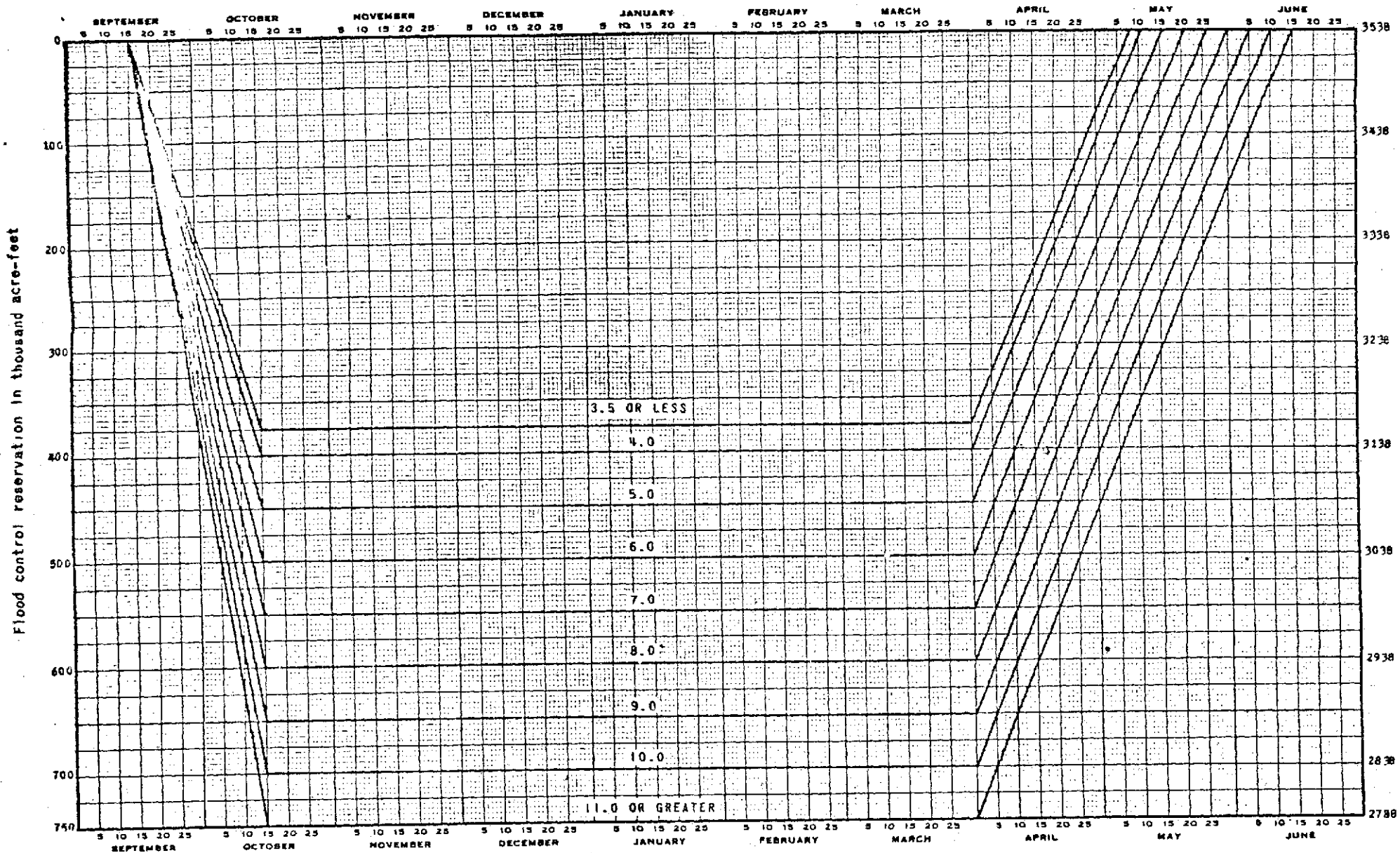


Figure I.1: Schedule of Required Unfilled Flood Control Volume and Associated Drawdown and Fill Rates by Ground Wetness Index for Oroville Reservoir.

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

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 I.2. 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 Forecast Center will be described in Appendix II 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

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 I.2: Release Schedule for Oroville Reservoir Under Normal Conditions. From Department of the Army (1970), Chart A-1 .

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. Secondly 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 meteorological 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.

APPENDIX II MODELS FOR ESTIMATING WATER YIELD

A. 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:

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

where

DSE = Daily Root Mean Square error in Cubic feet per second (CFS) per square mile of watershed (SQMI)

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

MSE = Monthly Root Mean Square error

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

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

A GENERALIZED HYDROLOGIC MODEL

2-60

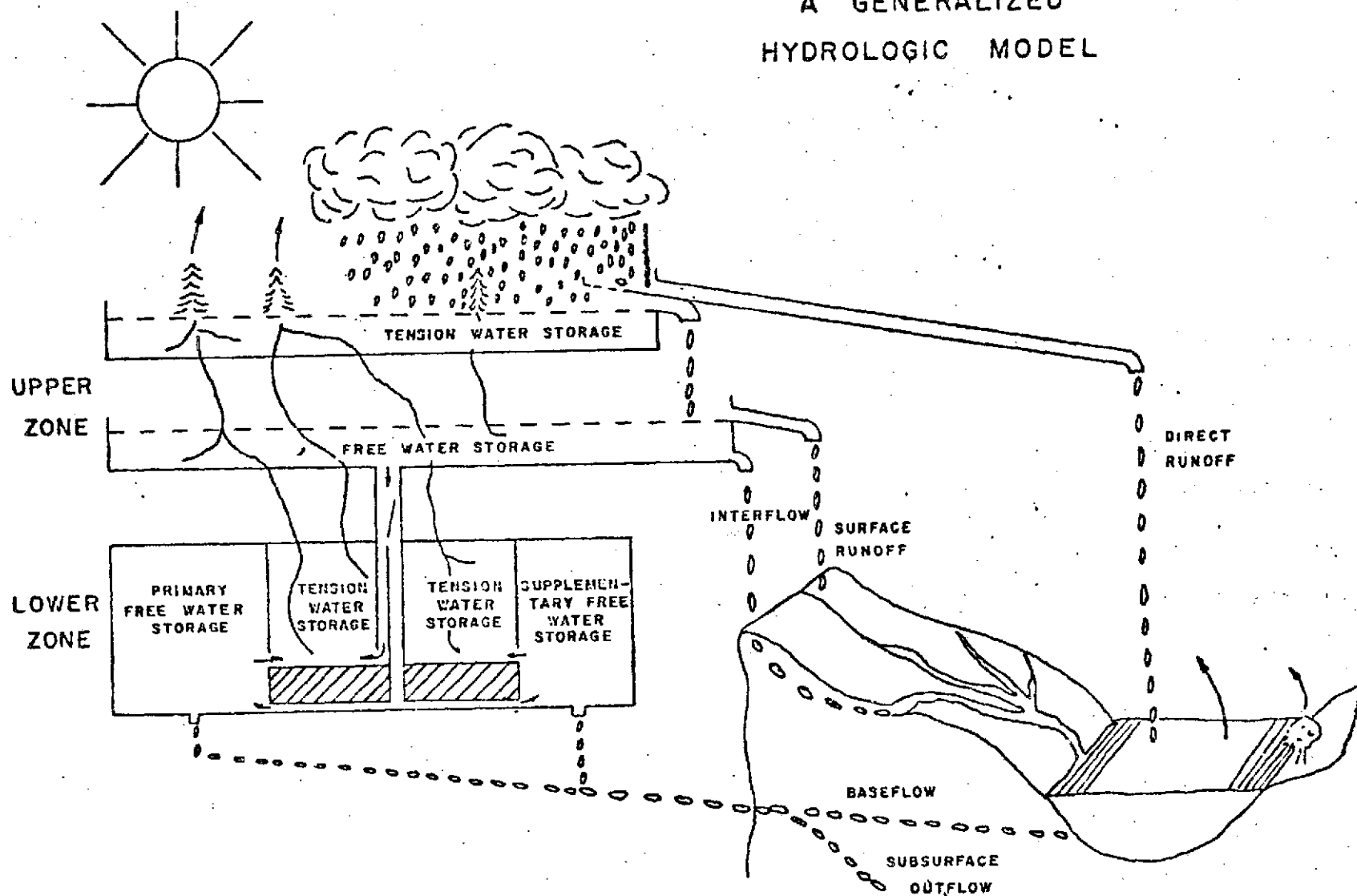


Figure II.1: Base concept on which the River Forecasting Model is based. From Burnash et al. (1973).

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 II.1. 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.

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 compartment 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 following a 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 II.2. Input parameters along with a listing of RFC model components necessary for water yield simulation are described in Table II.1 in terms of their computer mnemonics. The method of derivation of the listed parameters is also given.

Table II.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 ground meteorological station readouts, or from phoned-in rain gauge

¹The 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 commercial 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 microwave 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, modification 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 II.1. (continued)

No.	Parameter	How Derived
		<p>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.</p>
2)	<p>Monthly weights for matching evapotranspiration estimates or mean pan evaporation data to the basin's characteristic climate and plant cycles, PCTPN.</p>	<p>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.</p>
3)	<p>Direct runoff and evaporation</p>	
	<p>a) Fraction of impervious basin contiguous with stream channels, PCTIM.</p>	<p>Derived from hydrograph analysis (i.e., based on an analysis of the characteristics of flow volume past a gaging station with respect to time).</p>
	<p>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.</p>	<p>Derived from hydrograph analysis.</p>
	<p>c) Fraction of the basin covered by streams, lakes, and riparian vegetation SARVA.</p>	<p>Derived from PCTIM or detailed maps.</p>
	<p>d) Evapotranspiration demand, ED.</p>	<p>Derived from (2).</p>

Table II.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 II.1 (continued)

No.	Parameter	How Derived
(8) Lower zone free water		
a) Supplemental free water storage.		
1)	Maximum capacity in inches, LZFSM	Derived by hydrograph analysis.
2)	Contents in inches, LZFSM	Initially set at start of simulation. Adjusted later if necessary.
3)	Lateral draining rate expressed as a fraction of contents per day, LZSK	Derived by hydrograph analysis.
b) Primary free water storage		
1)	Maximum capacity in inches, LZFSM	Derived by hydrograph analysis
2)	Contents in inches, LZFSM	Initially set at start of simulation. Adjusted later if necessary.
3)	Lateral drainage rate expressed as a fraction of contents per day, LZPK	Derived by hydrograph analysis.
c) Direct percolation to Lower Zone Free Water, PFREE, the percentage of percolated water which directly enters the lower free water aquifers without a prior claim by lower zone tension water deficiencies.		
Initially set at start of simulation. Established by optimization during simulation. May also be established in some instances through hydrograph analysis.		
d) Ground water discharge not observable in the river channel		
1)	Ratio of non-channel subsurface outflow to channel baseflow, SIDE.	Established by optimization during simulation.
2)	Discharge required by channel underflow, SSOUT	Initially set at start of simulation. Adjusted later as optimization requires.
e) Fraction of lower zone free water incapable of resupplying lower zone tension, RSERV		
Initially set at the start of simulation.		

Table II.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 now 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:

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

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:

$$CCMLT = ((TD - 32) \times 0.0104 + (TBAR - TD) \times 0.00305) \times WS \times ELTRM$$

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 percentage 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 lapping from recording station values) - 4° F.

Table II.2 RELATIONSHIP BETWEEN TEMPERATURE AND PERCENTAGE OF PRECIPITATION THAT IS IN THE FORM OF RAIN

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

From Burnash and Bard (1973).

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 II.3.

B. The Primary CCSS Model

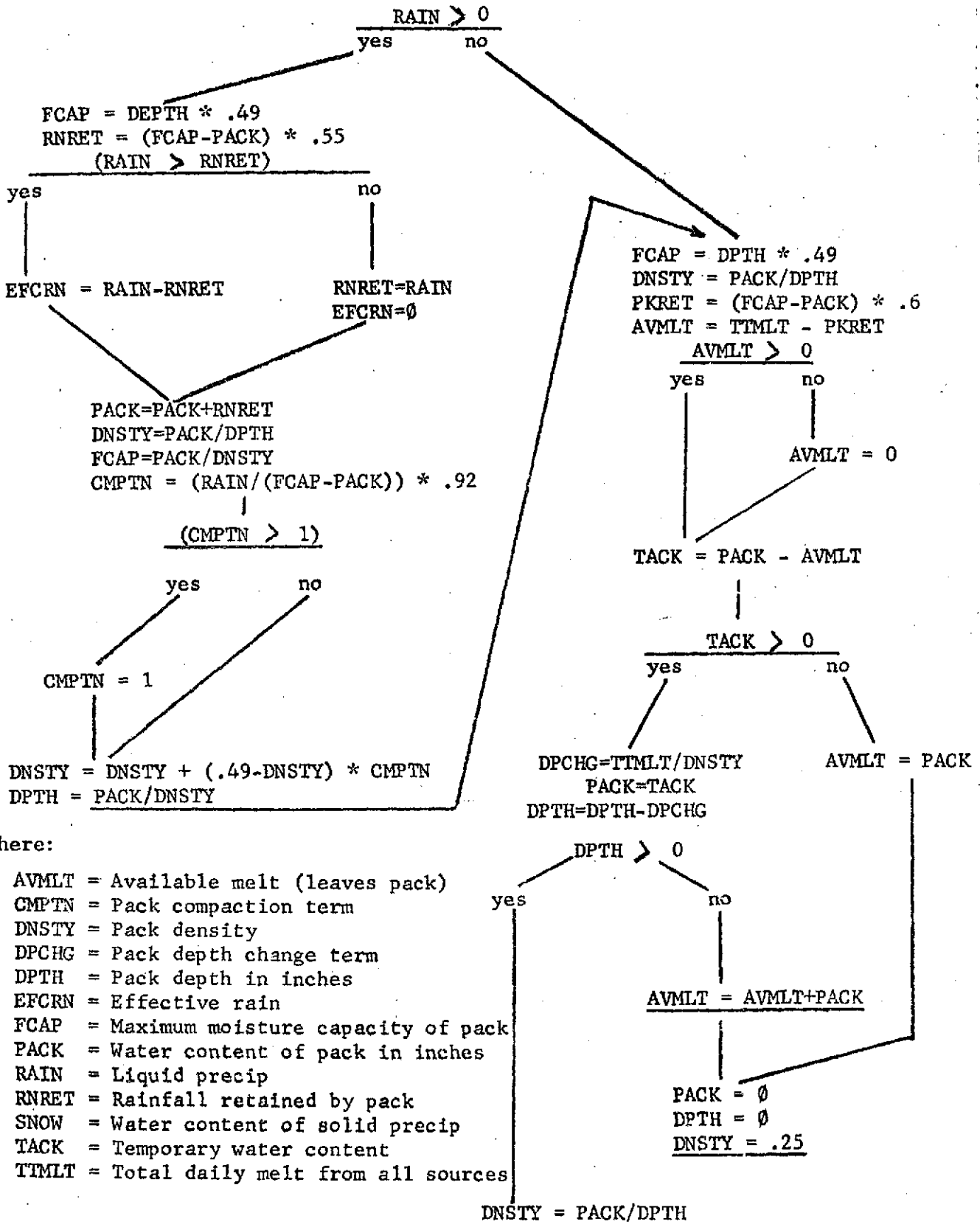
The major inputs into the California Cooperative Snow Surveys' primary model (Howard, 1973) consist of (1) an April 1st snow pack index, (2) an October to March precipitation index, (3) an October to March runoff index, (4) the previous year's snow pack index, and (5) an April to June precipitation index. 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 II.4. 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

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



where:

- AVMLT = Available melt (leaves pack)
- CMP TN = 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 II.3. Model showing mechanics involved in determining snowpack. From Burnash and Baird (1973).

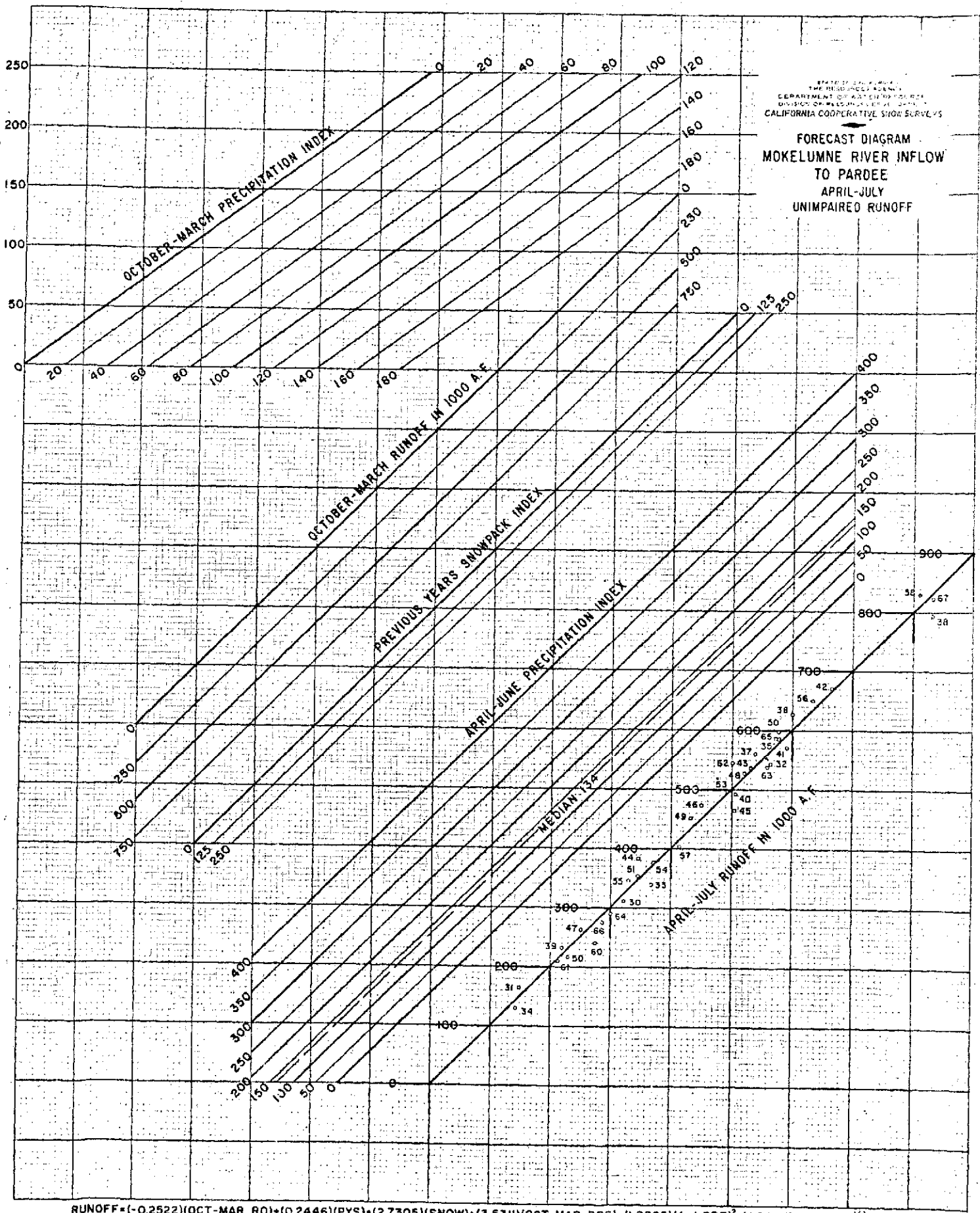


Figure II.4. Plot of regression equations used in forecasting river flow in the Sierra, as explained in the text.

to July forecast is made. An example forecast computation form appears in Figure II.5 and of a forecast range diagram in the lower right-hand corner of Figure II.6. 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 ten.

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

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

Since the CCSS hydrologic model is probabilistic in nature, a statement of confidence about predicted water yields can also be constructed. This statement consists of a claim that the actually observed 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 predicted value. This statement 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:

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

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 $Y_{\text{observed runoff}}$ will actually fall

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

$\widehat{V(Y_{\text{predicted runoff}})}$ = 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

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

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 \pm 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 the CCSS.

According to California Cooperative Snow Surveys procedure, at least some snow course 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 III.6. 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.s, 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 February 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 runoff 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 II.5. 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 II.5 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 II.5. 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. Columns 13 and 15 in the top table of Figure II.5 are then utilized to derive an average February precipitation index. This value is entered into Column 3 of the lower

right-hand corner table of Figure II.5. The addition of the calculated 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 updating 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 II.5. Forecasts of April to July runoff made on February 1st utilize the sum of monthly 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 represents a prediction of the October to March water yield volume as estimated on February 1st.

An estimate of this third independent variable for runoff prediction 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 California 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 II.5. 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 precipitation 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 index is thus derived. A similar procedure, utilizing the two tables at the bottom of Figure II.5 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 II.5 this average index is 134.

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

regression equation at the bottom of Figure II.4. An alternative way to determine April to July runoff from the independent variables is given by the linear relationships in the body of Figure II.4. In this representation, the slope of each line and the relative juxtaposition 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 II.4, 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 II.5 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 II.6. 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 approximately with that obtained in Figure II.4. 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 to or subtracted from 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.

c. The Modified (Dynamic) CCSS Model

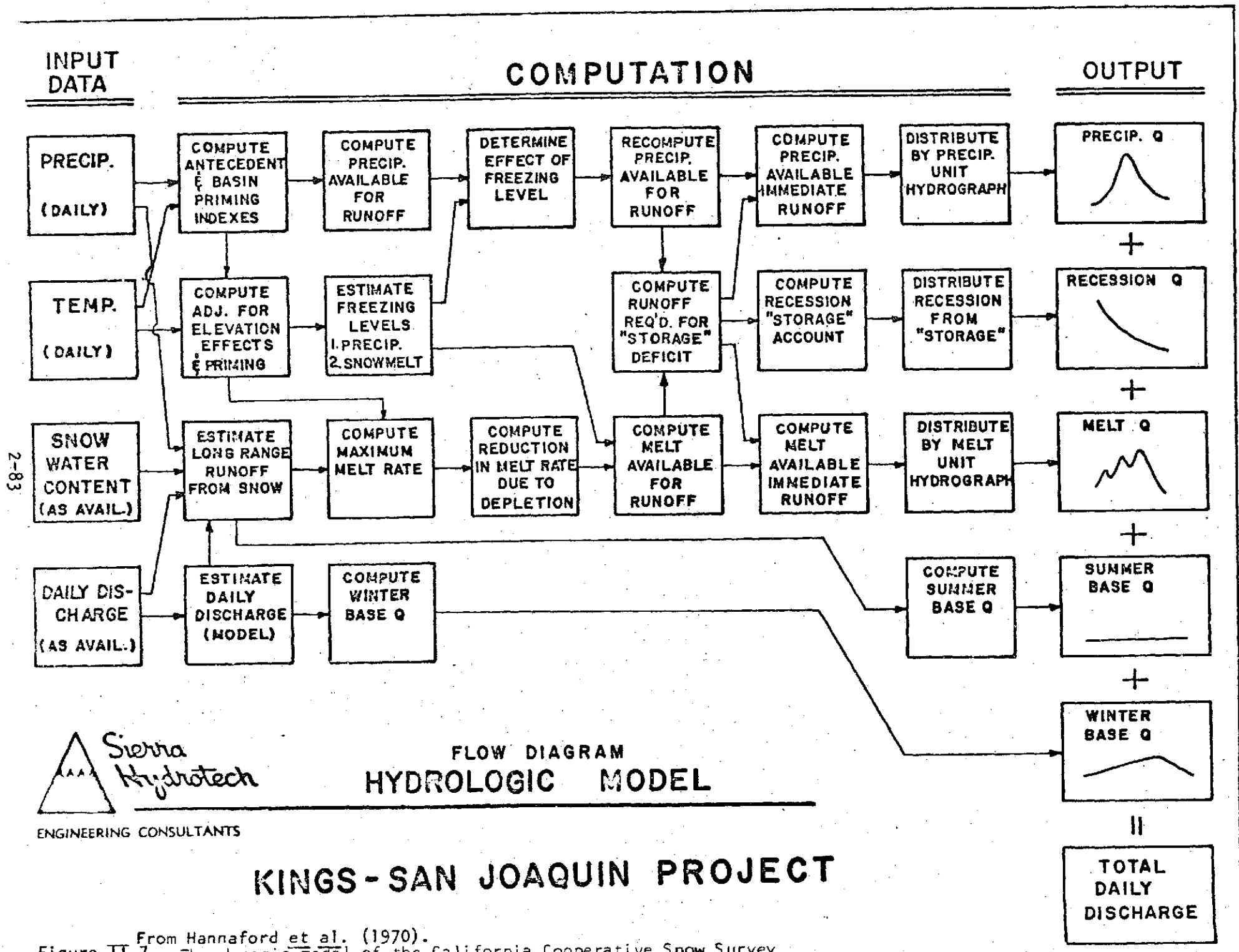
A second hydrologic model (Hannaford et al., 1970) used by the California Cooperative Snow Surveys is dynamic, that is it involves real-time water yield forecasts, and is based on probabilistic relationships. This model was developed by a private firm in conjunction with the CCSS and is presently utilized 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 potentially 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 recording 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 especially 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 pattern 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 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.

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. Precipitation, 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



From Hannaford et al. (1970).
Figure II.7. The dynamic model of the California Cooperative Snow Survey

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 II.7.

The models as described here have provided the basis for the analysis of potential remote sensing applications discussed earlier in this chapter.

APPENDIX III REMOTE SENSING TECHNIQUE DEVELOPMENT

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 procedure, 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.

A. Vegetation/Terrain Type Mapping

1. 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, classification scheme used, mapping techniques used, personnel requirements, and estimated project costs. It was felt that such an exercise would result in a more meaningful evaluation of the potential for mapping from ERTS than if an arbitrary classification scheme were generated.

It should be emphasized that this preliminary study was oriented toward purely manual (i.e., non-automated) mapping procedures and was viewed as a useful first step in the application of remote sensing imagery to more specific water-related studies.

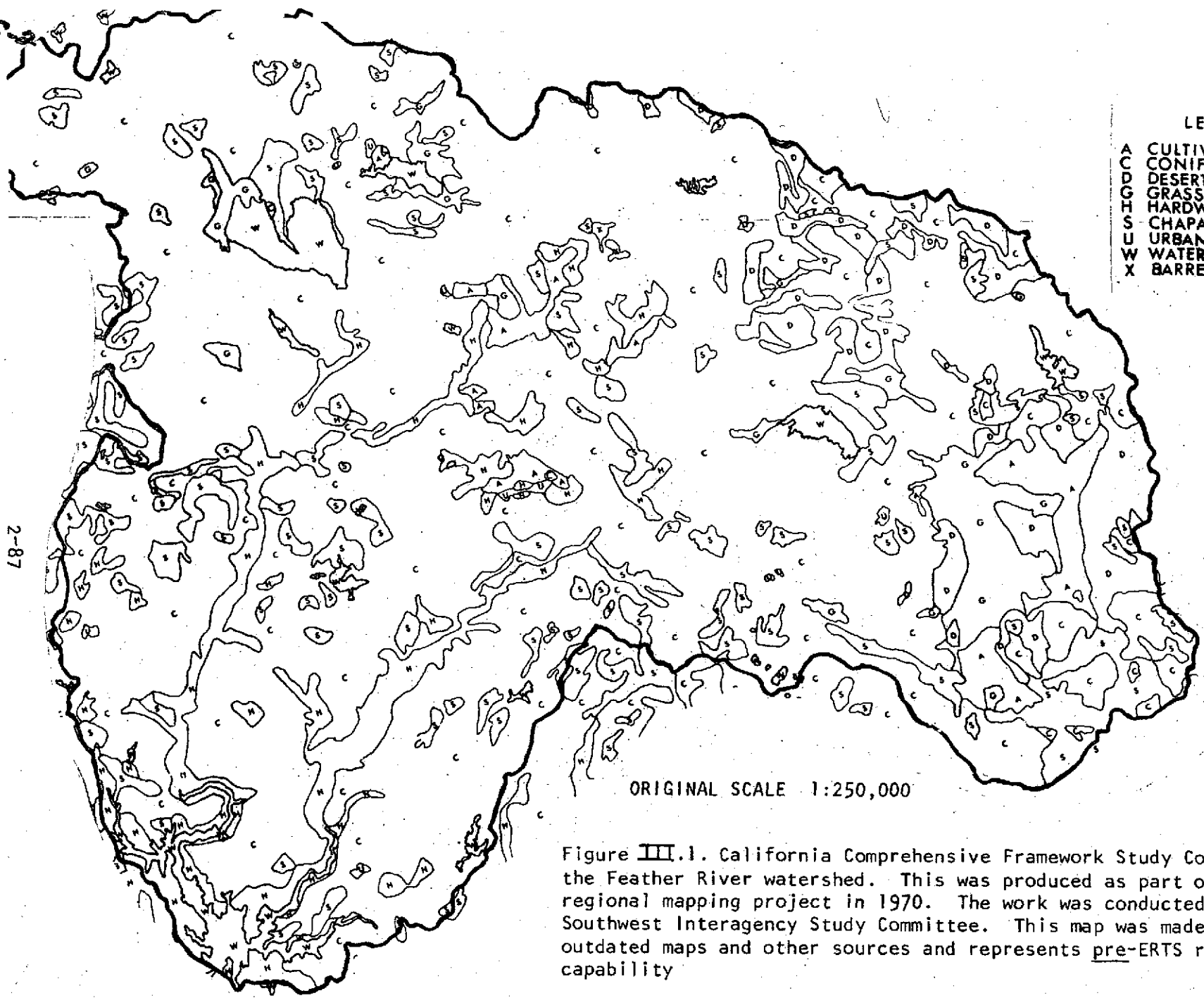
The objectives of the study were (1) to map with ERTS-1 imagery the resource complex within the entire Feather River watershed, using the generalized Framework Study mapping objectives as a guide; (2) to determine the level of accuracy associated with the generalized map made from ERTS-1 by comparing it with the map made from high altitude false-color infrared photography; (3) to 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; (4) 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 (5) to determine the timing and cost factors associated with preparing the generalized and the detailed maps made from the ERTS-1 imagery.

2. 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. These 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 identifiable 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 III.2.

3. Accuracy of Generalized Map

An evaluation of the level of accuracy associated with the generalized ERTS-1 map shown in Figure III.2 is presented in Figure III.3. 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 these 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 III.3. 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.

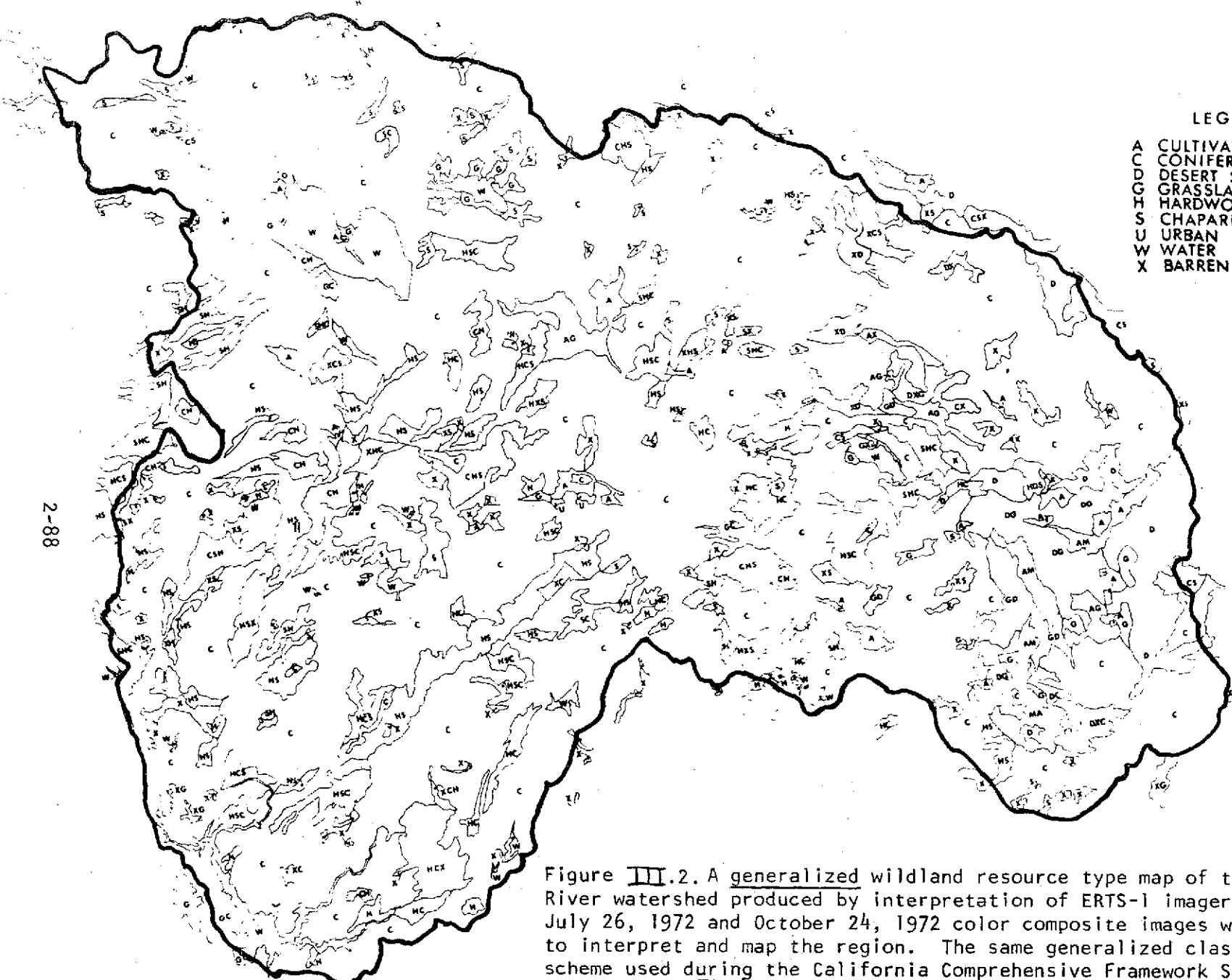


- LEGEND**
- A CULTIVATED & PASTURE
 - C CONIFER
 - D DESERT SHRUB
 - G GRASSLAND
 - H HARDWOODS
 - S CHAPARRAL
 - U URBAN
 - W WATER
 - X BARREN

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ORIGINAL SCALE 1:250,000

Figure III.1. 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

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Figure III.2. 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 III.1) was used when making this map.

		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*
HIGH ALTITUDE GROUND COMPARATIVE MAP DATA	CONIFER (A, B, BB, C, E)	294	7	287	1	6	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, M)	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										0	100
	TOTALS	674	62											
TOTAL INDICATED**				320	17	46	13	19	22	23	13	1	474	
TOTAL COMMITTED				33	5	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%

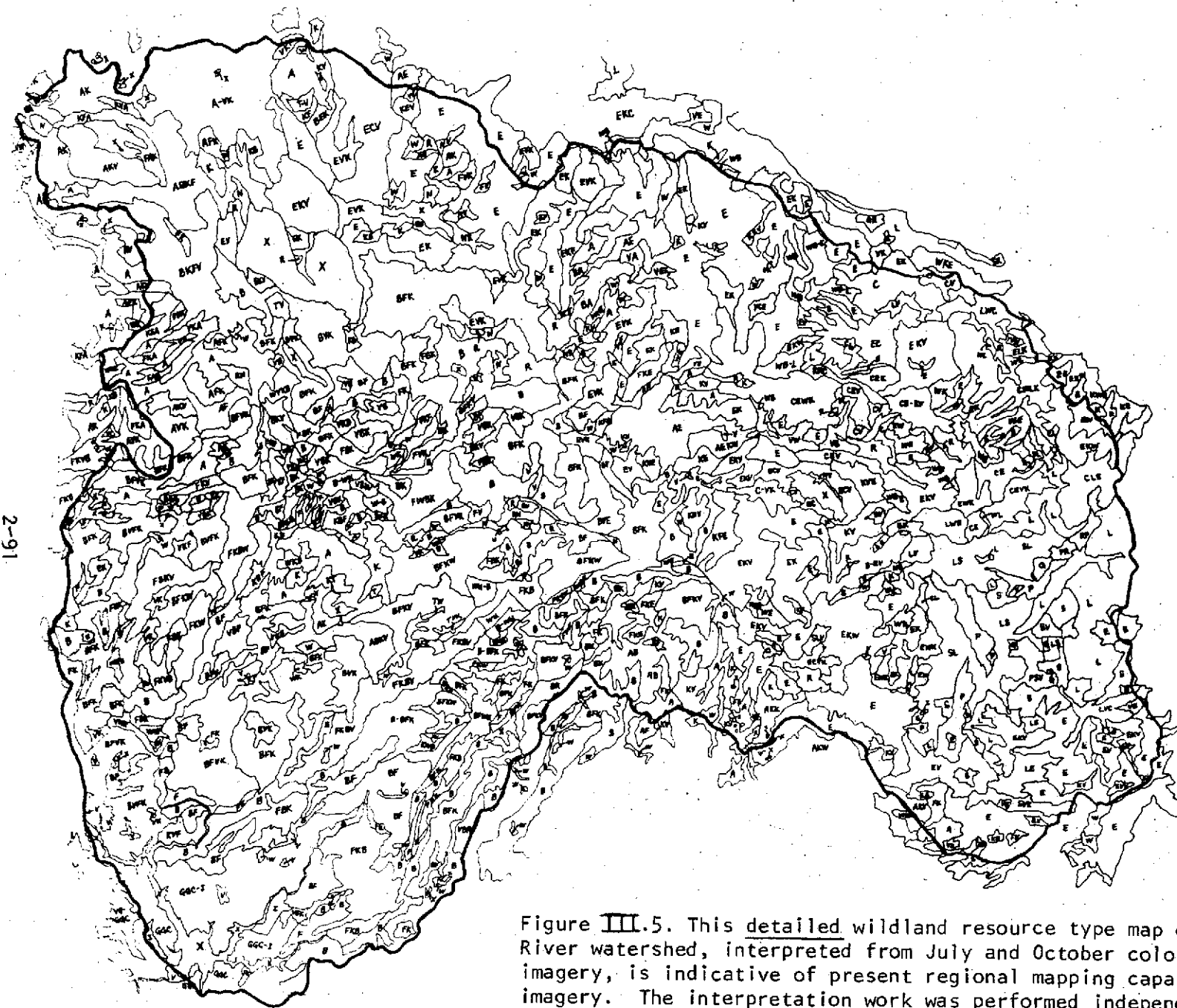
Figure III.3. An evaluation of the ERTS-1 generalized resource type map (see Figure III,2) is presented in the above table. Comparisons of the ERTS-1 map with the high flight map indicate excellent agreement. The percent correct results for the identification and mapping of conifer, hardwood, grassland, 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*
HIGH ALTITUDE GROUND COMPARATIVE MAP DATA	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, N)	22	7	2	2		15	2	1				32	68
	CULTIVATED & PASTURE (P, Q, R, H)	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		

AVERAGE PERCENT CORRECT=68%

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

Figure III.4. An evaluation of the Comprehensive Framework Study Committee Map Base (see Figure III.1) is presented in the above table. Comparisons of the Framework Study map with the high flight map (see Figure III.2) 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 possibility 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
- GOC 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 III.5. 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.

4. 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 III.5 illustrates the classification scheme used and the final map product derived from ERTS-1 imagery.

5. Accuracy of Detailed ERTS-1 Map

A point-by-point evaluation was made of the detailed ERTS-1 map shown in Figure III.5 by comparing it with the high flight map. The summary results for 474 points are given in Figure III.6. 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 III.6 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 presented each sample was small.

The high omission errors shown in Figure III.6 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.

Table III.1 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 (Gen- eralized) from ERTS-1 Color Composite Imagery	Mapping (Detailed) From ERTS-1 Color Compos- ite 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
Delineation 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	<u>120.0 hours</u>	<u>3.0 hours</u>	<u>7.0 hours</u>
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 to 1	10 to 1	

6. 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 (Figure III.2) and the detailed ERTS-1 map (Figure III.5) are presented in Table III.1. 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 III.1. 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.

7. Conclusions

The Case Study presented above was designed to determine the practical usefulness of ERTS-1 imagery for vegetation/terrain mapping over vast, inaccessible 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.

		PRINCIPAL RESOURCE TYPE MAP FROM ERTS-1																								
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*		
HIGH ALTITUDE COMPARATIVE MAP DATA	FIR FORESTS	72	25	47	19		5	1																34	65	
	MIXED CONIFER	129	28	8	101		18	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															23	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			6							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	105	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	35	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 III.6. 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.

B. Multistage Sampling Study

1. Introduction

As indicated in the discussion of the DWR 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. While the selection of timber volume as the parameter of interest in this initial study was justified on the basis of strong interest on the part of the U.S. Forest Service, the study is presented here as an illustration of a technique which, with minor modification, could be applied to the inventory of any number of wildland resource parameters relating to the water supply. Thus, what is of particular interest here is not the specific results, but rather the approach to a resource inventory problem in which satellite data, automated classification techniques and statistically valid multistage sampling techniques play crucial roles.

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.

Additional 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 aircraft data in reducing the sampling error, (4) to compare the costs of this 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.

2. The Sampling Design

A three stage sampling design was tested in which "timber volume" was the variable estimated. At each stage volume estimates were made

from sampling units whose probabilities of selection for 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 volume classes. Within the classified area, subsamples were selected (called primary sampling units or "PSU") from which a more refined estimate of 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 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 estimates by photo measurement of all merchantable trees. Selected trees were then precisely measured on the ground and these measurements in turn were expanded through various stages of the sample design to estimate total timber volume over the national forest land within the Quincy Ranger District.

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 volume classes based upon photo interpreter selection of 33 training cells which, in turn, had been 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 then proceeded by matching each data point (picture element) with the corresponding training cell and the results were grouped into four timber volume classes. The accuracy achieved by automatic classification of ERTS tapes lends credence to the efficiency which can be gained in the inventory through analysis of ERTS data tapes in the initial stages of the sample design.

The classified ERTS data of the Quincy Ranger District were divided into rectangular sampling units called primary sampling units (PSU's). 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 PSU'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, with probability of selection proportional to their estimated volumes. The locations of the four selected PSU's were transferred from the ERTS classified 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.

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. Thus, the photo coverage for each PSU consisted of ten large scale stereo triplets and ten small scale photographs.

* 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 photo-interpreters. 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.

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 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, 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. 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,

* 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.

3. Results

The total volume of timber on the Quincy Ranger District 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 give a probability of .8 percent that the interval 352-462 million cubic feet contains the true volume of the district. This result can be compared with the generally acceptable sampling error for district inventories of 20 percent and the resulting wider (less desirable) confidence intervals.

There were only a total of thirty-one trees measured 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).

4. 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 volume estimates as a fundamental first step in selecting primary sampling units in the first stage of the inventory.

5. Statistical Methods Used

Volume predictions were made in each of the three stages of the inventory for the purpose of selecting sample plots whose probability of selection would be proportional to the predictions. Thus, variable probability sampling methods were used.

Three variables proportional to timber volume were used in generating the selection probabilities: (1) "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 used a scheme where probability of selection is proportional to the estimated volume, the effort is focused on the areas

* 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.

of higher timber volume and thus adds to the overall cost-efficiency. The ability to list the populations at each stage prompted the selection of list sampling as the variable probability sampling scheme.

6. 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

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

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

A sample of a chosen size was then drawn by applying random integers from 1 to n and observing the probability interval and

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

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 1; 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 i^{th} PSU in the h^{th} stratum

y_{hi} = total volume of the i^{th} PSU in the h^{th} stratum (remains to be estimated by subsequent stages).

Stage II: To estimate the total volume (y_{hi}) of the i^{th} PSU, a sample of n_{hi} out of the N_{hi} secondary sampling units (.4 acre plots) was drawn with pps. 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: $r = 1, 2, \dots, R$ refers to the CALSCAN volume strata

p_{hir} = selection probability of the r^{th} volume stratum of the i^{th} PSU in the h^{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^{th} plot of the r^{th} volume stratum, of the i^{th} PSU in the h^{th} stratum

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

Stage III: To estimate the total volume of the j^{th} plot, a sample of n_{hirj} out of the N_{hirj} tertiary sampling units (trees) was drawn with pps. 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 k^{th} sample tree of the j^{th} plot of the r^{th} volume stratum of the i^{th} PSU of the h^{th} stratum.

y_{hirjk} = the dendrometer-measured volume of the k^{th} sample tree of the j^{th} plot of the r^{th} volume stratum of the i^{th} PSU of the h^{th} stratum.

Combining the various stages above, the entire estimator became:

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

7. 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:

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

which has an unbiased estimator:

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

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

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

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

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

8. Sample Size

(a) From the usual confidence statement

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

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

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

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

Since

$$\text{Var}(\hat{V}) = \frac{1}{n} \underbrace{\sum_{i=1}^N p_i \left(\frac{y_i}{p_i} - v_h \right)^2}_{S^2}$$

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 interpretation, the population variance S^2 is obtained by

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

where y_i denotes the total volume of the i^{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,

$$y_i = \sum_{l=1}^n \sum_{k=1}^m w \cdot c$$

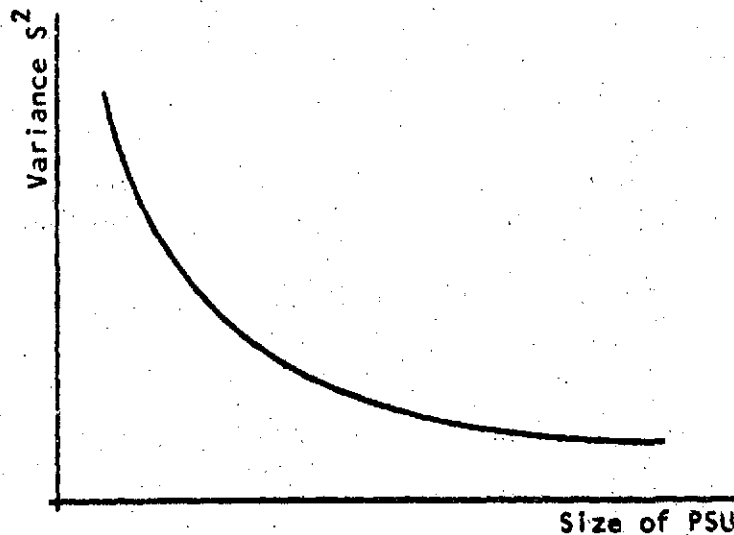
where $k = 1, \dots, m$ is no. of rows of picture elements in PSU

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

w = volume weight for c

c = CALSCAN class assigned to the kl^{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 5 x 43 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 $d = t \cdot s_{\bar{x}} = .10$ (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 $d = t \cdot s_{\bar{x}} = .05$, i.e. $s_{\bar{x}} = 2.5\%$

Then

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

C. SLANT HAAR TRANSFORM

Abstract; The Slant Haar transform (SHT) is defined and related to the Slant Walsh-Hadamard transform (SWHT). A fast algorithm for the SHT is presented and its computational complexity computed. In most applications, SHT is faster and performs as well as SWHT.

Introduction: The SWHT (originally called Slant transform) has been proposed by Enomoto et al. [1] for the order 8 and used in TV image encoding. Pratt, Chen et al. [2] [3] have generalized this transform to any order 2^n and compared its performance with other transforms. In [4], we have given a simpler definition of the SWHT as a particular case of a unified treatment of fast unitary transforms and computed the number of elementary operations required by its fast algorithm¹. The interesting feature of the SWHT is the presence of a slant vector with linearly decreasing components in its basis. On the other hand we have found that locally dependent basis vectors, such as in the Haar transform, are of interest [5]. In this letter, we define a composite fast unitary transform: the SHT. We show that its relations to the SWHT parallel the relations between the Haar (HT) and Walsh-Hadamard (WHT) transforms [6]. This previous work leads us to expect that SHT has an advantage over SWHT because of its speed and comparable performance.

Definition: The generalized Kronecker product of the set $\{A^j\}$ of n matrices $[A^j]$ ($j=0, \dots, n-1$) of order m and the set $\{B^k\}$ of m matrices $[B^k]$ ($k=0, \dots, m-1$) of order n is the matrix $[C]$ of order mn such that $C_{um+w, u'+w'} = A_{uu'}^w B_{ww'}^{u'}$ when $u, u' < n$ and $w, w' < m$. $[C]$ can be factorized and has a fast algorithm [4].

The generalized Kronecker product provides a simple way to recursively define fast unitary transforms. Consider the matrix of order 2 $[T_2] = [F_2(\pi/4)] = \frac{1}{\sqrt{2}} \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix}$. Then the matrix of order 2^n , denoted $[T_{2^n}]$ is obtained from the matrix

of order 2^{n-1} by $\{\mathcal{A}\} \otimes \{[T_{2^{n-1}}], [T_{2^{n-1}}]\}$ where \otimes denotes a generalized Kronecker product. With this recursive notation, the HT is obtained for

$$\{\mathcal{A}\} = [F_2(\pi/4)], [I_2], \dots, [I_2] \text{ and the WHT for } \{\mathcal{A}\} = [F_2(\pi/4)], \dots, [F_2(\pi/4)].$$

For the slant transforms SHT and SWHT, the recursive definitions are as above except for a supplementary rotation of the rows 1 and 2^{n-1} by the matrix

$$[V_2(\theta_n)] = \begin{bmatrix} \sin \theta_n & \cos \theta_n \\ \cos \theta_n & -\sin \theta_n \end{bmatrix} \text{ with } \theta_n < \pi/2 \text{ given by } \cos \theta_n = \frac{2^{n-1}}{\sqrt{2^{2n-1} - 1}}$$

This rotation introduces the "slant vector", the components of which are linearly decreasing (see [7] for a complete description of slant vectors).

Ordering of the basis vectors : In signal processing practice, the vectors of the HT are used in rank order [4] and those of the WHT are used in sequency (number of sign changes) order. There is an ordering of the slant transforms consistent with these orderings: the basis vectors obtained by the above recursive definitions are ordered by :

- 1) decreasing number of non-zero elements (from globally to locally dependent basis vectors)
- 2) increasing number of zero-crossings
- 3) from left to right.

The ordered matrices $[SHT_8]$ and $[SWHT_8]$ are shown in Fig. III.7.

Relations between SHT and SWHT : The SHT and SWHT have relations similar to the relations between HT and WHT [6]. Partition the ordered SHT (SWHT) into $2n$ rectangular submatrices, denoted $[MSH_{2^n}^{k,i}]$ ($[MSWH_{2^n}^{k,i}]$), $k=0, \dots, n-1$ and $i=0,1$. For $k,i=0,1$ $[MSH_{2^n}^{0,0}]$, $[MSH_{2^n}^{0,1}]$, $[MSH_{2^n}^{1,0}]$ and $[MSH_{2^n}^{1,1}]$ are the four first rows of the ordered matrix $[SHT_{2^n}]$. For $k,i > 1$, $[MSH_{2^n}^{k,i}]$ is formed from the rows of ranks $2^{k-1} + i 2^{k-2} \leq r < 3 \times 2^{k-2} + i 2^{k-2}$. The matrices $[MSWH_{2^n}^{k,i}]$ are similarly defined. The submatrices for the order 8 are shown in Fig. 1. It can be shown, following the proof given in [6], that :

$$[MSWH_{2^n}^{k,i}] = [S_{2^{k-2}}]^{i-1} [WHT_{2^{k-2}}] [MSH_{2^n}^{k,i}] \quad (1)$$

where $[S_m] = \begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix}$ and $[WHT_{2^n}]$ is the ordered WH matrix or order 2^n .

As for the H and WH transforms, these relations imply "zonal" relations between the components of the representation of a vector by the SH and SWH transforms and in particular an identical energy partition according to these zones.

Fast algorithm : The framework developed in [4] gives the fast algorithm presented in Fig. III.8a for the order 8. Note that the step-by-step normalizations in the rotations by the matrix $[F_2(\theta_n)]$ can be delayed so that the rows 1 and 2^{n-1} are in fact rotated

by the matrix
$$\begin{bmatrix} 1 & 2^{n-1} \\ 2^{n-1} - \frac{(2^{2n-2}-1)}{3} & \end{bmatrix}$$
 which requires only 2 shifts,

2 additions, and 1 multiplication. This algorithm can be reorganized as shown in Fig. III.8b to give the ordered transform.

The relations (1) also yield a decomposition of the SWHT algorithm into a SHT and WH transforms of lower orders.

Computational complexity: The required number of each elementary operation can be computed with general formulas [4] and the previous definition of the SHT. We find that the computation of the SHT of a vector of order 2^n requires $2^{n+2}-6$ additions, $2^{n-2}-1$ multiplications, 2^{n-2} shifts and $3 \cdot 2^{n-2}$ normalizations² at the last stage of computation.

By another algorithm, the SHT of order 4 which is also the SWHT of the same order can be performed with 8 additions and 2 multiplications [3], compared with 10 additions and 2 shifts as given by the above formulas. This order 4 algorithm can be introduced in the recursive definition to trade 2^{n-1} additions and 2^{n-1} shifts for 2^{n-1} multiplications in the above results.

The SHT has the same number of multiplications and shifts than the SWHT but has $(n-3)2^n + 4$ fewer additions and 1 more normalization; therefore the SHT is faster than the SWHT.

Other Slant transforms: The two slant transforms considered in this letter are only two members of a large family of slant transforms; this family has been studied in some detail in [7].

Conclusions : We have defined the Slant Haar transform and presented some properties of this transform mainly compared to the slant W-H transform which has been successfully considered for image encoding. The SHT is faster and preserves some local properties of the signal and we believe it should be preferred over the SWHT.

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$$[\text{SHT}_8] = \frac{1}{\sqrt{8}} \begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 7 & 5 & 3 & 1 & -1 & -3 & -5 & -7 \times 1/\sqrt{21} \\ 3 & 1 & -1 & -3 & -3 & -1 & 1 & 1 \times 1/\sqrt{5} \\ 7 & -1 & -9 & -17 & 17 & 9 & 1 & -7 \times 1/\sqrt{105} \\ 1 & -1 & -1 & 1 & 0 & 0 & 0 & 0 \times \sqrt{2} \\ 0 & 0 & 0 & 0 & 1 & -1 & -1 & 1 \times \sqrt{2} \\ 1 & -3 & 3 & -1 & 0 & 0 & 0 & 0 \times \sqrt{2/5} \\ 0 & 0 & 0 & 0 & 1 & -3 & 3 & -1 \times \sqrt{2/5} \end{bmatrix} \begin{matrix} [\text{MSH}_8^{0,0}] \\ [\text{MSH}_8^{0,1}] \\ [\text{MSH}_8^{1,0}] \\ [\text{MSH}_8^{1,1}] \\ \left. \begin{matrix} [\text{MSH}_8^{2,0}] \\ [\text{MSH}_8^{2,1}] \end{matrix} \right\} \end{matrix}$$

a - Slant Haar transform

$$[\text{SWHT}_8] = \frac{1}{\sqrt{8}} \begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 7 & 5 & 3 & 1 & -1 & -3 & -5 & -7 \times 1/\sqrt{21} \\ 3 & 1 & -1 & -3 & -3 & -1 & 1 & 3 \times 1/\sqrt{5} \\ 7 & -1 & -9 & -17 & 17 & 9 & 1 & -7 \times 1/\sqrt{105} \\ 1 & -1 & -1 & 1 & 1 & -1 & -1 & 1 \\ 1 & -1 & -1 & 1 & -1 & 1 & 1 & -1 \\ 1 & -3 & 3 & -1 & -1 & 3 & -3 & 1 \times 1/\sqrt{5} \\ 1 & -3 & 3 & -1 & 1 & -3 & 3 & -1 \times 1/\sqrt{5} \end{bmatrix} \begin{matrix} [\text{MSWH}_8^{0,0}] \\ [\text{MSWH}_8^{0,1}] \\ [\text{MSWH}_8^{1,0}] \\ [\text{MSWH}_8^{1,1}] \\ \left. \begin{matrix} [\text{MSWH}_8^{2,0}] \\ [\text{MSWH}_8^{2,1}] \end{matrix} \right\} \end{matrix}$$

b - Slant Walsh-Hadamard transform

Fig. III.7 Ordered Slant transforms of order 8

Footnotes :

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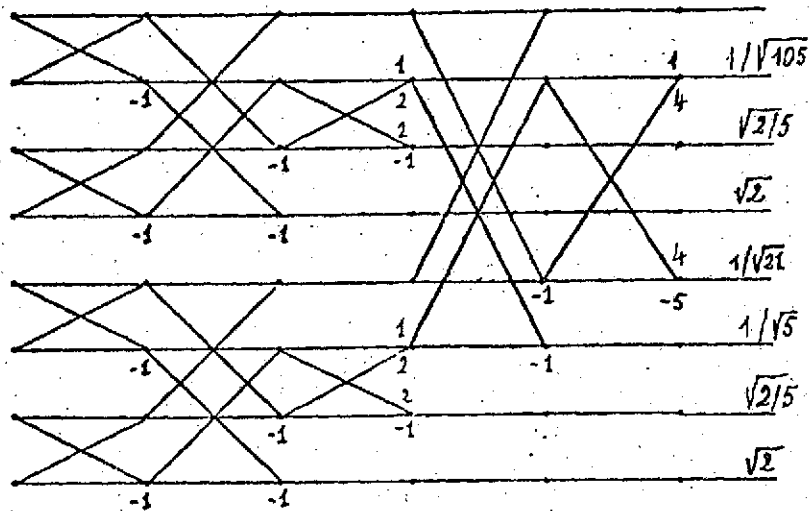
¹Note that the number of operations given in [3] seems in error and that fewer operations may in fact be needed in a different organization [4].

²We assume that the transform coefficients are scaled to the most commonly encountered normalization factor ; thus, the transform is unitary within a scale factor.

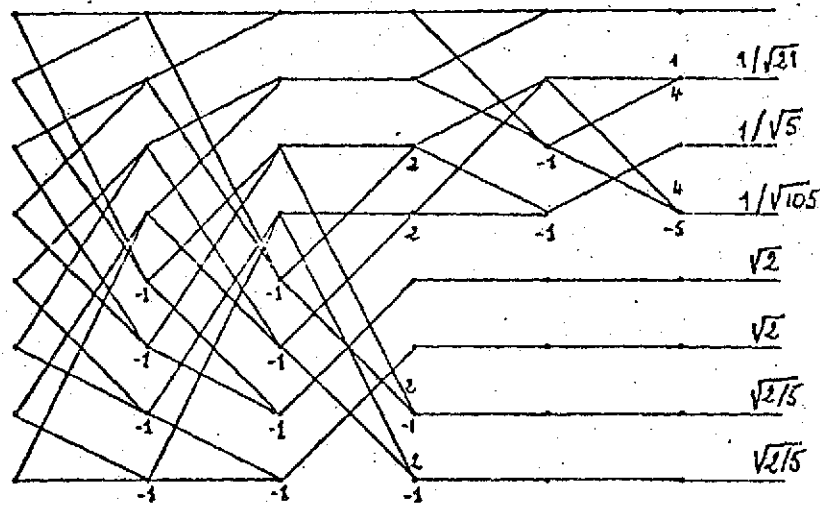
Captions:

Fig. III.7: Ordered slant transforms of order 8
a) Slant Haar transform
b) Slant Walsh-Hadamard transform

Fig. III.8: Fast algorithm for the Slant Haar transform of order 8
a) Unordered rows
b) Ordered rows.



a) algorithm (natural order)



b) algorithm (ordered rows)

Fig. III.8. Fast algorithm for the Slant Haar transform of order 8.

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Chapter 3

WATER DEMAND STUDIES IN CENTRAL CALIFORNIA

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I. INTRODUCTION

A. Location, Scope and Objectives:

Major research activities of the GRSU during this reporting period include: A) continued assessment of critical inputs for water demand models (paralleling similar studies conducted by the Riverside group); B) development and analysis of remote sensing techniques for meeting and generating such inputs; C) comparisons between conventional methods and remote sensing techniques; D) analysis of the economic impact resulting from changes in water demand information; and, E) determination of cost of information gathering utilizing conventional techniques.

Activity related to the generation of input to these areas of investigation 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 Kern County Water Agency (KCWA) Hydrologic Model currently being used within the GRSU Test Site; 3) Understanding the construction of that model and of those remote sensing inputs to it with special emphasis on agricultural land use inventories, crop surveys, and regions which contain perched water tables and associated soil salinity problems.

B. Investigation Tasks:

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 determination of the inputs.

C. Work Plan:

Figure 3.1 shows the test areas for the water demand studies.

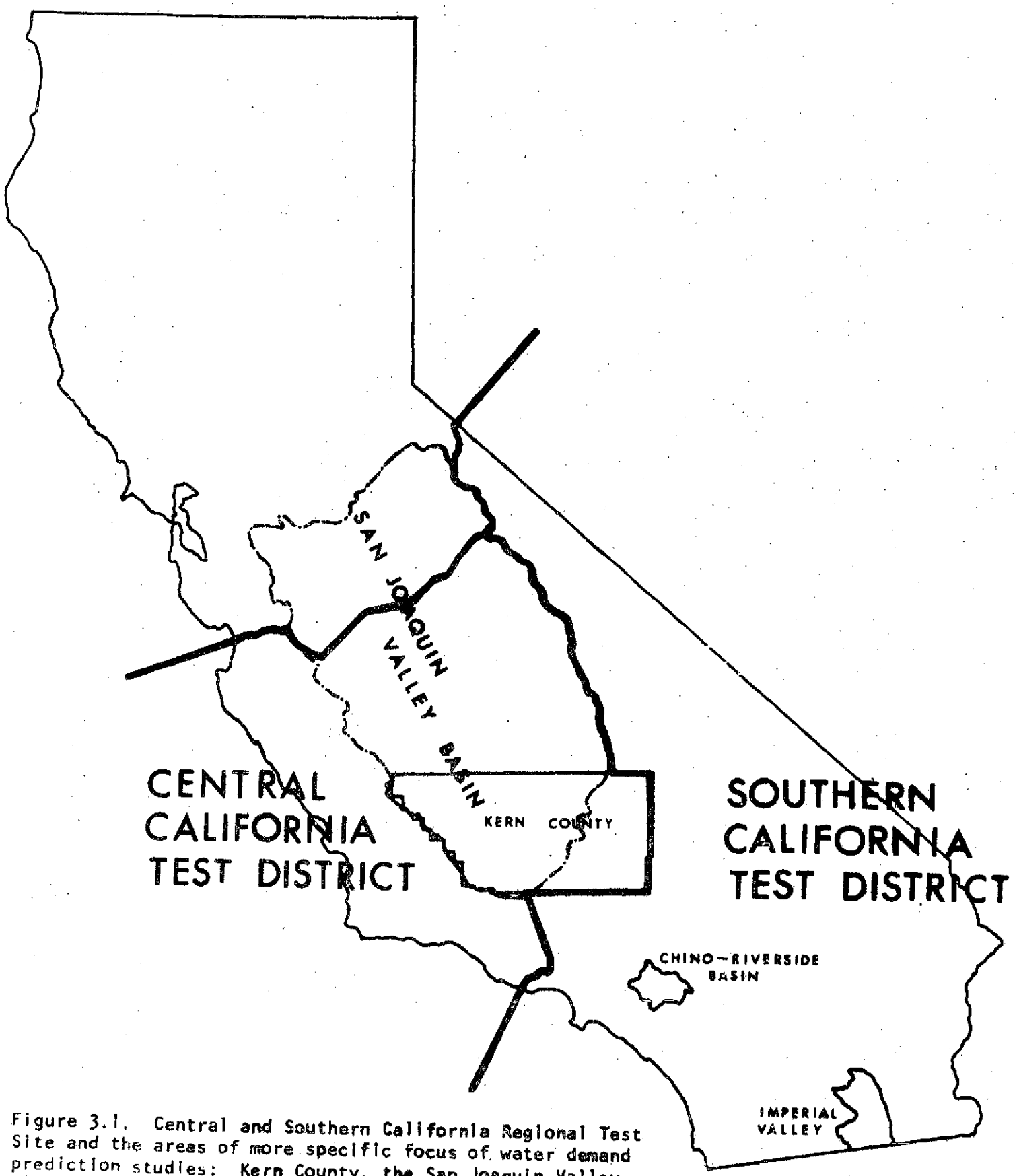


Figure 3.1. Central and Southern California Regional Test Site and the areas of more specific focus of water demand prediction studies: Kern County, the San Joaquin Valley Basin, the Chino-Riverside Basin and the Imperial Valley.

Chronological Plan for the Performance of Water Demand Studies

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

Figure 3.2
CHRONOLOGICAL PLAN FOR THE PERFORMANCE OF WATER DEMAND STUDIES

Figure 3.2 provides a listing of these tasks along with the investigators who are involved in performing them.

Referring to Figure 3.2 it can be seen that during the current funding year the bulk of the effort has been in the area of defining information requirements.

During the next funding year it is planned that the study will continue to progress along the lines indicated in Figures 3.1 and 3.2. Specifically, it is planned that the work will be concerned with the applying of various remote sensing techniques in a manner that will facilitate the gathering of information of the types needed in water demand models in Central California, as defined during the current year.

II. 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 those 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 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. In addition to these contacts, agencies concerned with water-related parameters, or having an expertise in crops, soil, hydrology modeling, etc., were also contacted on an "as-needed" basis. These contacts were made primarily to aid in the interpretation and definition of environmental parameters important in terms of hydrologic modeling. Notable among these ancillary agency contacts were: The United States Department of Agriculture-Soil Conservation Service (USDA-SCS) at Davis (for soils); The University of California Agricultural Extension Service (UC-AES) at Bakersfield (for soil 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).

III. THE KCWA HYDROLOGY MODEL

The computer model of Kern County 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 accounting model". As Kern County is mainly a "water-deficit" environment, that is, its arid climate and widespread agriculture require extensive importation of water, it is appropriate to examine all model inputs for possible remote sensing applications.

Within the model, water demand is reflected in the amounts of water applied or consumed by the various users throughout the county -- such as municipalities, industrial users, agriculturalists, etc. With respect to demand, the model can be categorized as being "static" in that some important and dynamic variables such as changes in the amount and condition of irrigable lands, water pricing, agricultural technology, and markets are not incorporated. Consequently the deduced demand is valid only for the values of these variables that exist during a given study period, while trends are ignored. 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 will be computed and compared with actual conditions. Ultimately, it is anticipated that some of the variables mentioned above will be incorporated into the model, thereby allowing longer term projections to be made. The addition of these and other factors will add the required dynamic dimension to predictions of water demand. Other anticipated uses of the model include water quality studies, and determination of proper taxation schedules through the delineation of zones of equal benefits.

IV. CONSTRUCTION OF THE KCWA MODEL

Construction of the model utilized by 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 with greater homogeneity assumed, i.e., generalizations made.

Within the context of the model the subdivisions that have been made and the assumptions related to them include: 1) subdivision of the surface areas of Kern County into 251 polygons or nodal areas (see Figure 3.3), most of which represent one quarter of a township or approximately 24 square kilometers; 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 of "flow paths" connecting the nodes. The insert in Figure 3.3 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. Data, then, are collected and generalized 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.

V. MODEL ANALYSIS

Before remote sensing techniques could be used to generate meaningful inputs to this water demand model, it was necessary to determine

exactly what types of input were likely to be useful. Based upon an analysis of the KCWA model, listings of all external quantities that serve as inputs to the model were compiled (see Table 3.1) and analyzed with the aid of KCWA personnel and the following steps were taken: 1) all data inputs were precisely defined; 2) related data inputs were grouped and categorized; 3) present sources of input data were identified; and, 4) preliminary determinations were made as to which inputs could be generated more efficiently utilizing remote sensing technology.

To date our research indicates that, in many cases, remote sensing techniques may be the key to providing more accurate, timely and economical information. In our study of the nature and importance of the various model input parameters a number of the more promising applications of remote sensing technology have been examined. Several of these applications, discussed below, have recently been studied in an attempt to interface them with both KCWA and DWR informational needs. These include: 1) an inventory of all Kern County agricultural lands; 2) an analysis and determination of crop types grown within the study area; and 3) a study of perched water tables and their associated areas of excessive salinity.

As previously stated, the San Joaquin Valley portion of Kern County contains an overwhelming proportion of the County's total agricultural activity. This region, like most of the county, lies in an extremely arid zone -- averaging only 8 to 13 centimeters (3 to 5 inches) of precipitation yearly. To sustain the 3,200 square kilometers (1.236 square miles) of irrigated cropland present, replenish the receding groundwater level and reduce its salinity, an increasing reliance is being placed upon the importation of water from the state's water regions. Currently, approximately 111,060 hectare-meters (900,000 acre-feet) of water per year is imported, while future contractual agreements call for 197,440 hectare-meters (2.42 acre-feet) for irrigation, and little precipitation available, one can appreciate the importance that must be placed upon determining irrigated acreages as input to the hydrologic model. As stated by 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..."

Past sources used by KCWA for estimating irrigated acreages have included:

California Department of Water Resources Surveys

Method: Low altitude oblique photography surveys with ground checking, undertaken once every 5 years.

Cost : \$10-12,000 for irrigated vs. non-irrigated information, \$34,000 for general land use and crop type (seven categories) information.

California Department of Agriculture's Yearly Crop Reports

Method: Grower contacts, etc., and limited conventional field surveys, undertaken yearly.

Cost : \$20-25,000 for crop type and yield-value information.

Individual Water District (15 in KCWA) Updates

Method: Conventional field surveys, sporadically undertaken

Cost : \$1-3,000 for crop or crop group information (various district sizes)

These surveys are at once both expensive and time consuming. For example, the \$20,000 Yearly California Department of Agriculture Crop Reports are commonly not available until May of the following year.

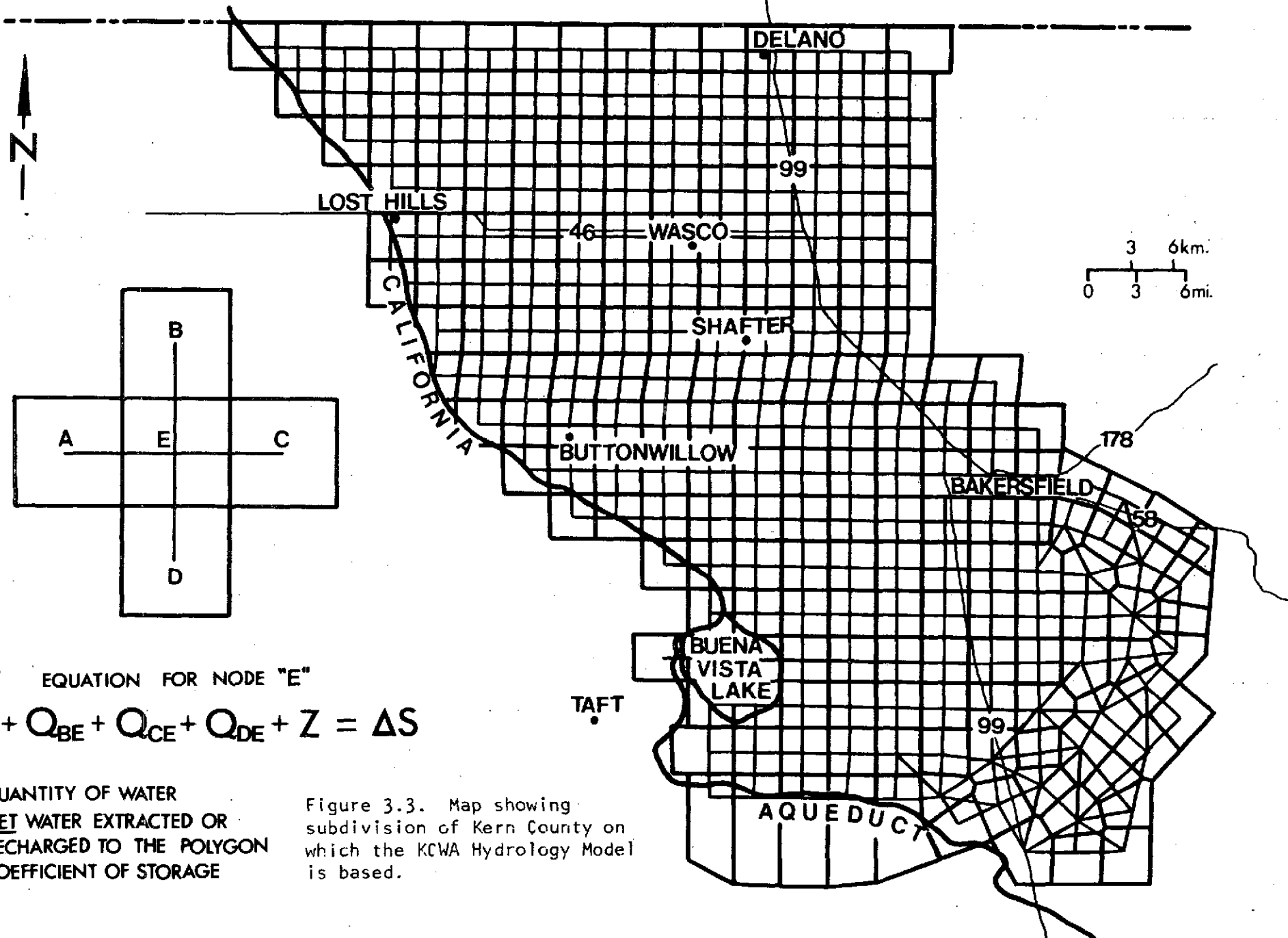
GRSU is currently examining the potential of NASA high-flight photography and Earth Resources Technology Satellite (ERTS-1) imagery to provide both acreage data and crop type information as input into KCWA's hydrologic model. ERTS-1 imagery of Kern County has been available to GRSU personnel since July, 1972, at 18-day intervals in four spectral bands (green, red, near infrared, and far infrared). It has already been established that even at normal contact scales of 1:1,000,000 accurate estimates of irrigated acreage can be accomplished with significant savings both in terms of time and actual dollar costs. The principal objective of this portion of our study was to determine the utility of small scale high-flight and satellite imagery for mapping agricultural cropland in Kern County. As can be inferred from the preceding paragraphs, an up-to-date determination of the total area in hectares of 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 by our GRSU personnel using National Aeronautics and Space Administration (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 fallow or bare soil condition. Non-agricultural land included forests and woodland urban areas, as well as extractive industries and poorly drained, saline land. Interpretation was performed visually with the aid of an 8 times (8X) magnifier. In those instances where doubt occurred, interpretations were checked using NASA, 1971, 1:120,000 high-flight color infrared photography.

The map produced, on an acetate overlay using this methodology, was then enlarged to a scale of 1:112,000 using a map-o-graph so that the resultant scale would coincide with Kern County Water Agencies' County Nodal area map (this scale has subsequently been adhered to for all completed agricultural/non-agricultural maps of Kern County, from which measurements were made). Similar maps were subsequently 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 multiband black-and-white images, size 9x9 inches, from 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. Since 1972 then, GRSU has been furnishing KCWA with ERTS-1 derived maps of the county's irrigated lands (such as Figure 3.4). Table 3.2 summarizes the acreage estimates calculated from these maps.

KERN COUNTY: NODAL POLYGON NETWORK

3-8



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

Figure 3.3. Map showing subdivision of Kern County on which the KCWA Hydrology Model is based.

TABLE 3.1. KERN COUNTY WATER AGENCY: HYDROLOGY MODEL INPUTS

<u>EXTERNAL QUANTITIES</u>	<u>DEFINITION</u>	<u>SOURCE(S)</u>	<u>REMOTE SENSING CAPABILITY (IDENTIFY-MEASURE)</u>
<u>Agriculture usage</u>			
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, crops experimentation with individual 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
<u>Municipal & industrial usage</u>			
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 usage rates	

TABLE 3.1. (Cont'd)

<u>EXTERNAL QUANTITIES</u>	<u>DEFINITION</u>	<u>SOURCE(S)</u>	<u>REMOTE SENSING CAPABILITY</u> (IDENTIFY-MEASURE)
<u>Municipal & industrial usage</u>			
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 effluent 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
<u>Recreational usage</u>			
recreational irrigated acres	irrigated areas primarily devoted 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 3.1. (Cont'd)

<u>EXTERNAL QUANTITIES</u>	<u>DEFINITION</u>	<u>SOURCE(S)</u>	<u>REMOTE SENSING CAPABILITY</u> (IDENTIFY-MEASURE)
<u>Surface & groundwater movement</u>			
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 3.1. (Cont'd)

<u>EXTERNAL QUANTITIES</u>	<u>DEFINITION</u>	<u>SOURCE(S)</u>	<u>REMOTE SENSING CAPABILITY (IDENTIFY-MEASURE)</u>
<u>Surface & groundwater movement</u>			
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	

3-12

TABLE 3.1. (Cont'd)

<u>EXTERNAL QUANTITIES</u>	<u>DEFINITION</u>	<u>SOURCE(S)</u>	<u>REMOTE SENSING CAPABILITY</u> (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)

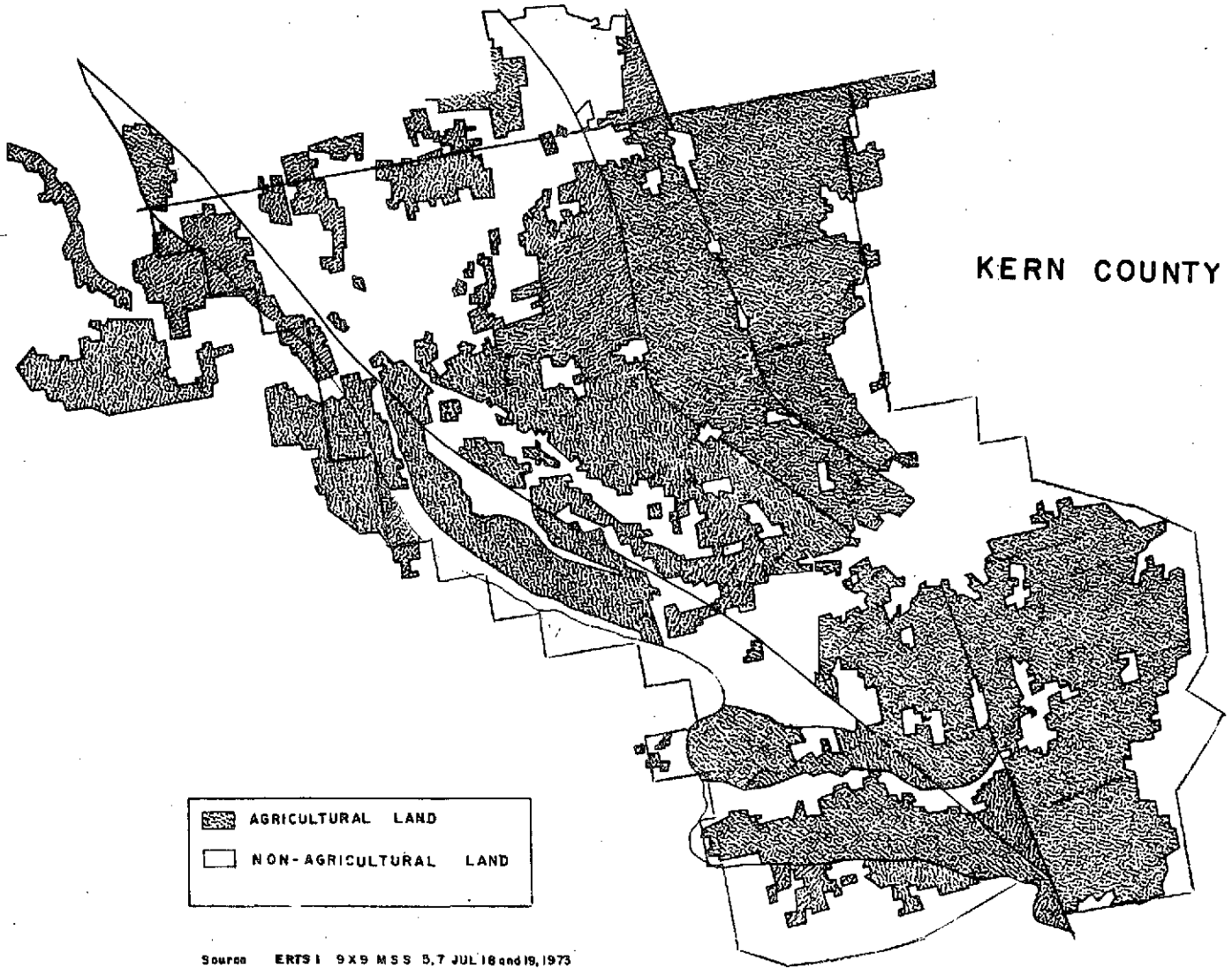


Figure 3. 4. Map of Agricultural Land for Kern County prepared from July 1973 ERTS-1 imagery. The total area of agricultural land measured off this map is currently being used by KCWA as input to the hydrologic model.

TABLE 3.2

TOTAL IRRIGATED AGRICULTURAL LAND: KERN COUNTY

IN HECTARES AND (ACRES)

1971 K.C. Crop Survey	NASA 1971 High-Flight	1972 K.C. Crop Survey	July 1972 ERTS-1	Sept. 1972 ERTS-1	Mar. 1973 ERTS-1	July 1973 ERTS-1	Nov. 1973 High-Flight
320,617 (792,254)	321,842 (795,280)	322,483 (796,865)	302,728 (748,050)	321,543 (794,541)	322,037 (795,763)	319,705 (790,000)	311,721 (770,272)

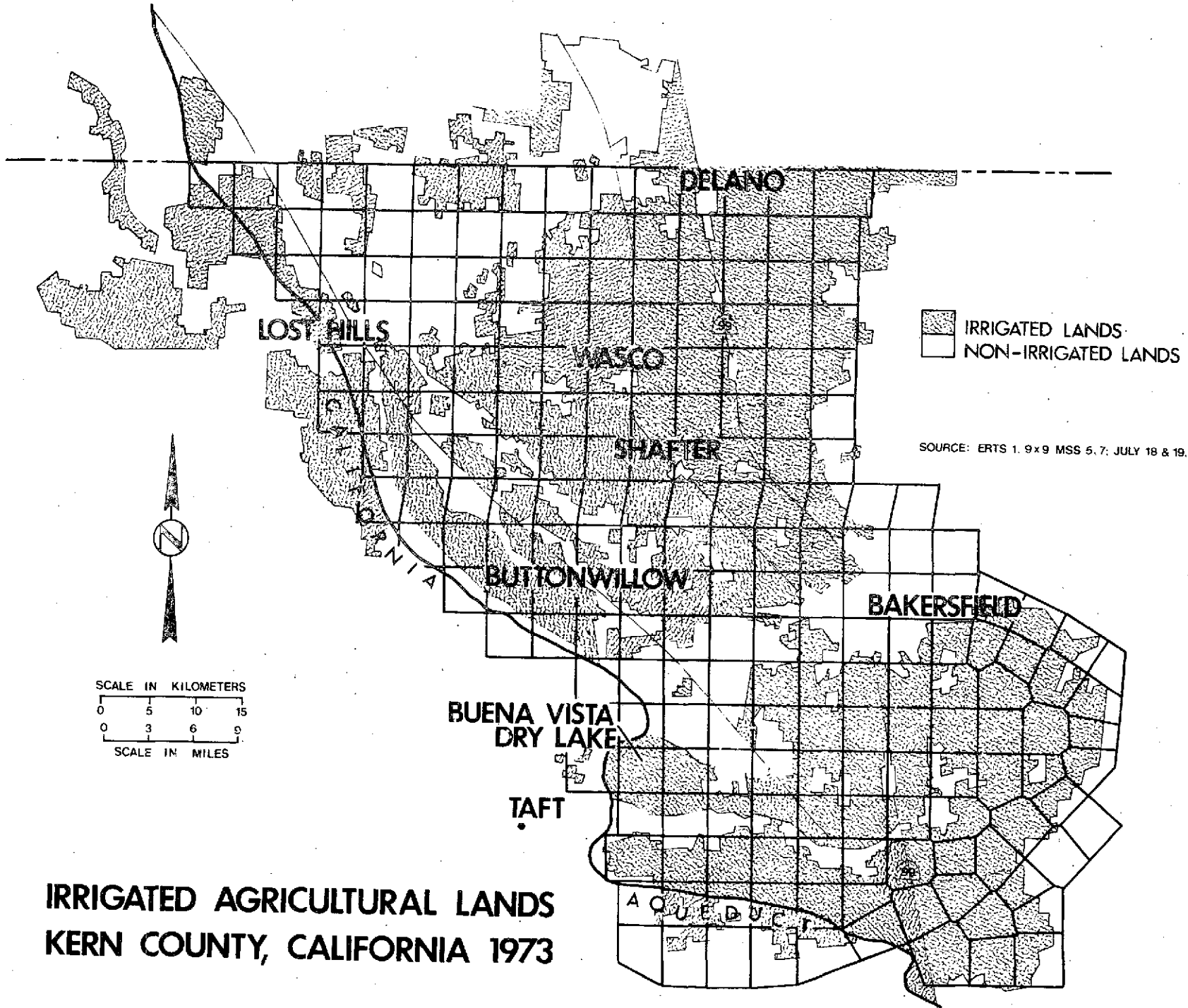
As can be seen from Table 3.2, figures obtained from the maps that were made using high-flight and satellite imagery agreed very closely with those obtained through conventional on-the-ground surveys. The low acreage estimate for July 1972 is possibly the result of several factors. Two possibilities 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. It is noteworthy that by September of 1972 GRSU produced an estimate of irrigated acreage that was within 9.3% of the 1972 Yearly Crop Report -- which was not available until May of 1973. The cost comparison between an ERTS-1 interpretation and a conventional survey of Kern County's irrigated lands is even more striking as seen in Table 3.3.

TABLE 3.3

KERN COUNTY: ERTS-1 INTERPRETATION VS. CONVENTIONAL SURVEY OF IRRIGATED LANDS

ERTS-1 Interpretation	Conventional Survey
Cost: \$200*	\$10-12,000
Time: One week	Three months

* Lower estimate of December 31, 1973 Progress Report did not include time for assuring geometric fidelity of enlarging process, an improvement sought by KCWA and presently incorporated into our procedure for generating these maps.



**IRRIGATED AGRICULTURAL LANDS
KERN COUNTY, CALIFORNIA 1973**

From this portion of our study, several observations can be made; 1) high-flight and satellite imagery has very high potential for mapping agricultural lands, accuracies ranging from 95-99% have been 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 correspondingly more 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 time and costs associated with conventional techniques. For example, as seen in Table III above, 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 require only about 15 to 20 man-hours, at a cost of little more than \$200. 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 being cultivated for the first time.

Data being generated as a result of these investigations are currently being sent to and used on an operational basis by the Kern County Water Agency, as an input to their hydrology model. As more high-flight and satellite imagery is obtained, information concerning total agricultural land for Kern County will continue to be interpreted, mapped and our estimates of accuracies and cost efficiencies refined.

Determination of Crop Type by Node for Input to KCWA Model

As previously mentioned, individual data points, termed nodes, within KCWA's model represent activities occurring in areas averaging 15 square kilometers (9 square miles) (see figure 3.1). Presently, the amount of water applied via irrigation is estimated by multiplying the irrigated acreage of each node by the county-wide average application rate of .30 hectare-meters (2.42 acre-feet). Even at the generalized level afforded by 15 square kilometers (9 square miles) nodes a large error factor is introduced by assuming that the average application rate accurately portrays the actual application rate in each node. This can be seen by examining Table 3.4, irrigation requirements of the three major crops present in Kern County and by knowing that concentrations of specific crops often occur (e.g., where the soils are most favorable for that crop), increasing the need for a nodal determination of crop type.

TABLE 3.4

IRRIGATION REQUIREMENTS FOR KERN COUNTY

<u>Crop</u>	<u>Requirements</u>	<u>Percent Total County Irrigated Acreage</u>
Barley	.17 hectare-meters (1.4 acre-feet/acre-year)	7%
Cotton	.32 hectare-meters (2.6 acre-feet/acre-year)	24%
Alfalfa	.49 hectare-meters (4.0 acre-feet/acre-year)	17%

The need is obvious. To develop a methodology for generating statistics as to the location and areal extent of various crops (or for groups of crops with equal irrigation requirements). The cost of conventional surveys for furnishing this type of data generally precludes their undertaking. However, techniques amenable for use with ERTS-1 imagery have offered and proved a potential for detecting those changes apparent as a field goes through the planting-growing-harvesting cycle (see Table 3.5). This cycle is often unique for individual crops and/or major types of crops, thereby allowing comparison of unique groupings of data with either a crop calendar (such as Table 3.5) or empirically derived information (i.e., ground truth). Such a temporal classification procedure may be further aided by the spectral response of a crop being unique for any one or combination of the four bands available from ERTS-1 as indicated by Figure 3.3. This spectral differentiation may permit correct classifications to be determined even between crops that share similar life cycles and might otherwise be indiscernible from one another.

Although the validity of temporal and spectral analyses have both been proven for crop identification from ERTS-1 imagery, their extension to an operational procedure for a county-wide area as large as Kern County (approximately 1:1,000,000) and the unsuitability of most sampling procedures for satisfying KCWA's informational requirements (that data be gathered by nodes). The 15 square kilometer (9 square miles) size of the model's nodes necessitates abandoning most sampling techniques in favor of a "total inventory" approach, i.e., observation of each and every field. At ERTS-1 scale, though, it is a difficult task to keep track of individual fields, for some are extremely small and when similar conditions exist in neighboring fields they often appear as one. One method by many researchers has been to enlarge the image to a more operable scale. However, any photographic process will entail the loss of a large amount of the information visible on the original image.

TABLE 3.5

CROP CALENDAR DATA FOR
PRINCIPAL CROPS (BY AREA) OF KERN COUNTY

	Hectares (Acres)	Per Cent total Area	Planting Dates ... Growing Period +++ Harvesting Dates ---												
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Cotton	99,150 (245,000)	28			+++	+++	+++	+++	+++	+++	---	---	---
Alfalfa	52,610 (130,000)	15													
Fall			+++	+++	+++	---	---	---	---	---	---	---	---
Early Spring			+++	+++	---	---	---	---	---	---	---
Grapes	24,818	7													
Raisin															
Wine															
Table															
Barley	23,068 (57,000)	7	+++	+++	+++	+++	+++	---	---	---	---	---	---+
Potatoes	13,753 (33,984)	4													
Fall			---	---	---	---	---	---	---	---	..+	+++	+++	+++	---
Early Spring			..+	+++	+++	---	---	---	---	---	---	---	---	---	---
Total	213,396 (527,301)	61													

TONAL RANGES

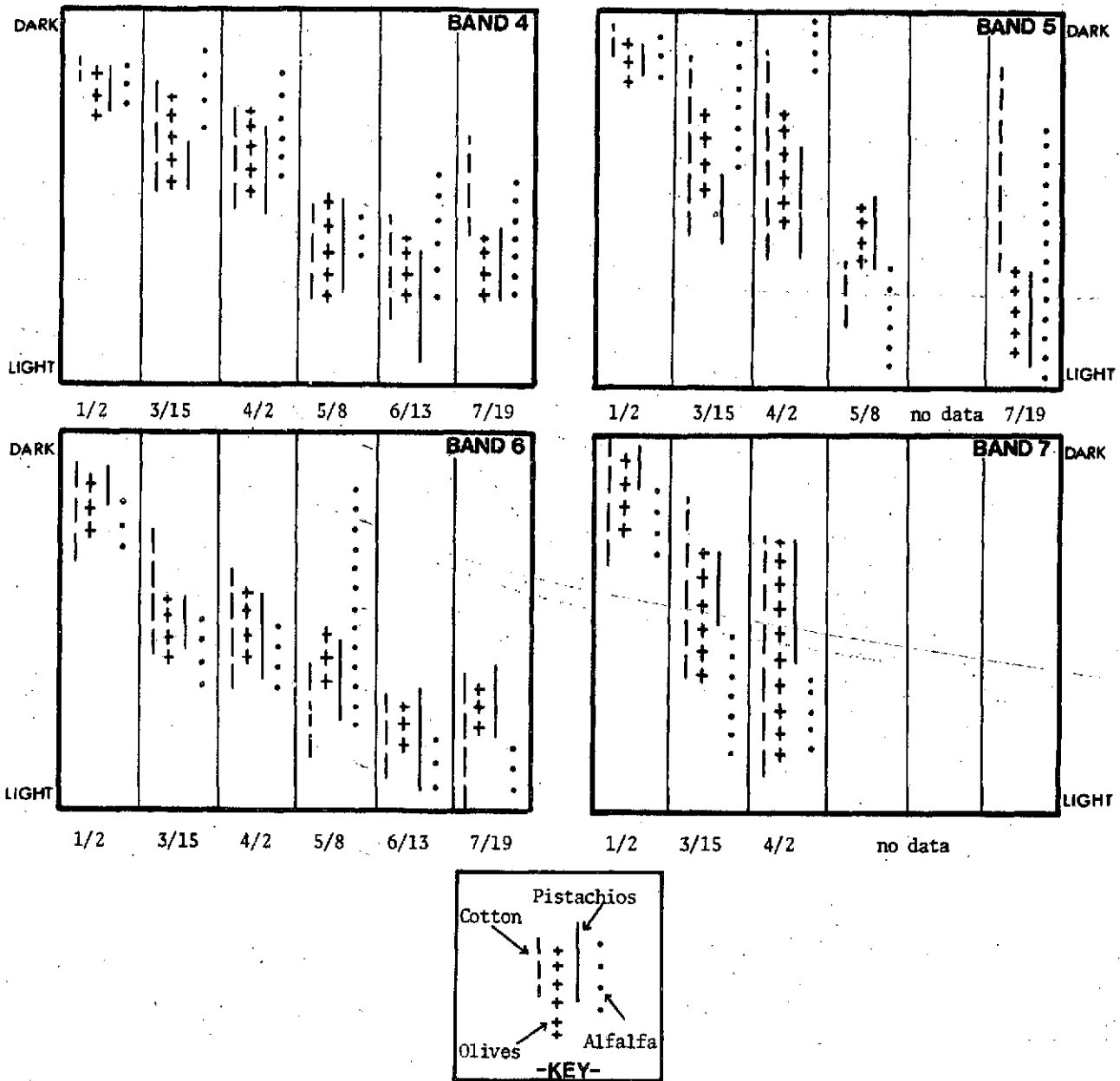


Figure 3.5
TONAL RANGES.

Using 1973 ERTS-1 imagery nodes 1 and 2, covering 15 square kilometers, have been examined using GRSU equipment and techniques. The tonal ranges above are for the four major crops present: olives - 31% of the area, cotton - 27%, pistachios - 17%, and alfalfa - 7%. All values have been normalized to an arbitrary "standard" ERTS greyscale, hence no units are shown.

The GRSU is currently investigating techniques for operating at the original image scale of 1:1,000,000 under 60X optical magnification. The task of identifying individual fields will be accomplished by producing a field boundary map depicting all of the county's fields and then reducing it to the exact scale of ERTS-1 imagery. Preliminary studies indicate the feasibility of this technique. The following diagram (figure 3.6) outlines the procedure used while figure 3.7 is an example of a field boundary map before reduction to ERTS scale.

Once a field is accurately identified, its tonal value is determined for each date and band of ERTS imagery available. This is accomplished by either visually assigning a tonal value, a difficult task at best, or by using a light measuring device such as a densitometer. GRSU is currently employing a densitometer that has been adapted to one lens of a binocular microscope such that the operator can visually sight individual fields through one lens while the densitometer can be focused upon a much smaller area, such as one field or a part thereof, while the locating lens used by the operator will view a much larger multi-field area.

With this technique, data are currently being generated that are at once considered economical and accurate -- while still incorporating accurate "field boundary" knowledge. Once sequential and multi-spectral field condition data have been generated they can either be directly interpreted or utilized as base data for further statistical manipulations that can reduce or eliminate variations in tone that may hinder proper classifications. GRSU is presently developing such correcting algorithms. Preliminary results indicate that accuracies as good as, or better than, those achieved utilizing conventional methods may be obtained with savings of both time and costs. The availability of relatively inexpensive and timely crop type information will greatly benefit not only those concerned with hydrologic modeling but others interested in such data as well.

VI. PERCHED WATER AND SOIL SALINITY STUDIES

The final area of investigation that GRSU is presently concentrating upon concerns the detection and delineation of areas of excessive soil moisture and salinity. The mean annual precipitation for the valley and desert areas of Kern County is between 8 and 13 centimeters (3 to 5 inches). Somewhat ironic for such an arid region, the importation of water to sustain and expand croplands has brought about new problems associated with water drainage. In some areas it appears that the solution to drainage problems may well be as expensive as, if not more expensive than, the original costs involved in the importation of water.

Most of Kern County's drainage problems are related to the existence of "perched water tables" formed by the application or intrusion of water over impermeable clay layers. Unfortunately for Kern County, clay layers underlie most of the county -- especially in the agricultural regions. The problem is compounded by the arid environment, as high evaporation rates lead to above normal irrigation to replace evaporated water.

OVERLAY PROCEDURE

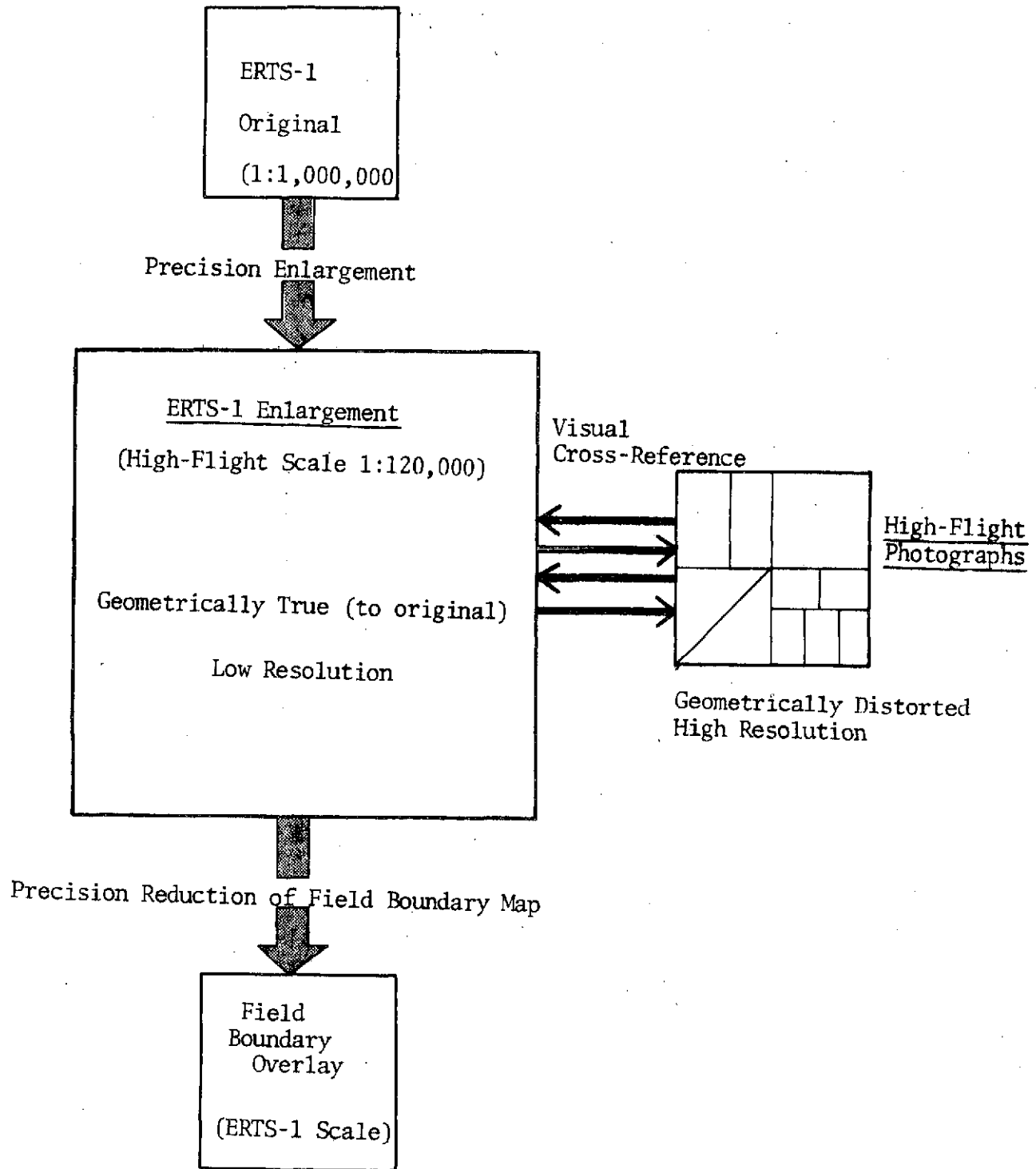


Figure 3.6
OVERLAY PROCEDURE.

Using an ERTS-1 enlargement as a geometrically true base a map of all field boundaries is made. Those boundaries not visible on the ERTS image are added by examination of high-flight photography, the same scales easing comparison. The boundary map is then reduced exactly to the ERTS image scale, thereby allowing the resulting field boundary - resembling microfilm, to be laid directly upon an ERTS image. Having the same geometry as ERTS images it instills correct field boundary knowledge aiding further analyses.

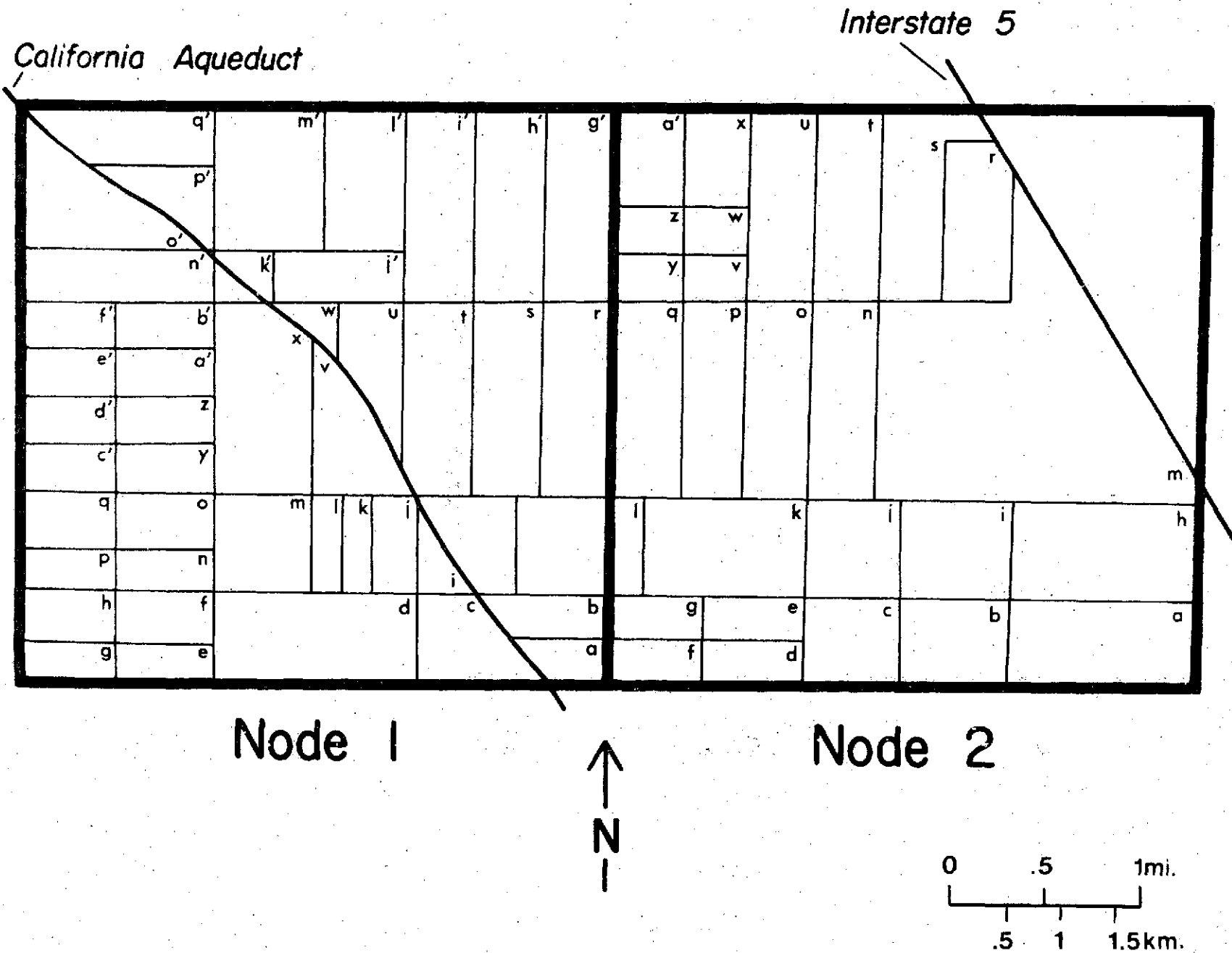


FIGURE 3.7 An enlarged portion of field boundary map for nodes 1 and 2 (15 square kilometers). Note the identification letter in the corner of each field to ease recognition.

SALT BALANCE OF GROUNDWATER BASIN

2-21

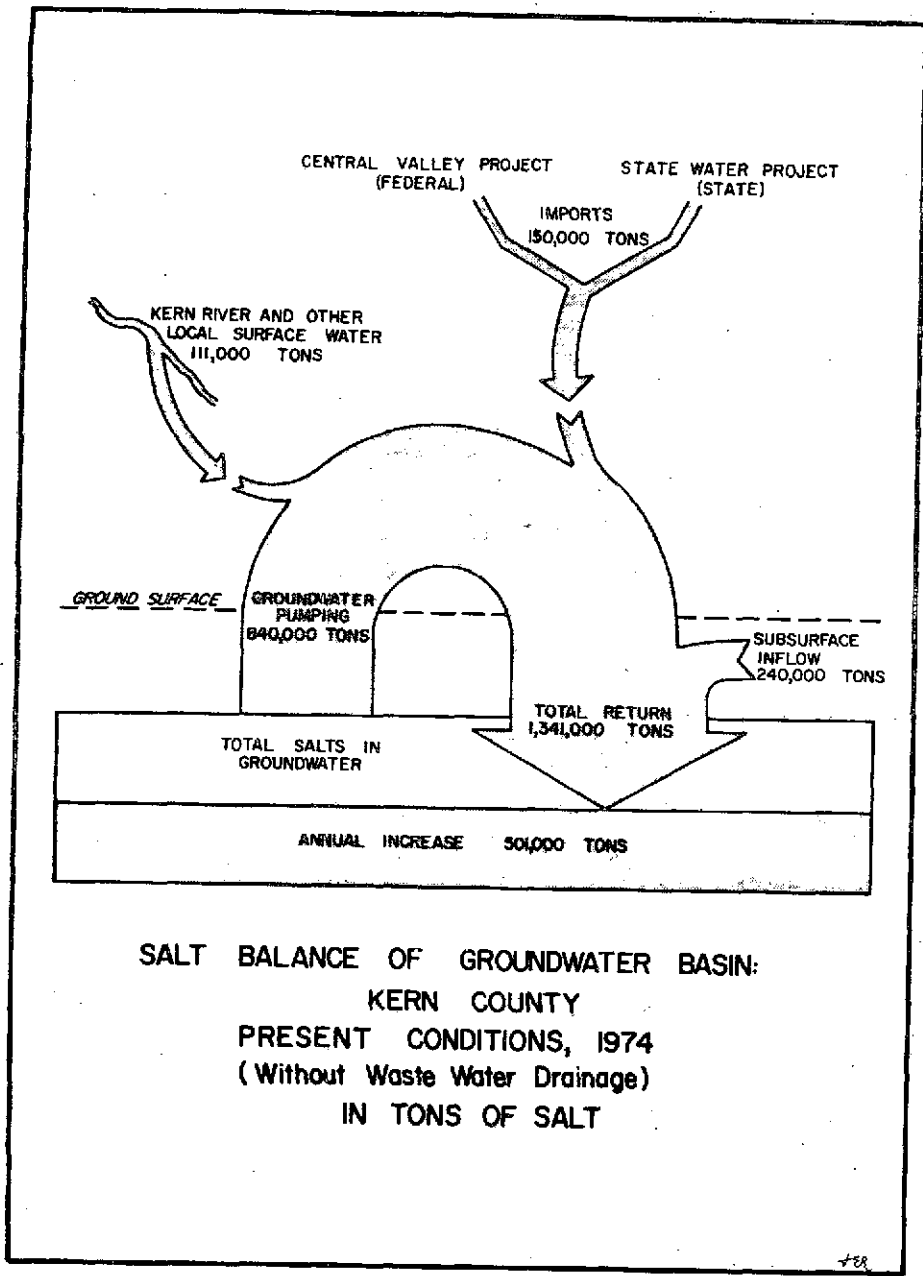


FIGURE 3.8a

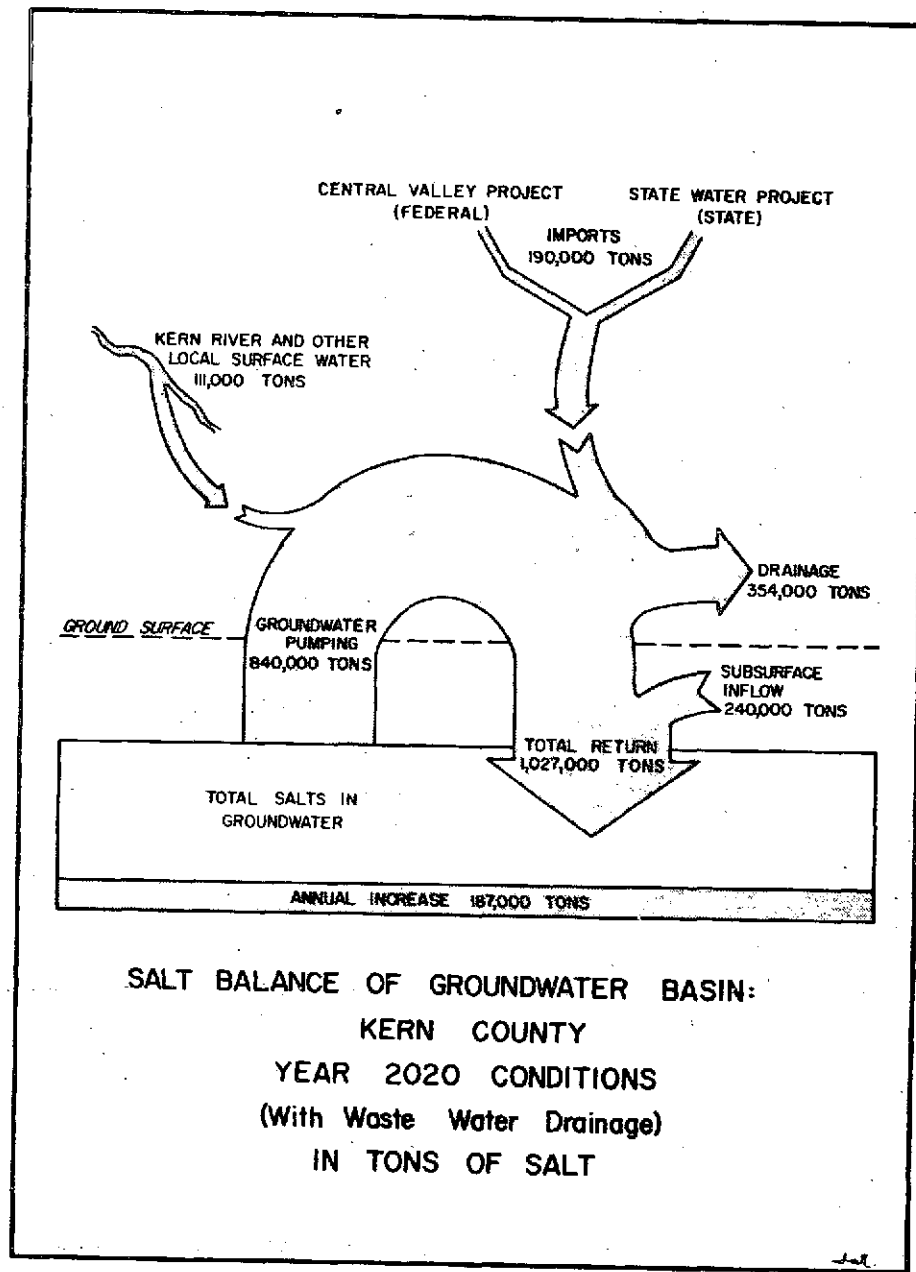


FIGURE 3.8b

An initial study of the Buena Vista Dry Lake Basin by KCWA verified the presence of approximately 230 square kilometers (57,000 acres) of agricultural land underlain by "perched water" within 3 meters (10 feet) of the surface. An additional region, of some 1,011 square kilometers (250,000 acres) between Buena Vista and Tulare Dry Lakes, has been described by the Department of Water Resources (DWR) as having "potential drainage problems". An in depth study of this area, in terms of both drain problems and soil salinity, will soon be undertaken by KCWA.

The high salinity of perched water, and associated soils, decreases both the variety and yield of crops that can be grown in a given area. In severe cases actual flooding can and does occur. With the continued importation of surface water for irrigation, it is predicted that both the areal extent and the severity of the problems associated with perched water will continue to increase, unless some drainage system is provided. Figures 3.8a and 3.8b depict the situation as it exists now with no drainage system and as it is predicted to exist in the year 2020 with a drainage system. As can readily be noted, the county is currently suffering from a major influx of salts into the ground water.

The major objective of this portion of our investigation has been to examine the operational use of high-flight and satellite imagery for the mapping and evaluation of areas with perched water tables -- as indicated by areas of high soil moisture. An associated task has been the identification and mapping of regions with highly saline deposits.

Problem areas surrounding dry lake Buena Vista (most of which are attributable to perched water tables and excessive soil salinity) have previously been field surveyed and mapped by KCWA personnel. The areas of perched water tables show a strong correlation with dark regions visible on both NASA high-flight photography and satellite imagery. Areas of saline deposits characteristically are very light in tone.

As previously mentioned, KCWA will shortly undertake an indepth study of the region between Buena Vista and Tulare Dry Lakes. In an attempt to provide input to this survey, GRSU's immediate attention has been focused upon mapping boundaries within the area from 1:120,000 scale infrared ektachrome, high-flight photography. Employing a generalized classification scheme the photography was interpreted and the information mapped onto acetate overlays. Figure 3.9a is the result of this effort and it can be seen by comparison with Figure 3.9b, produced by field surveys, that for salinity at least, reliable information is being gathered. Figure 3.10 is a SKYLAB image of a portion of the same area depicted in Figures 3.9a and 3.9b. GRSU personnel have found this type of imagery extremely useful for the interpretation and delineation of areas of high soil moisture content and salt accumulations. When the results of the KCWA field surveys become available GRSU will perform comparative analyses on salinity as well as perched water tables, as a check upon the accuracy of our previous interpretations.

Although interpretations from ERTS-1 satellite imagery will necessarily be at a more generalized level, preliminary examinations suggest that the use of sequential ERTS data will provide valuable insights into the drainage characteristics of these problem areas.

AREAS OF EXCESSIVE SOIL SALINITY

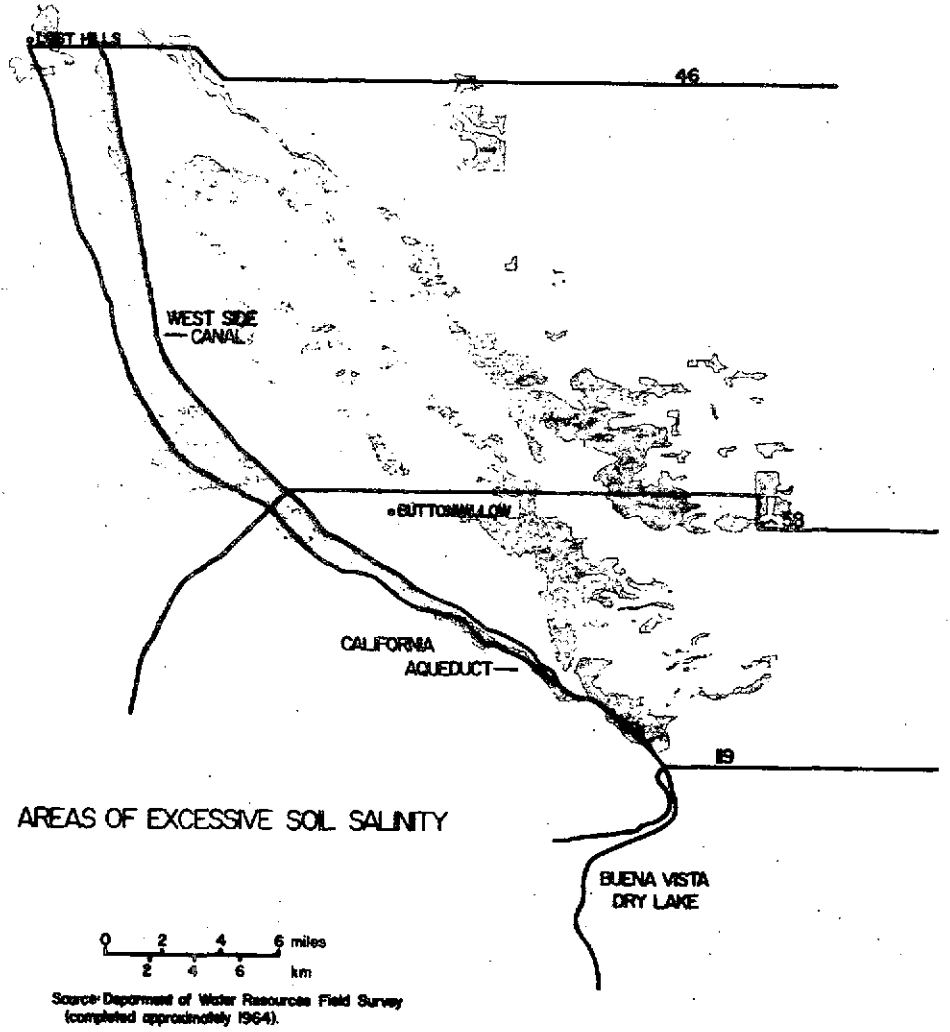
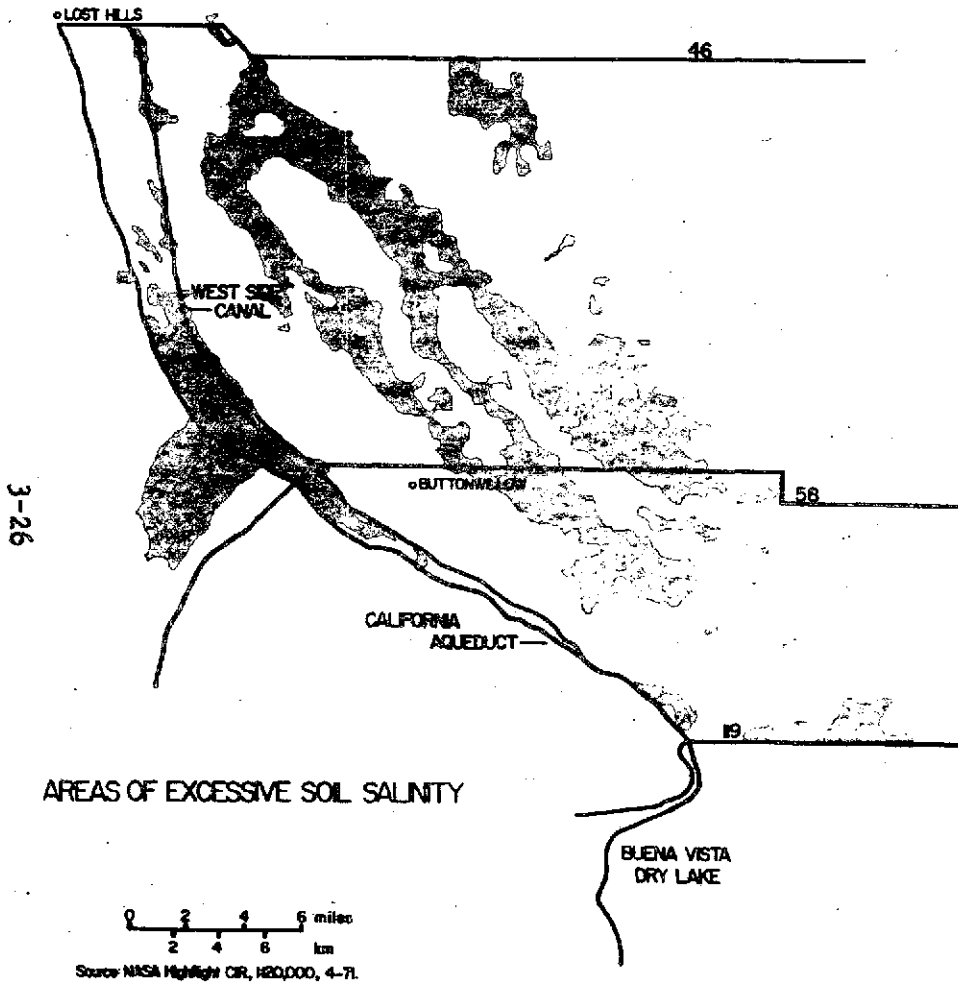


FIGURE 3.9a

FIGURE 3.9b



FIGURE 3.10 SKYLAB IMAGE. This Skylab image of June, 1973, is of the same area as figures 8A & B. Its high resolution allows the extraction of considerable information concerning the distribution and areal extent of high soil moisture and salt accumulations.

Some general observations which may be made concerning these preliminary studies conducted by GRSU are: 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 may be 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-flight scale photography; 3) 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); 4) ERTS type satellite coverage is useful as repetitive coverage facilitates the assigning of drainage characteristics to different areas; 5) within the easily detected problem areas accurate measurement by remote sensing techniques of salinity and moisture may be hampered owing to their opposing tonal values -- light for saline areas and dark for moist.

VII. FUTURE WORK TO BE PERFORMED BY THE SANTA BARBARA CAMPUS

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 integrated study.

In our case, however, as in the case of the other participants, due allowance was given by NASA to the completion of relevant projects which had been in progress prior to reorientation of the overall study. The result of this work may be seen in Appendix I to this chapter.

Assessment of Critical Parameters

As of this reporting date, GRSU has completed its intensive assessment of critical parameters of water demand models. However, as future studies dictate we will continue to evaluate our findings in this area. As future needs may dictate then, continued emphasis will be placed on defining informational requirements 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. Remembering that, 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 parameters, as well as the effect of variations within each model parameter.

Analysis of Economic Impact Resulting from Changes in Demand Information

During the coming year, 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, continued efforts will be made to ascertain the costs involved in generating similar data 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 economical 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, Berkeley, and Riverside, as well as the group economist).

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 actual experimentation with the remote sensing data (conventional photography as well as satellite imagery). Accordingly, research has been and will continue to 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 crop type and perched water tables and soil salinity), will be continued and in some instances expended in order to further improve the interpretive techniques, resultant accuracy and timeliness of these data. As previously mentioned, data on these parameters have already been given to both KCWA and DWR representatives who, in some cases, have already utilized this information in the formulation of planning decisions.

Similarly, 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, location of oil sumps, location and measurement of recreational areas (such as duck clubs) or wildlife refuges which have an effect on water distribution and/or demand, flooded areas (at opportune times), and the expansion and/or contraction and classification of urban areas and their 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. In addition, as seen in the body of this report, considerable work has already been accomplished in developing a system for identifying crop types, and it is envisioned that in the coming year 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. 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 season, which we are just beginning to receive, 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 continue to 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 have already 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; GRSU personnel will interface with the personnel of both R. Algazi's group and the Berkeley group in an attempt to automate appropriate aspects of the data extraction stage. This interaction has, to a limited extent, begun. Interaction is of particular value, at this time, in the cases of crop identification (where our colleagues at Berkeley have 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.

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 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 coming 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.

Work to Be Performed During the Coming 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 and Figure 3.2): 1) analysis of the economic impact resulting from changes in demand information; 2) evaluation and testing of remote sensing applications, to provide input data into the models under examination; 3) a comparison of remote sensing techniques tested with conventional methods of data acquisition to evaluate their relative cost efficiencies; and, 4) 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 (see chronological plan for the performance of water demand studies, Figure 3.2) much of the stepwise progress leading to its completion will have been made, as described in the following paragraphs.

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, as shown in the body of this report, in these areas already has led us to believe that valid cost/benefit information can be generated through GRSU, Riverside, RSRP, Davis, and Berkeley groups. Emphasis will be placed in these investigations on a determination of the benefits to the water management agency of better water resource data and on the potential for supplying more timely and accurate data of this type. 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.

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. Now that we have identified the critical parameters in water demand models, emphasis 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 body of this report as a guide, GRSU, in close cooperation with Riverside and Berkeley 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, crop type identification, location, perched water tables and soil salinity in the analysis of additional variables. Areas presently identified as requiring analysis, and for which work is already underway, include: determination of the extent and location of standing or ponded water areas and soil moisture surplus and/or deficit areas; 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.

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 RSRP, 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, 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 both the 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.

APPENDIX: LAND USE AND VEGETATION MAPS

The production of the maps found in this appendix was nearly completed prior to the reorientation of the work effort on this grant to Water Demand on the West Side of the San Joaquin Valley, California. In short, although the generalized maps, found in this appendix, completed in fulfillment of previous contractual 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.

Information of 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 locus of the work performed under the NASA Grant before the recent reorientation was on establishing a data base for land use and vegetation of 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 1.1 and 1.2 (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 1.1, 1.2, and 1.3 (land use); as well as in figures 1.4 through 1.10 (coastal vegetation); and figure 1.11 (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.

TABLE I.1 LAND USE CLASSIFICATION SCHEME USED
IN CONSTRUCTING KERN COUNTY MAPS

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.

	<u>CODE</u>
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 I.1 (Continued)

	<u>CODE</u>
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 I.1 (Continued)

	<u>CODE</u>
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 I.2. 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 I.1. 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.

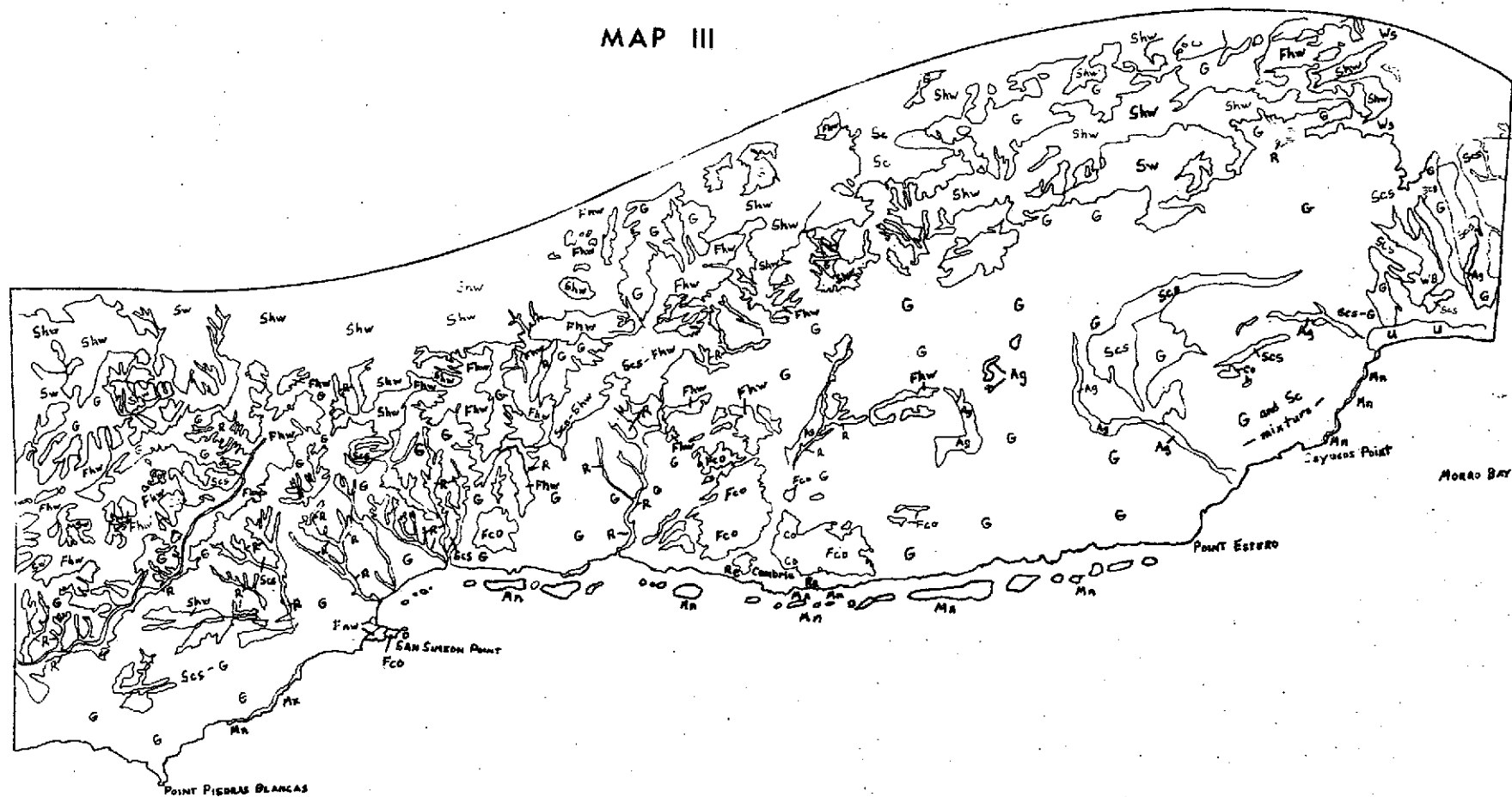


Figure I.6. Coastal Region Vegetation Data Base Map III. Constructed from April, 1971, 1:120,000 scale color infrared photography.

3-44

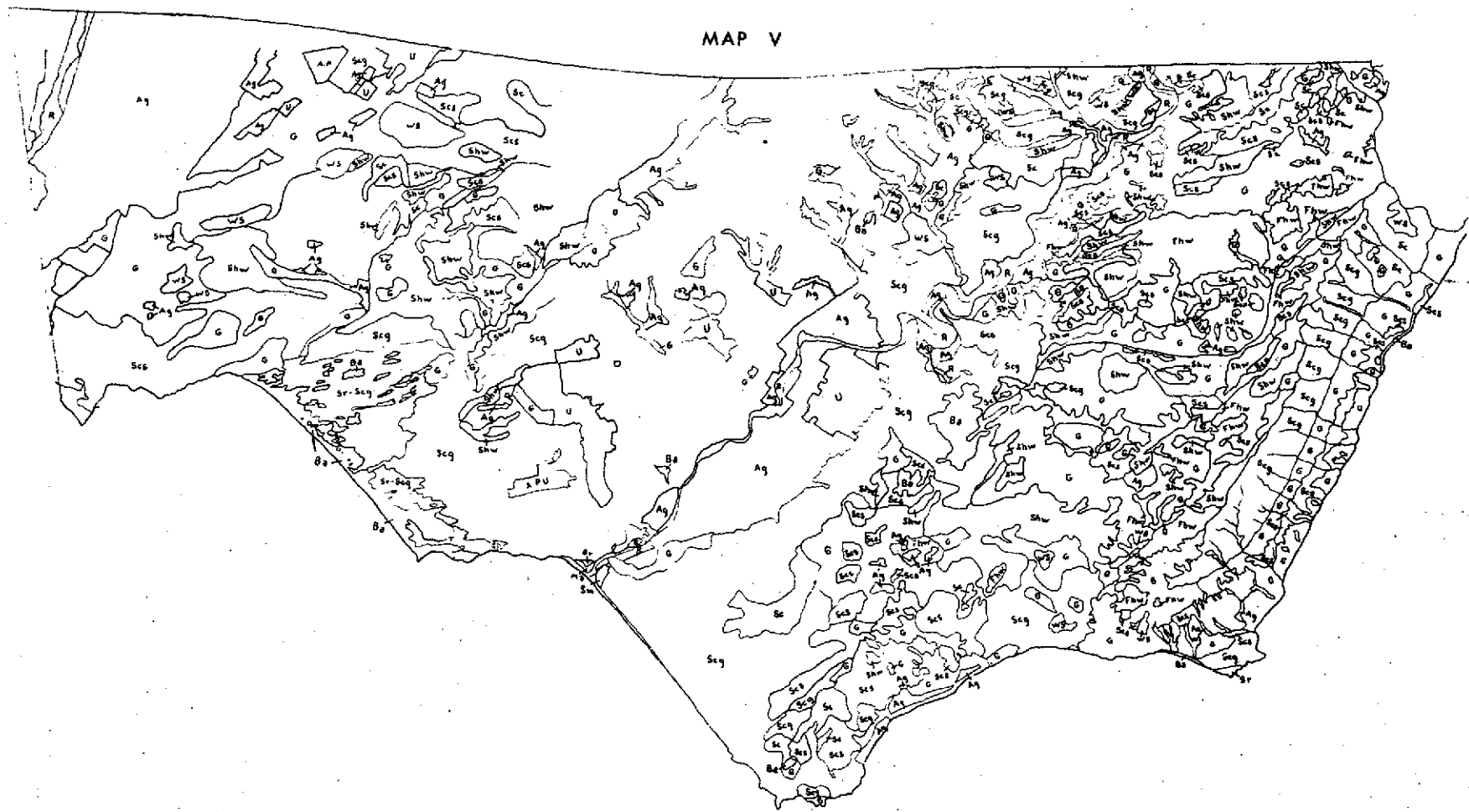


Figure I.8. Coastal Region Vegetation Data Base Map V. Constructed from April, 1971, 1:120,000 scale color infrared photography.

MAP VI



Figure I.9. Coastal Region Vegetation Data Base Map VI. Constructed from April, 1971, 1:120,000 scale color infrared photography.

MAP VII

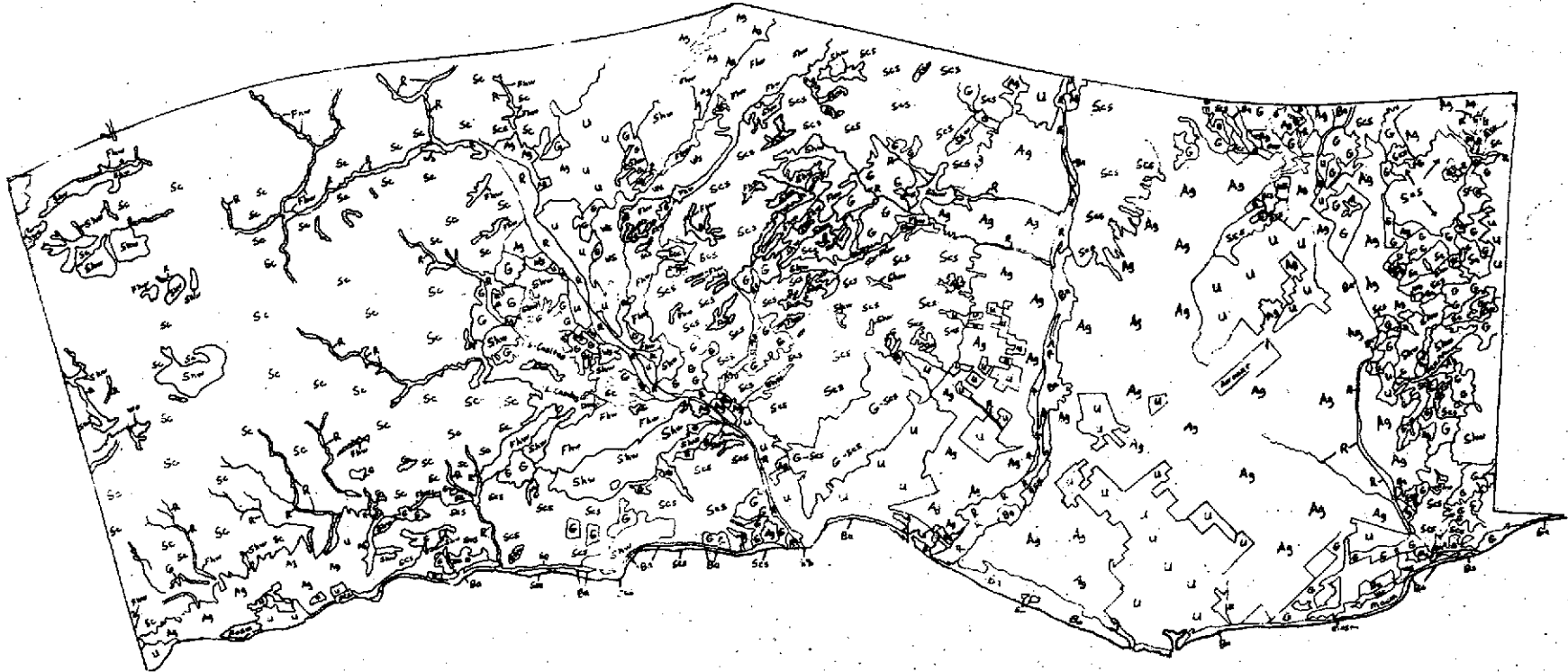


Figure I.10. Coastal Region Vegetation Data Base Map VII. Constructed from April, 1971, 1:120,000 scale color infrared photography.

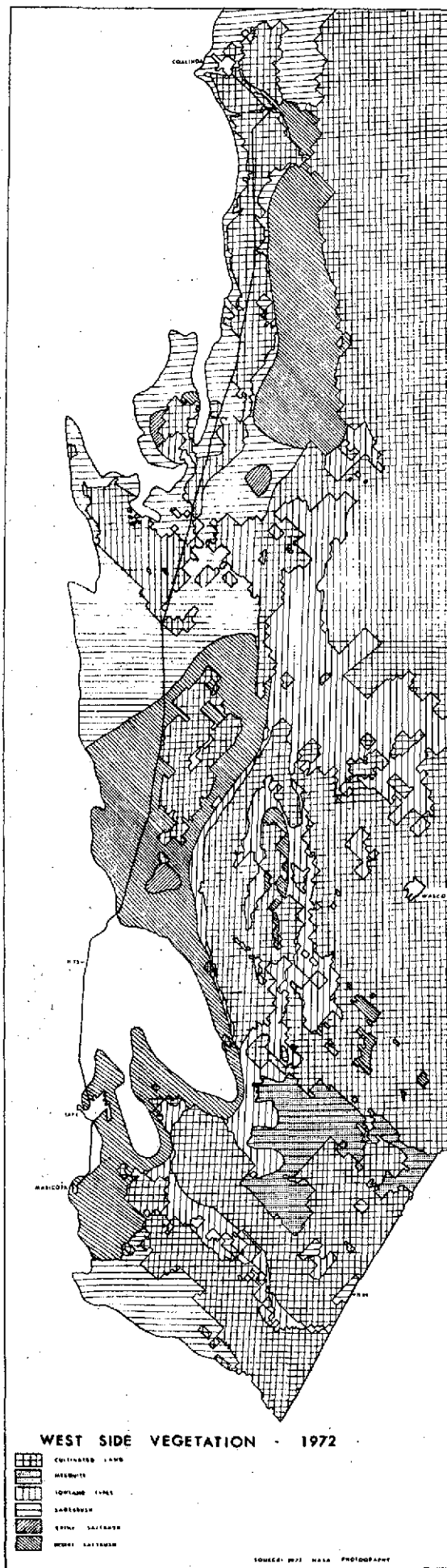


Figure 1.11.
 Map of Vegetation on
 West Side of San Joaquin
 County as of 1972.

TABLE I.2. NATURAL VEGETATION CLASSIFICATION

<u>Plant Community</u>	<u>CODE</u>
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

CHAPTER 4

WATER DEMAND STUDIES IN SOUTHERN CALIFORNIA

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J. Drake

I. INTRODUCTION

A. Location, Scope and Objectives:

The Riverside Campus has concentrated much of its study effort during the past year on the Upper Santa Ana River Basin (Figure 4.1) and 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. Accordingly, little new research has been undertaken in the Imperial Valley, California.

The most notable deficiency encountered in our investigation is the lack of current input data for water demand models presently employed by the Department of Water Resources. (It is common for 10 year old data to be 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. Although Department of Water Resources personnel realize that there are better methods, they apparently have neither the time nor the money to develop more precise techniques. An important output of our efforts will be to provide SWR with more cost-effective methods for data reduction. Research efforts to date have resulted in significant success.

During the 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. (We purposely have paralleled the efforts being made in this regard by the Santa Barbara group for the Central California Region in order to better compare models in two areas which not only are distinctly different from each other but which are also jointly the two primary water demand areas for the entire California Water Project); and (B) Developing and testing a water demand model, based upon remotely sensed data, within a controlled environment -- the Imperial Valley -- which is notably different from the environments dealt with in the Central California studies.

B. Investigation Tasks:

Most of our investigation tasks during the present reporting period

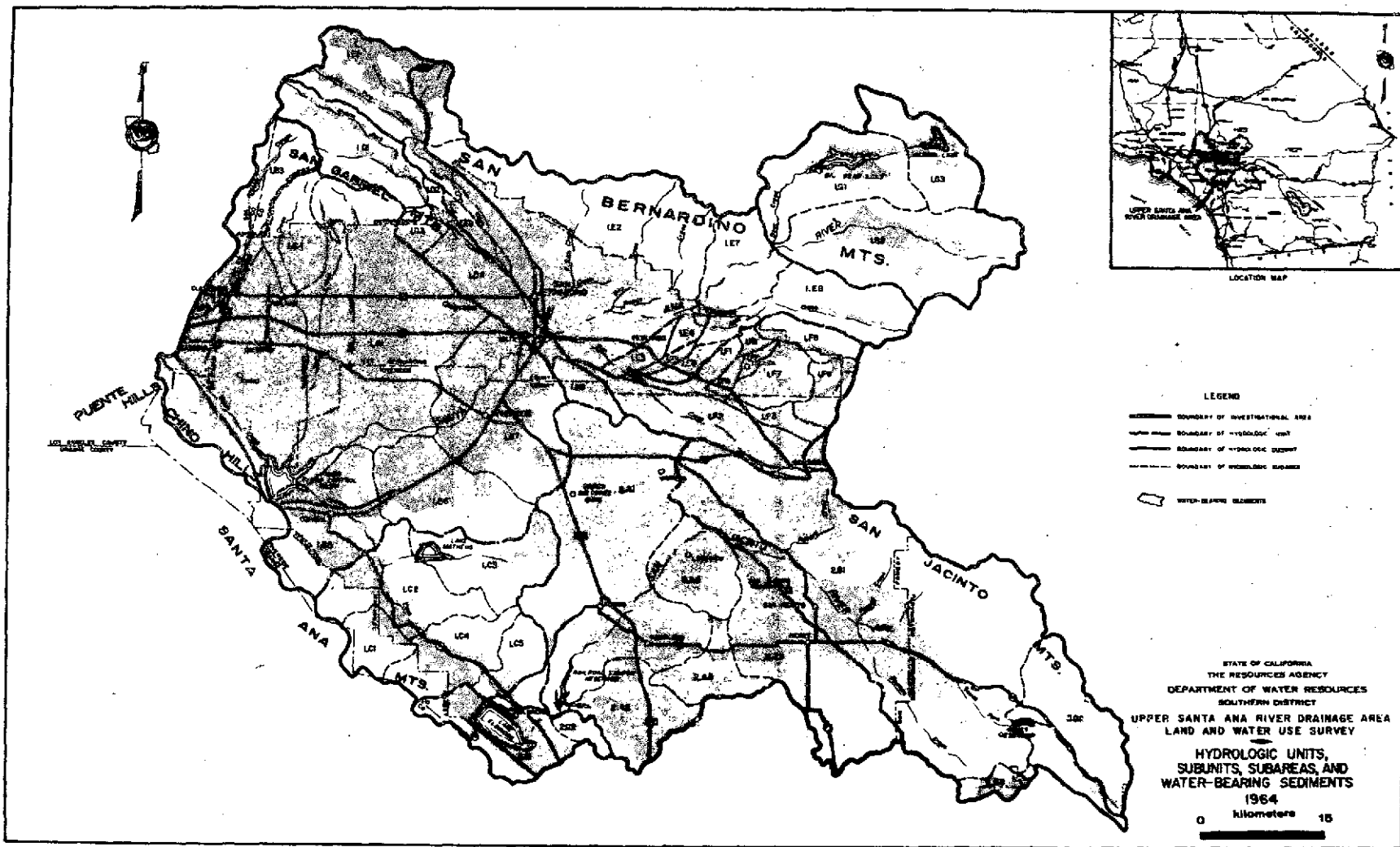


Figure 4.1 Map of Upper Santa Ana River Drainage Area employed in the Land and Water Use Survey.

have been concerned with determining the 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) climatic factors; (2) land use 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.

Climatic factors (specifically rainfall, evapo-transpiration, runoff and percolation) must 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 regard 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 model for determining corrected temperatures in mountainous terrain (for use in computing evapo-transpiration) has been developed and is summarized.

It is widely accepted 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 4.1 and 4.2). For urban areas, such a method is quite feasible, although, as a latter portion of our report shows, a considerable improvement in accuracy is possible. 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).

Updated information 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 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.

A final parameter which could potentially be the most critical is the pollution of the underground water supply by nitrates and nitrogenous wastes. Such pollution is brought about by the leaching of nitrogen-rich fertilizers and by inadequate waste-disposal techniques. Although additional investigation of this problem is necessary, steps must be taken to rid the basin of these wastes.

TABLE 4.1

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

Land Use Type	Consumptive Use Of Applied Water	Consumptive Use Of Precipitation	Total
Residential, single	36.6 (1.2)	27.4 (0.9)	64.0 (2.1)
Residential, estate	27.4 (0.9)	27.4 (0.9)	54.9 (1.8)
Residential, multiple	9.1 (0.3)	18.3 (0.6)	27.4 (0.9)
Recreational residential	6.1 (0.2)	*	*
Campgrounds	3.0 (0.1)	*	*
Farmsteads	24.4 (0.8)	24.4 (0.8)	48.8 (1.6)
Commercial, strip	12.2 (0.4)	15.2 (0.5)	27.4 (0.9)
Commercial, downtown	33.5 (1.1)	15.2 (0.5)	48.8 (1.6)
Industrial, manufacturing	42.7 (1.4)	18.3 (0.6)	61.0 (2.0)
Industrial, cannery	167.6 (5.5)	18.3 (0.6)	185.9 (6.1)
Industrial, high water using	**	**	**
Schools	12.2 (0.4)	21.3 (0.7)	33.5 (1.1)
Parks, cemeteries, and golf courses	76.2 (2.5)	36.6 (1.2)	34.7 (3.7)
Dairies	30.5 (1.0)	27.4 (0.9)	57.9 (1.9)
Livestock & poultry ranches	18.3 (0.6)	21.3 (0.7)	39.6 (1.3)
Industrial, extractive	—	18.3 (0.6)	18.3 (0.6)
Vacant	—	18.3 (0.6)	18.3 (0.6)
Streets and roads	—	15.2 (0.5)	15.2 (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.)

TABLE 4.2

ESTIMATED MEAN SEASONAL UNIT VALUES OF
CONSUMPTIVE USE OF WATER ON IRRIGATED LANDS,
UPPER SANTA ANA RIVER DRAINAGE AREA
Centimeters (feet)

	Santa Ana River Unit*			San Jacinto Valley Unit*		
	Applied Water	Precipitation	Total	Applied Water	Precipitation	Total
Alfalfa	73.2 (2.4)	39.6 (1.3)	112.8 (3.7)	82.3 (2.7)	30.5 (1.0)	112.8 (3.7)
Pasture	76.2 (2.5)	36.6 (1.2)	112.8 (3.7)	82.3 (2.7)	30.5 (1.0)	112.8 (3.7)
Deciduous & Nuts	48.8 (1.6)	39.6 (1.3)	8.4 (2.9)	57.9 (1.9)	30.5 (1.0)	88.4 (2.9)
Citrus	45.7 (1.5)	33.5 (1.1)	79.2 (2.6)	48.8 (1.6)	30.5 (1.0)	79.2 (2.6)
Truck Crops	36.6 (1.2)	27.4 (0.9)	64.0 (2.1)	42.7 (1.4)	21.3 (0.7)	64.0 (2.1)
Field	36.6 (1.2)	27.4 (0.9)	64.0 (2.1)	42.7 (1.4)	21.3 (0.7)	64.0 (2.1)
Small Grain	21.3 (0.7)	30.5 (1.0)	51.8 (1.7)	21.3 (0.7)	30.5 (1.0)	51.8 (1.7)
Vineyard	33.5 (1.1)	39.6 (1.3)	73.2 (2.4)	36.6 (1.2)	36.6 (1.2)	73.2 (2.4)
Streets & Roads	-- --	15.2 (0.5)	15.2 (0.5)	-- --	15.2 (0.5)	15.2 (0.5)

*The Elsinore Sub-unit is included with the Santa Ana River Unit because the climatic factors more closely resemble those in that unit than those in the San Jacinto Valley Unit. The values shown in this table are based on the work of Blaney and Criddel. Source: Department of Water Resources, Bulletin No. 71-64, Upper Santa Ana River Drainage Area Land and Water Use Survey, 1964. July, 1966 (p. 66)

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 on the efforts of the Riverside group during the past year 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 use changes since the changes determine, in part, the hydrologic impact.

C. Work Plan:

Figure 4.2 shows the relationship among the tasks just described.

Figure 4.3 provides a listing of these tasks along with the investigators who are involved in performing them.

Referring to Figure 4.3 it can be seen that during the current funding year the bulk of the effort has been in the area of defining information requirements.

During the next funding year it is planned that the study will continue to progress along the lines indicated in Figures 4.2 and 4.3. Specifically, it is planned that the work will be concerned with various phases of application of particular remote sensing techniques that will facilitate the gathering of information of the types needed in water demand models in Southern California, as defined during the current year.

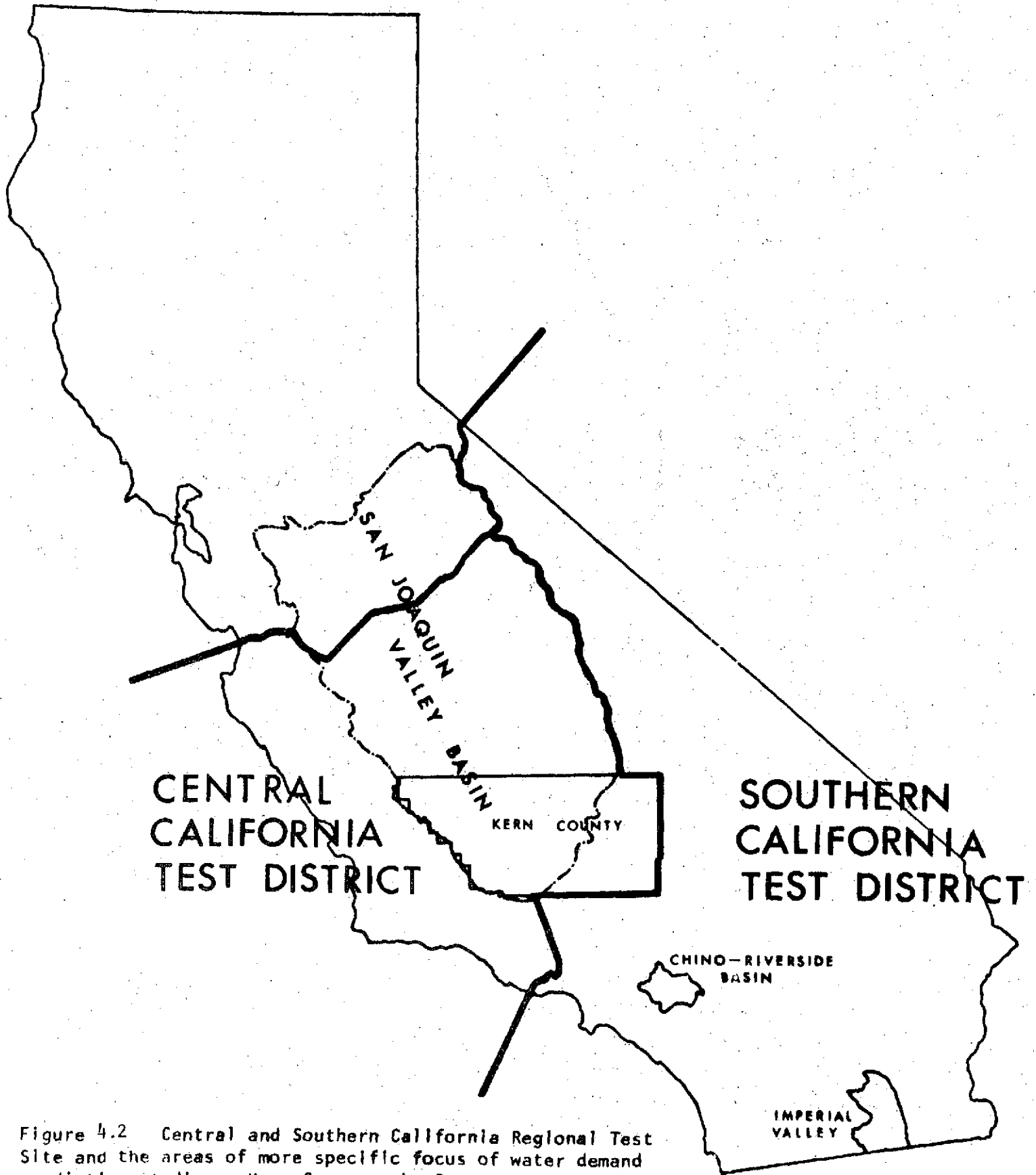


Figure 4.2 Central and Southern California Regional Test Site and the areas of more specific focus of water demand prediction studies: Kern County, the San Joaquin Valley Basin, the Chino-Riverside Basin and the Imperial Valley.

Chronological Plan for the Performance of Water Demand Studies

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

FIGURE 4.3
Chronological Plan for the Performance of Water Demand Studies

II. A THERMAL CALIBRATION MODEL FOR THE SAN BERNARDINO MOUNTAINS

The San Bernardino Mountains represent the major source of water for the Santa Ana River Basin. Runoff from the mountains is supplemented by exogenous water from the California Aquaduct. In order to have a more complete picture of the total water available for use within our study area, a model for more accurately determining temperature (used in computing evapo-transpiration) was developed.

In the derivation of evapo-transpiration data, based upon almost any model, temperature is a primary input. Areas with complex terrain, however, present a peculiarly difficult problem. Due to elevational influence upon temperature and the usually associated lack of climatic recording stations to deal with this variation, data are largely inaccurate and unreliable. In order to obtain reliable temperature data for hydrologic models, a method of calibrating temperature point data with a terrain model was needed. A thermal calibration model was constructed and tested using: 1) a statistical terrain surface identified by location at the center of a grid cell; 2) climatic summary data; 3) lapse rates approximating as closely as possible the area and time of the topography to be modeled; 4) a basic gravity model for generating a surface from randomly located point data, in this case the inverse of the distance squared; and 5) appropriate computer graphics programs for data analysis and display.

The assimilation of the first four items above yielded a generalized calibration model expressed in terms of the following equation:

$$Z_p = \left\{ \frac{\sum_{i=1}^n W_i Z_i}{\sum_{i=1}^n W_i} \right\} - \left\{ LR \left(T - \left(\frac{\sum_{i=1}^n W_i T_i}{\sum_{i=1}^n W_i} \right) \right) \right\}$$

- Where Z_p = Value to be calculated
 Z = Value at the i th data point
 W = Weight (Predominantly based on $1/\text{distance}^2$)
 n = Number of data points used for interpolation
 T_i = Topography at each data point
 W = Total weight of W_i from 1, N.
 T = Actual elevation at point p
 LP = Lapse rate

This model was tested using a study area encompassing most of the San Bernardino Mountains (California) and mean July maximum temperatures. A surface was generated using station data, Figure 4.5, and was compared to test stations which were not used in the surface generation, Figure 4.6. It was apparent that the model did not allow for expression of surface super-heating. Therefore, an empirical equation accounting for this heating factor was employed as given below:

$$Z_p = Z_p^1 + 1.12 (T - T_a)$$

Where Z_p^1 = Final value calculated at point P
 Z_p = Previous value calculated at point p
T = Actual topography at point p
 T_a = Assumed topography at point p.

The results of these surfaces are mapped in Figures 4.5 and 4.7. The test data are compiled for comparison in Figure 4.5. (The Strawberry peak recording station was discounted as a valid test site because of terrain model insensitivity at its particular location.)

The above demonstrates that thermal inputs to hydrologic and evapo-transpiration models can be greatly improved with very little effort, particularly in areas of complex terrain.

STATION DATA

Station	Elevation Meters (feet)	Mean July Max.	
		°C.	(°F.)
San Bernardino	343 (1125)	35.9	(96.6)
Redlands	412 (1352)	34.3	(93.7)
Squirrel Inn	1,731 (5680)	26.9	(80.4)
Lake Arrowhead	1,586 (5205)	27.8	(82.1)
Mill Creek	896 (2940)	34.0	(93.2)
Santa Ana River	843 (2765)	38.8	(83.9)

TEST DATA

Location	Elevation Meters (ft)	Observed Temperature	With Simple		With Lapse		With Lapse	
			Interpolation	Diff.	Rate Only	Diff.	Rate & Heating	Diff.
Converse	1712 (5618)	27.4 (81.34)	31.4 (88.45)	+ 4.0 (+ 7.11)	25.4 (77.76)	-2.0 (-3.58)	26.9 (80.40)	- .5 (- .94)
Strawberry Peak	6875 (6150)	25.9 (78.65)	27.0 (80.64)	+ 1.1 (+1.99)	27.9 (82.27)	+2.0 (3.62)	27.7 (81.86)	+1.8 (+3.21)
Butler Peak	2591 (8502)	21.7 (70.97)	30.7 (87.28)	+9.0 (+16.31)	19.5 (67.03)	-2.2 (-3.94)	22.2 (72.03)	+ .5 (+1.06)
Big Bear	3088 (6850)	26.4 (79.44)	31.2 (88.15)	+4.8 (+8.71)	22.1 (71.81)	-4.3 (-7.63)	24.4 (75.84)	-2.0 (-3.60)
Mean Difference				4.7 (8.53)		2.6 (4.69)		1.20 (2.20)
Mean Difference W/O Strawberry Peak				5.9 (10.71)		2.8 (5.05)		1.0 (1.87)

Figure 4.4

11-7

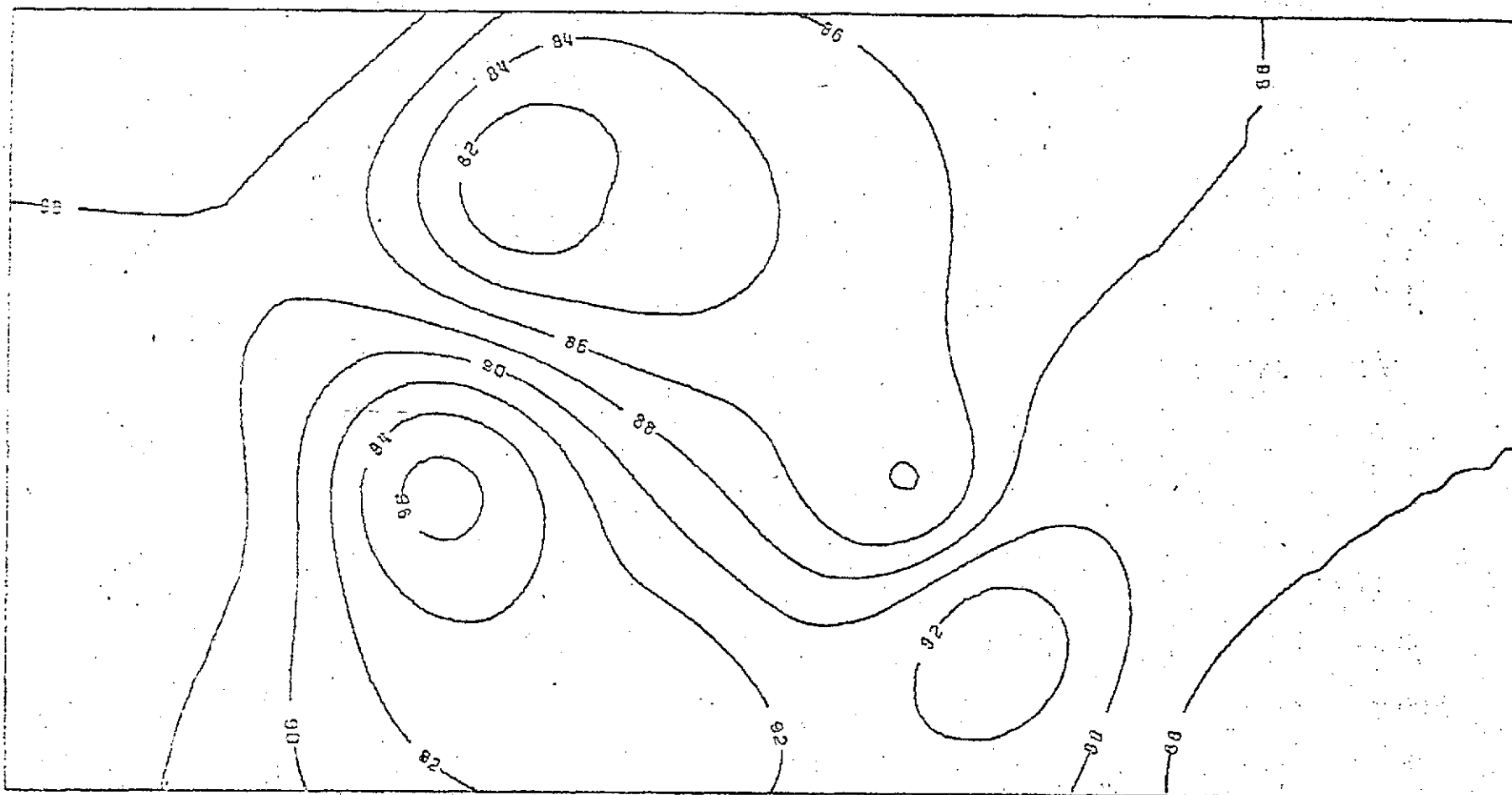


Figure 4.5 Mean July Temperature -- San Bernardino Mountain,
Valley Isothermal Map not calibrated to topography

1 cm = 2,500 meters

4-13

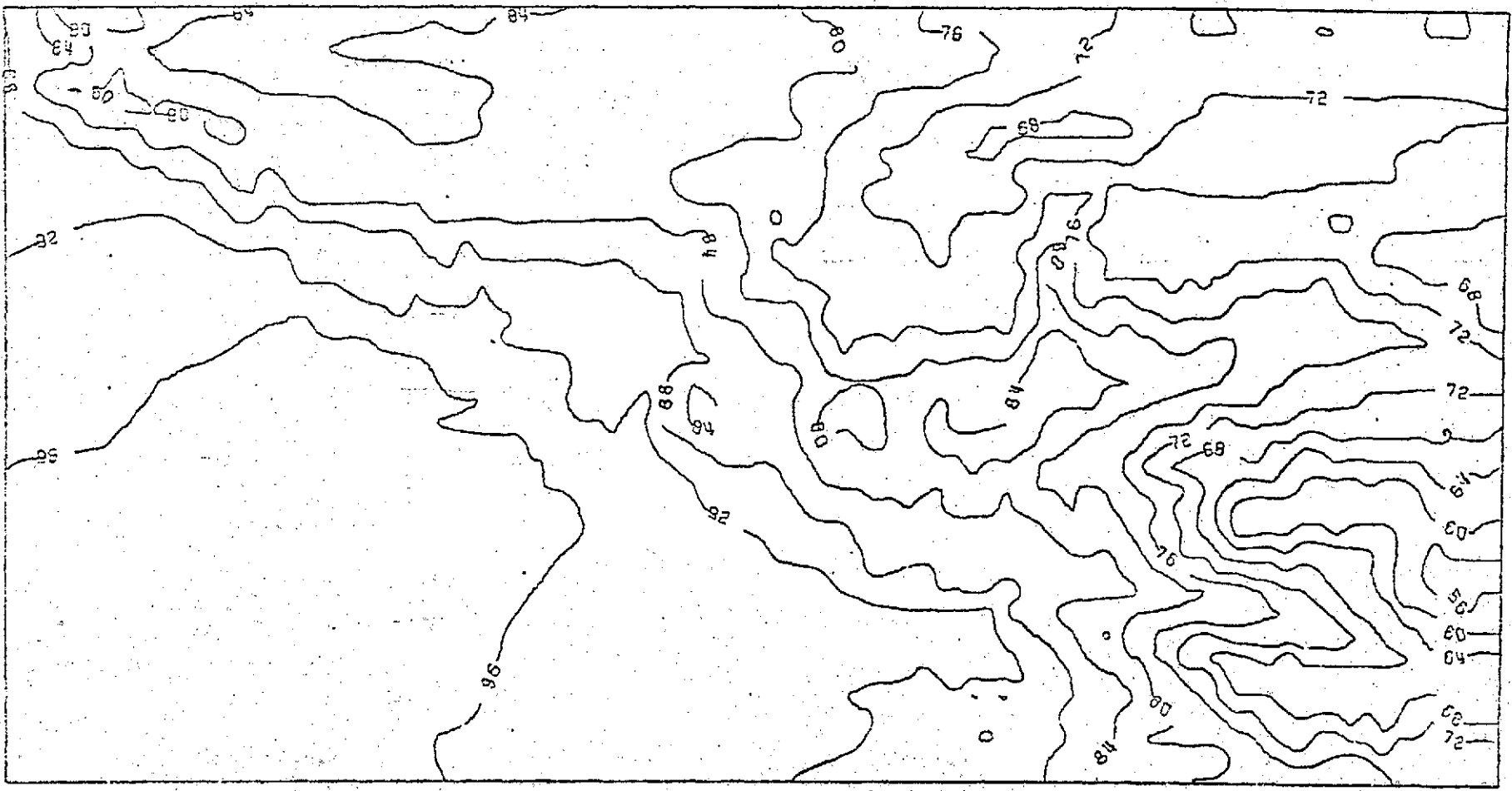


Figure 4.6 Mean July Maximum Temperature -- Calibrated to Topography:
without superheating calibration

1 cm = 2,500 meters

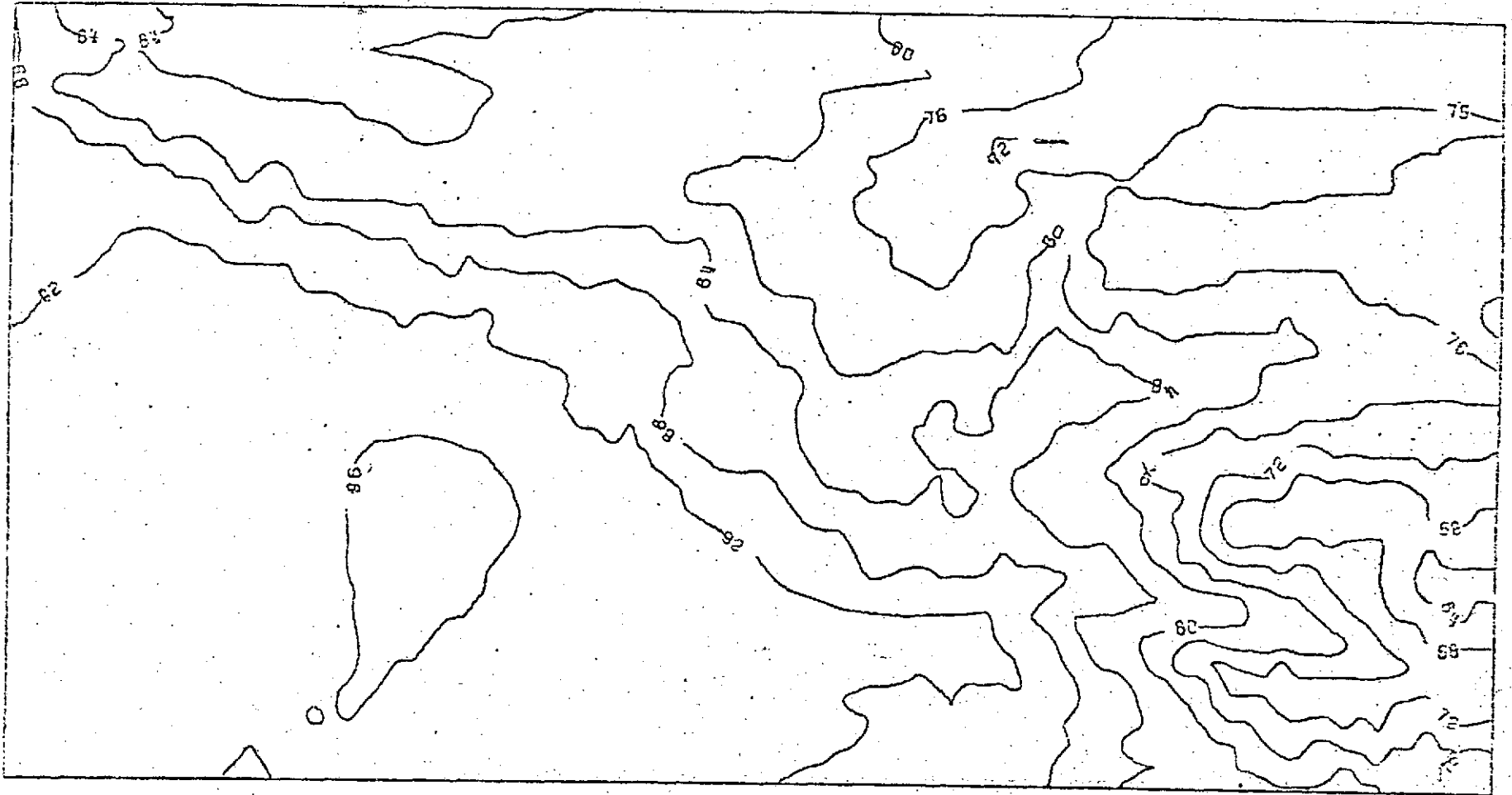


Figure 4.7 Mean July Temperature -- Calibrated to Topography:
with superheating calibration

1 cm = 2,500 meters

III. WATER DEMAND MODEL PARAMETERS: CHINO-RIVERSIDE BASIN LAND USE DYNAMICS

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 including U-2 underflights and ERTS-1 imagery. 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 and the San Jacinto Fault to 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 4.6, 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 area by 31 percent, decreases in irrigated agriculture areas 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-farmed 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 405 hectares (1,000 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. As a specific example, viticulture within the Basin has seen significant changes due to urban encroachment during the past decade. A study recently initiated is

CHINO RIVERSIDE BASIN

LAND USE

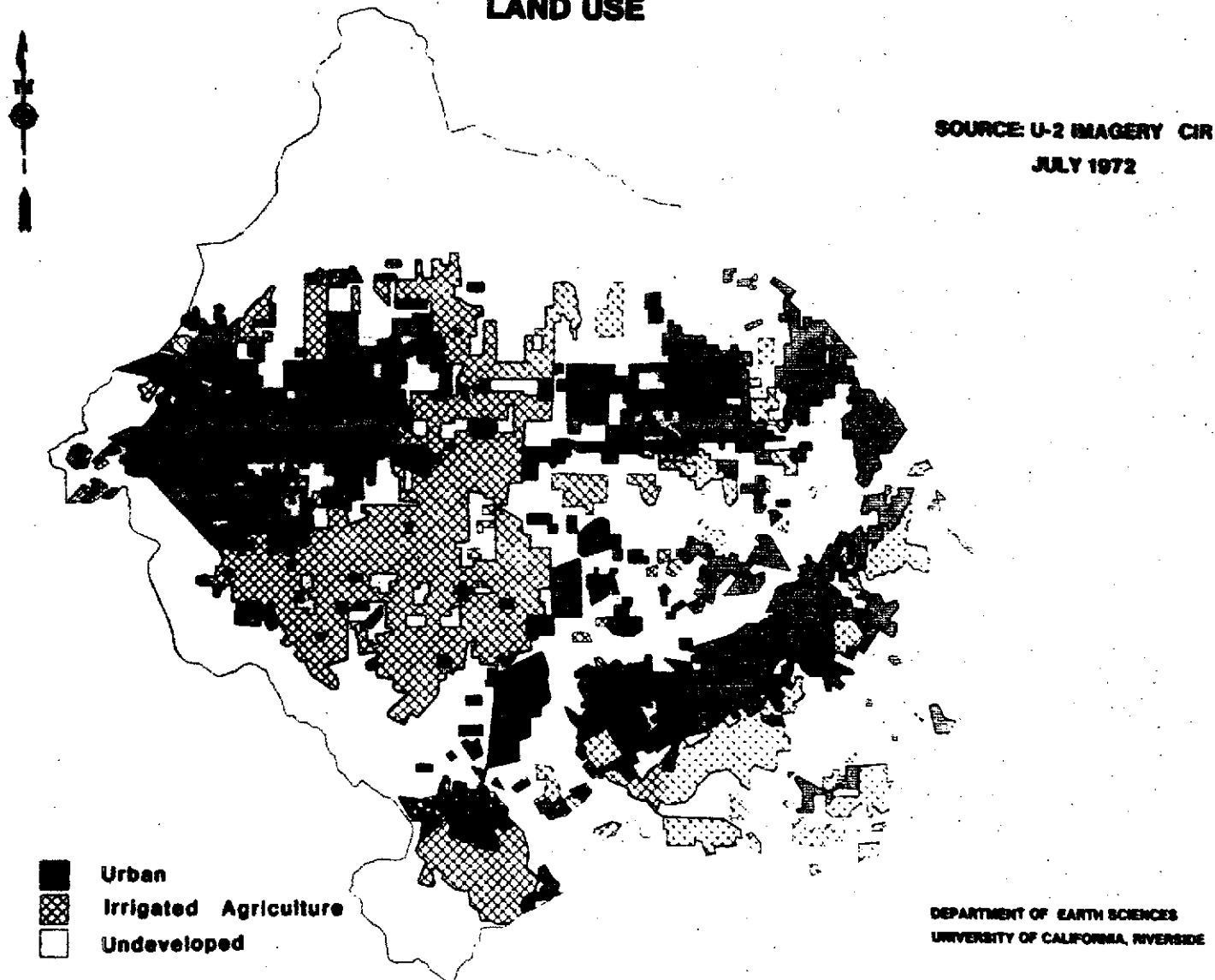


Figure 4.8 Map Showing Land Use in the Chino-Riverside Basin, based on Color Infrared Photography, Scale 1:120,000, acquired in July, 1972.

examining these changes because each year an increasing number of vineyards are becoming non-productive. The purpose of a study in this area is to examine the effect of a changing land-use pattern upon the total mosaic of water use of the area.

Viticulture was chosen because of its historical importance and because grapes constitute a permanent crop resulting in uniform water needs over time. The study has only been initiated, and to date only vineyards in the study area have been mapped from high altitude CIR imagery (July, 1972). The imagery was enlarged to a nominal scale of approximately 1:32,000. Ultimately the map will be digitized using the CALFORM program and total areas computed. At present, field checking is in progress in the eastern sector of the study area so that a pattern of healthy, dead or weedy conditions may be delimited aurally using color/texture differences apparent on the imagery. Once the map is completed, an accurate picture of water use can be obtained using known figures of applied water.

Specific figures are important in ascertaining the role that viticulture plays in the total scheme of water demand for the Basin. At the present, DWR utilizes a single value of consumptive water use for all facets of agriculture. It is expected that by examining the water needs of the different areas of the Basin and the needs of different crops, a more accurate determination of water demand can be produced thus making future plans more reliable.

The hydrologic significance of urban encroachment (e.g., the effects on runoff, ground water storage, and water quality) is an important consideration for water resource management within the Basin.

A. Runoff Characteristics

It has been previously established that alluvium in its natural state provides a significant degree of protection from flood hazard because 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 22,259 hectares (55,000 acres) of impermeable surface which now exists in the form of streets, roofs, 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. There are 45,124 hectares (111,500 acres) of urban and suburban area in the Basin, and probably one-half (or 22,259 hectares (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 groundwater 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 were perhaps a better indication of what could happen, given increased precipitation.

B. Groundwater Storage

The potential storage capacity of the Chino-Riverside groundwater basin was calculated to be about 2,258,220 hectare-meters (18,300,000 acre-feet) most of which occurs in the central part of the Basin. In 1934-35, the amount of groundwater in storage was 1,561,000 hectare-meters (12,650,000 acre-feet) and in 1959-60, the total had dropped to about 1,480,800 hectare-meters (12,000,000 acre-feet). The net decline of 80,210 hectare-meters (650,000 acre-feet) represents an average drop of 3,085 hectare-meters (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 7.6 meters (25 feet) during this period while those in the Pomona-C Claremont area declined 22.9 meters (75 feet) and those in the Colton-Rialto area dropped 15.2 meters (50 feet).

In order to account for the decline in total volume of groundwater, one 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 decline in precipitation since 1944 is a major factor. 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 groundwater pumpage, rising water, extractions by phreatophytes, and subsurface outflow which is considered to be constant. Significant trends are indicated by the total groundwater 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. Because the cultivated area has either remained constant or dropped since 1934, irrigated crops have displaced dry-farmed areas primarily vineyards. The decrease of rising water (water coming to the surface in stream channels) 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 groundwater 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 area 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.

C. 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, the amount of applied nitrogen and the amount recovered in the crop, can be calculated as a 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 groundwater table can be computed. The same may be accomplished for all crops requiring nitrogenous fertilization, such as citrus, which presently requires up to 166 Kg. of nitrogen per hectare per year (150 lbs. 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 groundwater basin if no new controls are implemented. The concern stems from the estimated output of 1.64 Kg. (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 188 to 355 liters (50 to 100 gallons) of waste water per day per cow. In the Chino-Riverside area this could amount to 33.75 million liters (9 million gallons) per day, most of which is diverted to irrigated pastures.

The impact of dairies on groundwater 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 18.14 million Kg. (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 1,345 hectare-meters (10,900 acre-feet) in 1934-35 to 6,370 hectare-meters (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, groundwater 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, changing 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.

IV. FACTORS FOR REDUCING GROSS WATER SERVICE AREA TO NET WATER SERVICE AREA

A. Introduction

Land surveys conducted to determine water demand divide a region's area into two broad categories: water service areas and nonwater service areas. However, within each water service area there occur nonwater using land areas of varied amounts that would be both difficult and extremely time consuming to differentiate during the initial survey. Nonwater using areas include: roads; streets; sidewalks; farm access roads; railroad rights of way; oilfields; tank farms; vacant lots; quarries; storage yards; miscellaneous impervious areas; and miscellaneous non-irrigated farm areas. For each class of land use within the water service area a factor for reduction is determined and is applied to the gross water service area to reduce this area to the net water service area.

Traditionally, the California Department of Water Resources (DWR) has used two methods in deriving these factors for reduction. For agricultural areas appropriate percentage factors were determined from detailed surveys of representative sample plots.¹ In urban areas net areas were derived through estimating what percentage the nonwater use lands were of total.² The inherent variation within each water use class indicates the need of extensive sampling to obtain a representative reduction factor. Also, inter-regional variation makes it necessary to calculate reduction factors on a regional basis. The time and resources consumed in making ground surveys limit the number of samples that can feasibly be made. The representative nature of the reduction factor can be questioned when limited sample bases and/or estimations are used.

It was felt that remote sensing techniques could be used to determine the reduction factors for reducing gross area to net area for each land use class within the water service area with a maximum cost efficiency.

B. Methodology

Percentage factors for reduction were calculated for the eight land use types classified by the DWR. The Upper Santa Ana River Drainage Area represented the study region. The format used is summarized in the following steps:

- 1) A general survey was made of the land uses in the drainage area using the CIR imagery of mission Mx 164(1:60,000) and mission 72-112(1:132,000). Sample plots were then located on large scale imagery [14 July 68 (Approx. 1:8,000), 13 July 70 (Approx. 1:12,000), 25 May 73 (Approx. 1:20,000)].

- 2) Film samples were then placed on a Kargl Reflecting Projector and enlarged 3 to 3.9 times. Boundaries and water use areas within these boundaries were traced onto acetate.

3) A number was assigned to each vertex on the schematic in sequential pattern. The schematic was then placed on the digitizer, and using the CALFORM Vertices Program, (x,y) values for each vertex were punched on IBM cards.

4) The cards for each schematic were then separated into groups according to a total area polygon and water use polygons. The area of each polygon was calculated and individual water use areas summed. In Figure 4.7 a six block area of the Riverside CBD is outlined. The total area on the original schematic was 175.24 sq. cm. (27.16 in.²) and the sum of the water use areas was 88.78 sq. cm. (13.76 in.²). By subtracting the water use area from the total area the nonwater use area is obtained. With this number it is a simple step of division and multiplication to get the percentage reduction factor. [86.46 cm. (13.40 in.)/175.24 cm. (27.16 in.) x 100 = 49.4%]

5) An estimation of the area of each sample was calculated. First a representative fraction was determined. The number of hectares per sq. cm. on the acetate overlay was calculated by squaring the representative fraction and dividing that number by the total number of sq. cm. per hectares. The area of the total area polygon was then multiplied by the number of hectares per sq. cm. to obtain the number of hectares contained in the sample plot. (Figure 4.7: $(2,330)^2/100,000,000 = .054$ ha./cm. (.864 acre/in.), $.054 \times 175.24 = 9.46$ hectares (.864 x 27.16 = 23.47 acres).

C. Results

Nineteen sample plots have been analyzed following the above methodology. The results are presented in Table 4.3. Percentage reduction factors obtained in this study and those cited by the DWR are both given.

FIGURE 4.9

Total Area Polygon With Water Use Polygons Enclosed

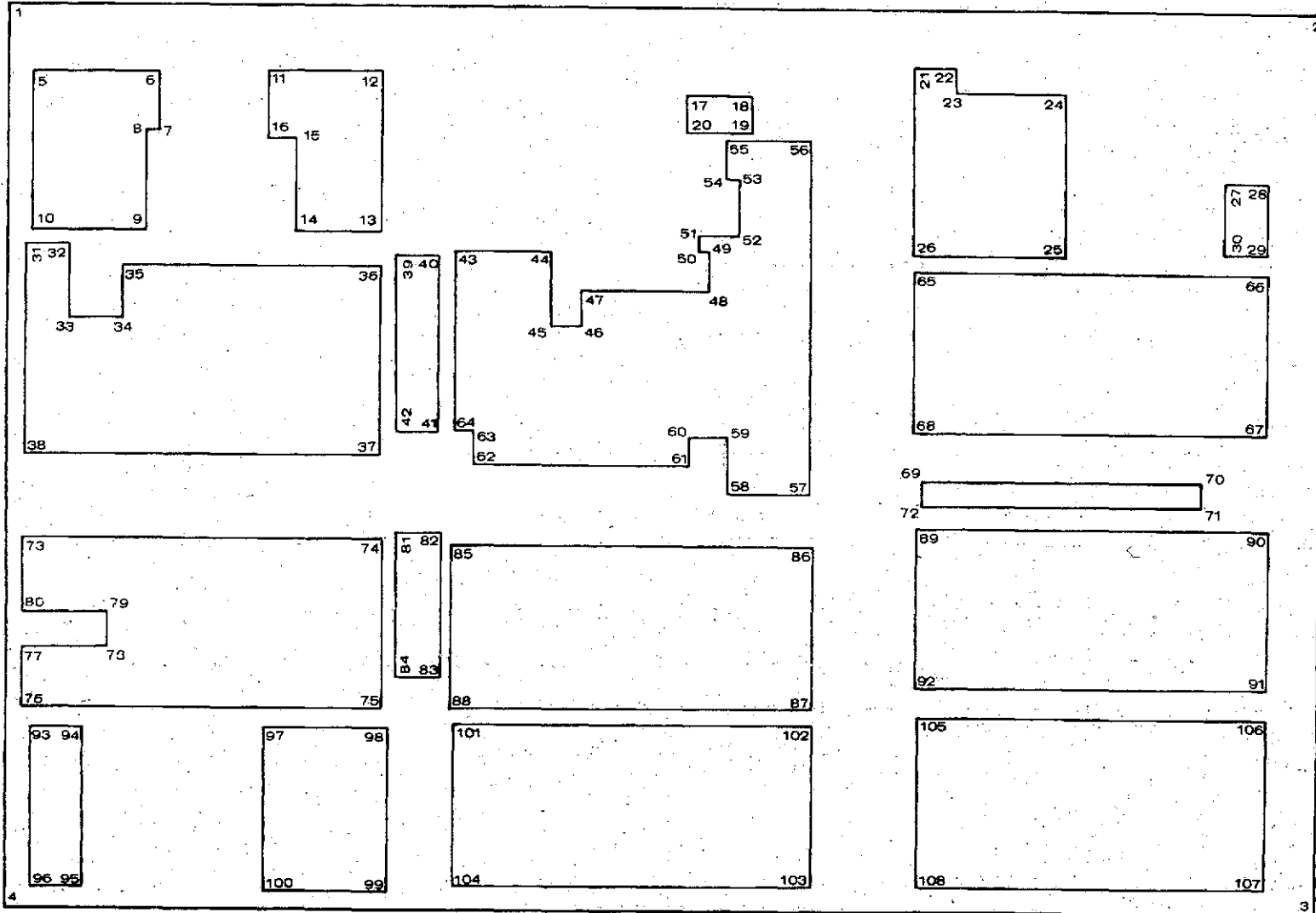


TABLE 4.3

FACTORS FOR REDUCTION OF GROSS AREAS TO NET AREAS

Land use class	Percent deducted from gross area	
	Study	DWR*
Residential	31.6	22
Residential (Low density)	20.7	10
Commercial	49.4	20
Schools	34.4	15
Industrial, manufacturing	49.9	25
Parks, cemeteries, golf courses	17.2	15
Farmsteads, livestock ranches, dairies	9.0	10
Irrigated agriculture	9.4	5

*Source: Department of Water Resources, Bulletin No. 71-64, Upper Santa Ana River Drainage Area Land and Water Use Survey, 1964.
July 1966, p. 59.

TABLE 4.4

Statistical record of each sample plot
Totals and averages are given where appropriate.

Plot	Total Sq.Cm.	NWUA Sq.Cm.	NWU%	Scale	Hectares Sq.Cm.	Land Area
A01	29.49	11.16	37.8	1:2,880	.082	2.42
A02	33.03	10.26	31.1	1:2,250	.051	1.68
A03	26.84	7.16	26.7	1:2,590	.067	1.80
A04	29.10	8.71	29.9	1:2,320	.054	1.57
A05	15.29	4.97	<u>32.5</u>	1:2,390	.057	<u>.87</u>
		Average	31.6			Total 8.34
B01	110.26	22.84	20.7	1:2,260	.051	5.62
C01	175.24	86.46	49.4	1:2,330	.054	9.46
D01	88.01	25.87	29.4	1:3,030	.092	8.10
D02	456.74	179.30	39.3	1:2,350	.055	25.12
D03	181.75	62.65	<u>34.5</u>	1:3,130	.100	<u>18.18</u>
		Average	34.4			Total 51.40
E01	143.75	81.42	56.6	1:3,030	.092	13.23
E02	101.36	32.45	32.0	1:3,030	.092	9.33
E03	176.72	107.94	<u>61.1</u>	1:2,990	.089	<u>15.80</u>
		Average	49.9			Total 38.36
F01	68.00	15.10	22.2	1:3,230	.104	7.09
F02	117.04	26.71	22.8	1:3,100	.096	11.25
F03	107.68	7.23	<u>6.7</u>	1:7,390	.546	<u>58.81</u>
		Average	17.2			Total 77.15
G01	199.17	17.87	9.0	1:5,570	.310	61.79
H01	116.52	4.13	3.5	1:3,900	.152	17.72
H02	1,512.09	231.37	<u>15.3</u>	1:2,300	.052	<u>79.99</u>
		Average	9.4			Total 97.71

NWUA=nonwater use area
NWU%=nonwater use percent
Land Area is in hectares

TABLE 4.5

List of the plots, land use class, and
a brief description of each

Plot	Land Use Class	Description
A01	Residential	Mixed single and multi-dwelling units
A02	Residential	Old high-value area
A03	Residential	Old low-value area
A04	Residential	Modern, mixed style
A05	Residential	New, look-alike
B01	Residential (low density)	Large estate type
C01	Commercial	Riverside, CBD
D01	School	Grade school without track
D02	School	Modern high school with track
D03	School	High school with track
E01	Industrial, Manufacturing	Concrete pipe with yard storage and settling basins
E02	Industrial, Manufacturing	Large plant under one roof
E03	Industrial, Manufacturing	Metals industry with outside storage
F01	Park	New Community park, with swimming pool
F02	Cemetery	Well developed with many access roads
F03	Golf course	With club house
G01	Dairy	Multiple dairies, Chino dairy district
H01	Irrigated Agriculture	Citrus grove
H02	Irrigated Agriculture	La Sierra truck farm

D. Summary

It is apparent from a comparison of the results that a disparity exists between the results of this study and the percentages cited by the DWR. A wide variation is also observed in the amount of nonwater use area occurring between different land use types within a land use class. As an example, the reduction factor of 6.7% for golf courses as opposed to that of 22.2% and 22.8% for parks and cemeteries, respectively. It may prove beneficial to separate or reclass some water use areas that differ significantly from other members of their land use class.

A broader sample base needs to be analyzed to establish the representative nature of these initial reduction factors. The problem of the normality of a sample or a group of samples is reduced by increasing the individual sample size and/or increasing the number of samples.

References:

¹California Water Resources Board, Bulletin No. 2, Water Utilization and Requirements of California, Vol. 1, June 1955, p. 43.

²Ibid. p. 44.

V. SUMMARY OF TOTAL LAND USE IN THE UPPER SANTA ANA RIVER BASIN

Land use is the prime factor in determining long term water demand of an area such as the Upper Santa Ana River Basin and currency of data for land use is necessary to make accurate estimates. The State Department of Water Resources completed the last land use survey prior to 1964 and the statistics compiled then are the ones currently being used by the various water agencies in predicting water demand. The reason for outdated inventories of land use is the lack of modern equipment. This study will show that the cost-benefits of obtaining and maintaining current land use inventories is worth the small investment (\$30,000) in equipment.

Table 4.6 is a tabulation of the major land use classifications compiled to date under this study. The 127,861 hectares (315,940 acres) represents 21.8% of the total 585,403 hectares (1,446,510 acres). Progress has been slow and perhaps no faster than it would have taken the water agency to compile the same map areas. However, the first eight maps have been used to develop methodology as well as being in the area of largest urban concentration.

The system under development is not necessarily any faster in the process of interpreting the data from the aerial imagery (NASA U-2, 1:128,000) than is presently performed by the water agency. Improvement in the system is being made in the ability to rapidly update the data from subsequent imagery and, most importantly, in the time taken to compile the statistics. These two improvements are possible because the initial data are compiled in a format that makes computer processing and plotting possible.

The area of each land use polygon is automatically calculated by the computer using planimetry techniques. Current water agency calculation techniques employ manual methods (cutting out and weighing the delineated areas as portrayed on maps) which are only as accurate as the cutting process and calibration of the scales used for weighing. The automatic technique requires the vertices of each polygon to be measured electro-mechanically to an accuracy of one-thousandth of an inch. For a single quad sheet of 15,986 hectares, (39,500 acres) the reduction process is much less tedious and faster by several man-days than the "cut-and-weigh" method. This automatic technique is one on which our study will focus in order to determine the cost-benefit savings resulting from its use.

Updating procedures have been greatly facilitated by automating the land use mapping. It is now possible within a few minutes to produce the outline map of any quad sheet to any desired scale. By making an outline map of previously known land use to the scale of the image, or by projecting the image onto the outline map, a quick update can be accomplished. The projection of the U-2 imagery through a photogrammetric enlarging system (i.e. K & E Kargl Projector) requires very little rectification. Consequently, a quad sheet can be updated in less than one hour.

Completion of the land use mapping of the entire Upper Santa Ana River Drainage Basin will provide the base map for modelling the water demands of the basin. The land use figures listed in Table 4.6 are for gross areas before reduction of offsite areas; the determination of precise reduction factors is being determined, as an earlier portion of this report described.

TABLE 4.6
 LAND USE IN THE UPPER SANTA ANA RIVER BASIN
 1974
 (Listed by USGS Topographic 7-1/2' Quad Areas)
 Hectares (Acres)

Classification	Prado Dam	Corona North	West Riverside	East Riverside	Guasti	Fontana	South San Bernardino	Devore	Total
Living Area	326 (806)	2,809 (6,941)	4,639 (11,462)	1,859 (4,593)	1,103 (2,726)	5,551 (13,717)	4,903 (12,115)	828 (2,047)	22,019 (54,407)
Industrial	53 (132)	69 (170)	178 (441)	190 (469)	1,174 (2,902)	357 (883)	494 (1,220)	54 (134)	2,570 (6,351)
Transportation, Commn., Utilities	248 (612)	1,045 (2,583)	505 (1,248)	216 (534)	811 (2,004)	204 (503)	735 (1,815)	201 (497)	3,964 (9,796)
Commercial	-- --	192 (474)	410 (1,014)	248 (612)	45 (110)	225 (555)	802 (1,981)	-- --	1,921 (4,746)
Services	207 (512)	185 (458)	571 (1,410)	2,299 (5,680)	78 (192)	246 (609)	575 (1,420)	31 (76)	4,191 (10,357)
Recreational & Cultural	141 (349)	223 (552)	368 (909)	416 (1,028)	421 (1,040)	134 (331)	259 (640)	209 (516)	2,171 (5,365)
Resources (Agricultural)	4,617 (11,409)	6,843 (16,910)	4,595 (11,354)	4,098 (10,127)	12,277 (30,335)	7,020 (17,347)	4,887 (12,075)	2,777 (6,863)	47,115 (116,420)
Undeveloped	10,370 (25,625)	4,600 (11,367)	4,726 (11,677)	6,627 (16,374)	210 (518)	2,202 (5,441)	3,322 (8,208)	11,853 (29,288)	43,909 (108,498)
TOTAL HECTARES	15,963	15,967	15,992	15,952	16,118	15,940	15,975	15,954	127,861
TOTAL ACRES	(39,445)	(39,455)	(39,515)	(39,417)	(39,827)	(39,386)	(39,474)	(39,421)	(315,940)

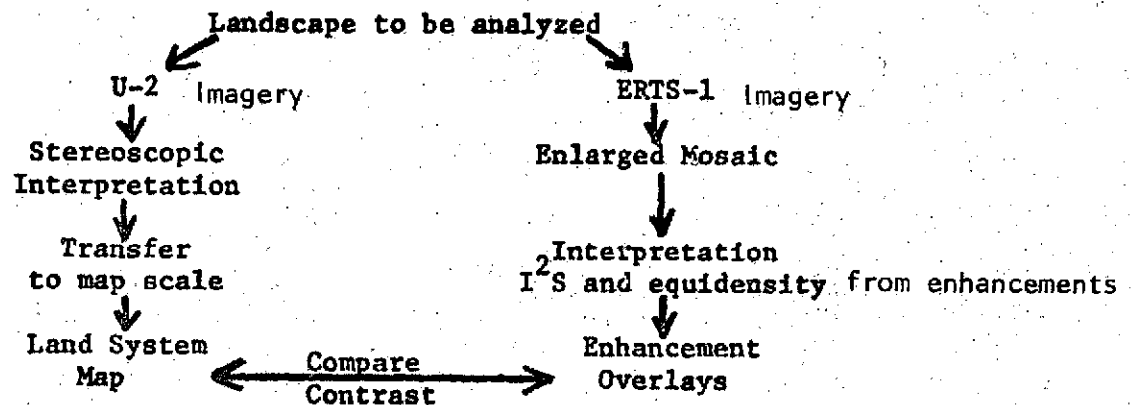
TOTAL AREA OF BASIN: 585,403 (1,446,510)

PER CENT COMPLETE APRIL 30, 1974: 21.8%

VI. A FEASIBILITY STUDY FOR LANDSCAPE DESCRIPTION: THE PERRIS PLAIN

The following study was initiated in order to test how well information portrayed on satellite and high altitude imagery can be accurately identified. Such a capability, if it proves feasible, will provide a quick inventory of land use data and natural environmental data, both of which are needed for estimating potential water demand.

In this study the Perris test site (near Riverside) was subdivided into discrete, homogeneous land-units, land-systems, and macro-landscapes. Data were extracted from both U-2 and ERTS-1 imagery. Photo enhancement techniques (silver-masking) were used in order to identify and map specific landscape units. Standard photo interpretation procedures were used for the analysis. Density analyses allowed for the most detailed comprehension. Data retrieval and research flow are represented below:



Subsequent to initial mapping, field checking was used to substantiate the findings.

The conclusions drawn from this study are directed towards a comprehensive assessment of the environment, based upon remote sensing techniques. The final product will be a Perris Landsystem Map. Essentially, the final map's individual units will be determined according to the following:

- (1) Satellite imagery will provide the single frame coverage
- (2) Whenever possible terrain types and large land systems will be detected and delineated from this imagery, exploiting the holistic method of environmental analysis
- (3) The reliability of boundary identifications will be increased through photographic techniques
- (4) Some natural landscape patterns may prove to be undetectable, Partly due to human modification of the landscape.

VII. THE EVALUATION AND TESTING OF REMOTE SENSING TECHNIQUES FOR THE PRODUCTION OF WATER DEMAND DATA IN A CONTROLLED ENVIRONMENT

Since the last reporting period research efforts at the Riverside Campus have been concentrated in the Chino-Riverside Basin and San Bernardino Mountains, the source of the Santa Ana River. Thus, little has been done in the original test area, the Imperial Valley, where past research had been concentrated. The Imperial Valley represented a controlled environment where the development and testing of water demand models, utilizing remote sensing data as a major input for either short or long term water demands, could be accomplished. The following report examines the model which has been developed and tested in the controlled environment of the Imperial Valley where exogenous water represents, essentially, the total supply.

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.

A. 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 as much as 1.5 m. (nearly 5 ft.), 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 the 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, (Agricultural Extension Service, 1972). Table 4.7 lists the monthly water requirements for the major crops of the Imperial Valley.

If it can be determined how many hectares of urban land are contained in a region, and how many irrigated hectares 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 land is in production, how much is lying fallow, and how much is in some stage in-between. 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.

TABLE 4.7
MONTHLY IRRIGATION WATER REQUIREMENTS
(Imperial Valley)

Crop	% of Annual Production	Month											
		Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
FIELD CROPS:													
Alfalfa	37.8	.051 (.416)	.051 (.416)	.051 (.416)	.051 (.416)	.077 (.628)	.100 (.814)	.100 (.814)	.101 (.816)	.101 (.816)	.076 (.616)	.051 (.416)	.051 (.416)
Cereal Grain	20.9	.059 (.482)	.062 (.504)	.062 (.505)	.062 (.505)	--	--	--	--	--	--	--	.062 (.505)
Cotton	6.5	--	--	.052 (.424)	.052 (.424)	.099 (.805)	.120 (.975)	.120 (.975)	.120 (.975)	.052 (.424)	--	--	--
Rye Grass	6.4	.040 (.327)	.040 (.327)	.075 (.606)	.041 (.334)	.075 (.606)	--	--	--	.040 (.327)	.040 (.327)	.040 (.327)	.040 (.327)
Safflower	0.2	.062 (.500)	.062 (.500)	.185 (1.500)	.185 (1.500)	.062 (.500)	--	--	--	--	--	--	--
Sudan-Sorghum	2.1	--	--	.123 (1.000)	.123 (1.000)	.123 (1.000)	.123 (1.000)	.123 (1.000)	.123 (1.000)	.123 (1.000)	.066 (.535)	--	--
Grain Sorghum	10.7	--	--	.062 (.500)	.125 (1.010)	.125 (1.010)	.125 (1.010)	.059 (.477)	--	--	--	--	--
Sugar Beets	14.2	.052 (.419)	.052 (.419)	.102 (.823)	.054 (.434)	.052 (.418)	--	--	--	.102 (.824)	.102 (.824)	.052 (.419)	.052 (.419)
Weighted Field Crops	(84.5)	.053 (.428)	.053 (.431)	.065 (.524)	.071 (.573)	.082 (.667)	.108 (.874)	.096 (.776)	.105 (.847)	.091 (.738)	.078 (.633)	.050 (.407)	.053 (.432)

Continued next page

TABLE 4.7
MONTHLY IRRIGATION WATER REQUIREMENTS
(Imperial Valley)

(Continued)

Crop	% of Annual Production	Meters (Feet)											
		Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
VEGETABLE CROPS:													
Melons	18.0	.098 (.795)	-- --	.098 (.795)	.098 (.795)	.041 (.331)	.035 (.285)	-- --	.098 (.795)	.098 (.795)	.041 (.331)	-- --	-- --
Carrots	6.7	-- --	.069 (.559)	.057 (.461)	-- --	-- --	-- --	-- --	-- --	.115 (.931)	.115 (.931)	.069 (.559)	.069 (.559)
Lettuce	55.1	.061 (.491)	.021 (.167)	-- --	-- --	-- --	-- --	-- --	-- --	.121 (.983)	.097 (.786)	.097 (.786)	.097 (.786)
Onions	6.7	.093 (.757)	.140 (1.136)	.073 (.593)	-- --	-- --	-- --	-- --	-- --	-- --	-- --	.093 (.757)	.093 (.757)
Tomatoes	3.1	.105 (.848)	.207 (1.680)	.207 (1.680)	.207 (1.680)	.137 (1.110)	-- --	-- --	-- --	-- --	-- --	-- --	-- --
Watermelons	4.4	.074 (.596)	-- --	.074 (.596)	.074 (.596)	.074 (.596)	-- --	.076 (.616)	-- --	-- --	-- --	-- --	-- --
Weighted Vegetable Crops	(12.8%)	.073 (.593)	.045 (.361)	.093 (.750)	.108 (.872)	.058 (.473)	.035 (.285)	.076 (.616)	.098 (.795)	.116 (.938)	.086 (.696)	.083 (.673)	.094 (.761)
Weighted Permanent Crops	(2.7%)	.013 (.105)	.045 (.365)	.047 (.378)	.080 (.645)	.047 (.378)	.047 (.378)	.061 (.494)	.048 (.392)	.047 (.378)	.047 (.378)	.013 (.105)	.080 (.645)
WEIGHTED TOTAL CROPS		.056 (.451)	.053 (.426)	.066 (.533)	.072 (.583)	.081 (.659)	.107 (.865)	.096 (.775)	.104 (.846)	.093 (.753)	.080 (.647)	.058 (.468)	.062 (.505)

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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.

B. 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 is quite obvious in the arid Imperial Valley, but fallow ground might not be so discernible in more humid areas. The in-between 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 from 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 on which every field was 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 4.8. 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 probably 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).

TABLE 4.8
CROP CALENDAR BY FIELD CONDITION CODE
(Imperial Valley)

CROP TYPE	FIELD CONDITION CODE BY DATE			
	August 26	October 1	November 6	December 12
<u>FIELD CROPS</u>				
Alfalfa	1	1	1	1
Cereal Grains	4	4	3	2
Cotton	1	1	5	4
Rye Grass	4	3	2	1
Sudan-Sorghum	1	5		
Grain Sorghum	1	5	4	
Sugar Beets	3	2	1	1
<u>VEGETABLE CROPS</u>				
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

By comparing each sequence of field conditions to the crop calendar in Table 4.8 the specific crop contained in each field can be identified. A computer program to perform the identifications has been developed and based on preliminary results it is anticipated that a 90 percent identification accuracy of specific crop types can be achieved from the comparative analysis of six 36-day cycles of ERTS imagery.

Table 4.9 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 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.

C. Determination of Monthly Water Requirements

The monthly water requirements as shown in Table 4.7 for each major crop in the Imperial Valley were given weights according to the average total number of hectares 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 sorgham 2.1 percent. In August of 1972 the only major crops in production were alfalfa, cotton, and forage sorgham. The weighted values of these crops became 81.5 percent for alfalfa, 14 percent for cotton, and 4.5 percent for sorgham. Referring back to Table 4.7 we can then adjust the weighted water requirement of alfalfa to .082 hectare-meters (.665 acre-feet), cotton .017 (.137), and sorghum .006 (.045), thus yielding a total requirement for all field crops in production in August to .105 Hectare-meters (.847 acre-feet) of water. Similarly the water requirement for the entire region can be given a weighted average for all producing crops for each month.

D. Estimation of Water Demand

Table 4.10 combines the area summary of each field condition with the average monthly water requirement to calculate the water demand for each field condition in hectare-meters of water. The demand for water by growing crops and seeded irrigation crops obviously results from the total hectares times the water requirement. However, the water demand for plowed fields must be adjusted to the number of hectares 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. Because of the fact that, in this study, no such factor was available, an after-the-fact value of actual hectares 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 4.7. Experience of interpretation over the four cycles indicated that approximately 3,238 hectares (8,000 acres) of fields would not be correctly identified because of several reasons. Those of less than

TABLE 4.9

SUMMARY OF FIELD CONDITIONS
AS INTERPRETED FROM ERTS-1 IMAGERY

(Imperial Valley)

Field Condition	(Code)	August 26 Hectares (Acres)	October 1 Hectares (Acres)	November 6 Hectares (Acres)	December 12 Hectares (Acres)
Growing Crops	(1)	62,133 (153,528)	57,486 (142,047)	80,615 (199,197)	86,295 (213,233)
Wet Seeded	(2)	16,339 (40,374)	27,971 (69,115)	48,698 (120,330)	47,118 (116,426)
Damp Plowed	(3)	51,890 (128,219)	60,847 (150,351)	19,723 (48,736)	22,478 (55,542)
Dry Bare	(4)	49,788 (123,025)	33,850 (83,642)	32,465 (80,221)	25,197 (62,262)
Stubble	(5)	1,067 (2,636)	318 (787)	127 (315)	435 (1,075)
Permanent Crop	(8)	1,473 (3,640)	1,473 (3,640)	1,473 (3,640)	1,473 (3,640)
No Data	(0)	3,885 (9,599)	4,237 (10,470)	3,087 (7,627)	3,347 (8,270)
TOTAL PRODUCING		186,575 (461,021)	186,183 (460,052)	186,189 (460,066)	186,343 (460,448)
Feed Lots		1,092 (2,698)	1,094 (2,703)	1,112 (2,747)	1,106 (2,734)
Farm Associated		73 (180)	74 (184)	187 (463)	197 (486)
Offsites		22,030 (54,436)	22,054 (54,495)	22,061 (54,512)	22,040 (54,459)
Urban		4,740 <u>11,712</u>	4,902 <u>12,112</u>	4,970 <u>12,280</u>	4,808 <u>11,880</u>
TOTAL ACRES		214,510 (530,047)	214,712 (530,546)	214,519 (530,068)	214,494 (530,007)

TABLE 4.10

ESTIMATED MONTHLY WATER DEMAND
(Imperial Valley)Hectare-Meters
(Acre-Feet)

Field Condition	September	October	November	December
Growing Crops	14,266 (115,606)	11,341 (91,904)	11,504 (93,224)	13,288 (107,682)
Wet Seeded Land	3,751 (30,401)	5,518 (44,717)	6,949 (56,314)	7,255 (58,795)
Damp Plowed	2,671 (21,642)	4,089 (33,136)	—	—
Dry Bare				
Stubble				
Permanent Crops	337 (2,730)	539 (4,368)	78 (634)	943 (7,644)
No Data	148 (1,200)	197 (1,598)		17 (137)
Feed Lots	251 (2,032)	216 (1,748)	159 (1,285)	170 (1,380)
Farm Associated	17 (136)	15 (119)	27 (217)	30 (245)
Offsites				
Urban	474 <u>(3,842)</u>	348 <u>(2,822)</u>	315 <u>(2,555)</u>	342 <u>(2,768)</u>
TOTAL ESTIMATED	21,914 (177,589)	22,263 (180,412)	19,032 (154,229)	22,045 (178,651)
ACTUAL DELIVERY	33,500 <u>(271,476)</u>	20,005 <u>(162,111)</u>	19,599 <u>(158,828)</u>	22,031 <u>(178,537)</u>
Difference	-11,586 (-93,887)	+2,258 (+18,301)	-568 (-4,599)	+14 (+114)
Percent ERROR	34.6%	11.3%	2.9%	0.1%

8 hectares (20 acres) could not always be detected and ground survey showed that most such fields were non-producing for one reason or another. Therefore, water demand was computed for only acreage above 3,238 hectares (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 applied 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 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 107 cm. (42 inches) annually. Through the use of a monthly percentage value of water consumption from the same water resources study a monthly urban water requirement was established.

E. 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 4.10. It is quite obvious that a gross error occurred in interpreting the August 26 imagery. A check of the Imperial Irrigation District's report of crops growing on July 15, 1972 shows that an error made by underestimating some 29,543 hectares (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.

F. 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 is exercised and long-term analyses are 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.

Chapter 5

SPECIAL STUDIES

- Special Study No. 1 - MULTISPECTRAL COMBINATION AND DISPLAY OF ERTS-1 DATA
- Special Study No. 2 - SEPARATION OF MANMADE AND NATURAL PATTERN IN HIGH ALTITUDE IMAGERY OF AGRICULTURAL AREAS
- Special Study No. 3 - ON THE FEASIBILITY OF BENEFIT-COST ANALYSIS APPLIED TO REMOTE SENSING PROJECTS
- Special Study No. 4 - ACTIVITIES OF THE SOCIAL SCIENCES GROUP, BERKELEY CAMPUS
- Special Study No. 5 - INVESTIGATION OF ATMOSPHERIC EFFECTS IN IMAGE TRANSFER
- Special Study No. 6 - POWER LAW TIME DEPENDENCE OF RIVER FLOOD DECAY AND ITS RELATIONSHIP TO LONG TERM DISCHARGE FREQUENCY DISTRIBUTION

Original photography may be purchased from
EROS Data Center
10th and Dakota Avenue
Sioux Falls, SD 57198

Special Study No. 1

N74-28854

color

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

$$\underline{I} = [A]\underline{I}' \quad (1)$$

in which $[A]$ is an $N \times N$ 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)

$$\underline{I} = [A]\underline{I}'' \quad (2)$$

$\hat{\underline{I}}$ is an approximation to \underline{I} . The goodness of the approximation is measured in a mean-square sense.

$$\epsilon_L = E[|\underline{I} - \hat{\underline{I}}|^2] = E[\sum_k (I_k - \hat{I}_k)^2] \quad (3)$$

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 , $k=1, \dots, N$ columns of the matrix A are obtained by solving the matrix equation

$$[\mu]\underline{e}_k = \lambda_k \underline{e}_k \quad (4)$$

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

$$\underline{I}' = [A]^T \underline{I} \quad (5)$$

From \underline{I}' , one obtains \underline{I} back by (1) since

$$[A]^T[A] = [I] \quad (6)$$

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

$$\epsilon_L = E(\sum_k (I_k - \hat{I}_k)^2) = \sum_{k=1}^L \lambda_k \quad (7)$$

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.

* 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.

1.0000	.9356	.5097	.3341	[ρ] Normalized Covariance Matrix
.8356	1.0000	.4317	.2429	
.5097	.4317	1.0000	.9633	
.3341	.2429	.9633	1.0000	
109	283	791	600	Variances

.8685	-.4939	-.03927	.001917	[A] ^T , Rows are Eigenvectors
.07850	.1941	-.6708	.7114	
.4659	.8220	-.05041	-.3232	
.1492	.2060	.7388	.6240	
9.278	10.79	325.1	1439.	{ λ_k } Eigenvalues

TABLE 2. Eigenvalues and Eigenvectors used in Optimizing 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.

1.0000	.9537	.2323	.0187	[ρ] Normalized Covariance Matrix
.9537	1.0000	.1226	-.0881	
.2323	.1226	1.0000	.9629	
.0187	-.0881	.9629	1.0000	
467	947	860	411	Variances

.1515	.0120	-.5699	.8074	[A] ^T Rows are Eigenvectors
.8118	-.5689	.0208	-.1292	
-.2358	-.4330	.6859	.5349	
.5120	.6990	.4517	.2123	
7.540	25.16	1186.	1467.	{ λ_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 -.60 .68 .26	.06	.74	-.58	Eigenvectors	Land only
	.76	-.20	.15		
	.60	-.70	-.40		
	.24	.63	.69		
23.1	25.4	541	1322	Eigenvalues	

Table 4 (continued)

80	35	4	8.5	Variances (MSS 4,5,6,7)	
.07	-.16	.98	-.02	Eigenvectors	Water only
.07	-.10	.00	.99		
-.48	.85	.18	.12		
.87	.49	.02	-.02		
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:

$$\begin{aligned}
I_{RV} &= g_R (I_{RD}) \\
I_{GV} &= g_G (I_{GB}) \\
I_{BV} &= g_B (I_{BD})
\end{aligned}
\tag{8}$$

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.

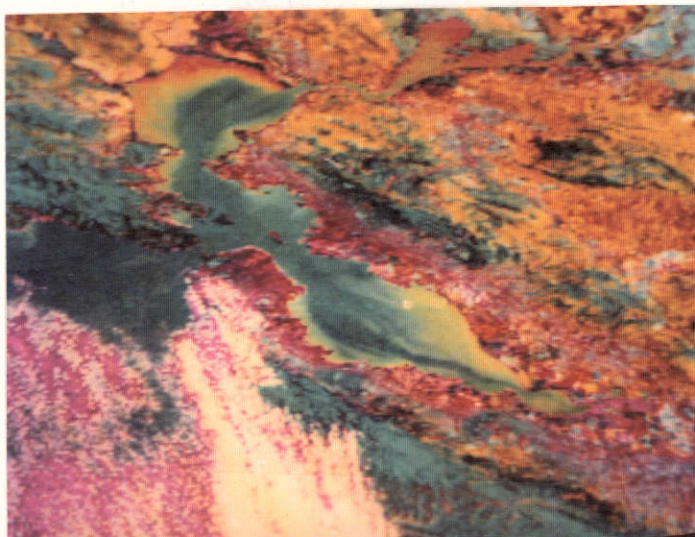


Figure 1. Bay Area, Image 1165-18175
MSS 4,5,6,7 Principal Components, Enhanced

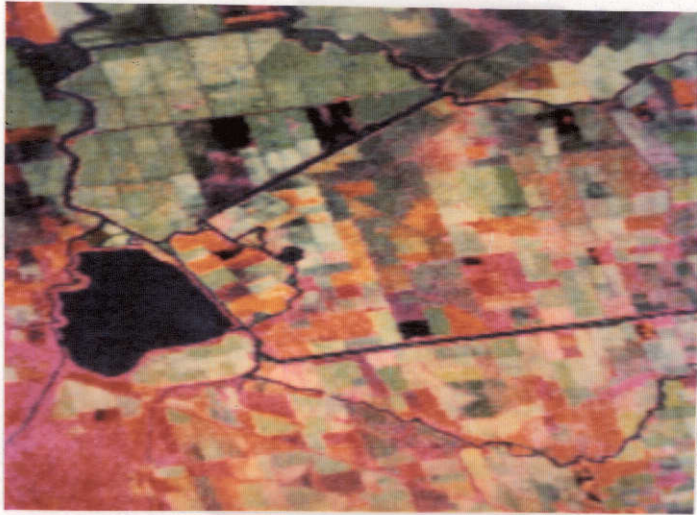


Figure 2. Farmland South of Isleton, Image 1003-18175
MSS 4,5,6,7 Principal Components, Enhanced

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Special Study No. 2

SEPARATION OF MANMADE AND NATURAL PATTERNS IN HIGH ALTITUDE
IMAGERY OF AGRICULTURAL AREAS

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1. Abstract

This work includes the design and implementation of a nonstationary linear digital filter which extracts the natural features from high altitude imagery of agricultural areas. Essentially, from an original image a new image is created which displays information related to soil properties, drainage patterns, crop disease and other natural phenomena, and contains no information about crop type.

A model is developed to express the recorded brightness in a narrow band image in terms of crop type and crop vigor and which describes statistically the spatial properties of each. Based on this model, the form of the minimum mean square error linear filter for estimation of the natural component of the scene is derived and a suboptimal filter is implemented. Nonstationarity of the two dimensional random processes contained in the model requires a unique technique for deriving the optimum filter.

Finally, the filter depends on knowledge of field boundaries. An algorithm for boundary location is proposed, discussed and implemented.

2. Introduction

Two projects designed to explore the possibilities of application of extremely high altitude imagery to the study of earth resources have born fruit in the last two years. The Earth Resource Technology Satellite (ERTS) and Skylab programs have provided thousands of images taken at altitudes of several hundred miles.

Image processing of various types can be a valuable tool in preparing images for viewing, substantially increasing their utility. Several categories of image processing exist. Three of the most commonly practiced can be described as follows: The first is automatic identification and appropriate labeling of items portrayed in an image [8], [11], [19], [25]. The second is removal from the image of noise and distortion introduced in the recording and transmitting process [25], [30], [31], [32]. The third consists of methods of distorting an image to improve certain image properties such as contrast and brightness, or to emphasize certain specific image contents such as edges [1], [25]. The last two methods are not directly related to the goals of the user of the imagery, while the first method assumes the items for which the user is looking can be well defined and specified. In the ensuing sections a new image processing approach is derived and explained. This concept lies between the extremes characterized by the first method on the one hand and the second and third on the other hand.

The underlying philosophy can be stated as follows: In many cases, automatic labeling of specific items of interest is not possible because of the complexity of the information desired, or because the properties of interest are not well defined, or finally because a human interpreter presented with the data in a proper form can make better judgements about the contents and significance of the information. It may be possible, however, for the user to specify certain features of the scene recorded in an image that obscure the desired information. Using knowledge of these features and any a priori information about the features of the image which are of interest, it may be possible to remove the obscuring features from the image. Then the processed image can be given to a human interpreter to analyze. In essence, we are taking the point of view that features in an image which are extraneous to the task at hand can be viewed as noise in the classical communication theory sense.

The following work consists of the application of this philosophy to a specific problem. In particular, a processing method is designed and implemented.

The goal of the processing is separation of the manmade and natural patterns in high altitude imagery of agricultural areas, and in particular, the extraction and display of the natural patterns. For many subjects of earth resource study, the actual planting patterns are of secondary interest. Often of primary interest are soil properties and hydrological properties of the earth [6]. Several factors combine to obscure the soil and hydrological features in agricultural areas. Among these are the vegetation canopy, the large variations in reflectance among different crops, the user of high altitude imagery is faced with the problem of separating contributions to the image due to what is growing and due to how well it is growing. Generally, for study of soil properties, the health of the crops is more useful. The goal of the processing method discussed here is to create a new image, which conveys information about crop health but not about crop type, from an original image. Since variations in reflectivity within any crop due to crop health, removal of crop type information allows fuller use of the contrast range of the display medium.

The processing method is derived as follows: First the original image is modeled in section three as a sample function of a random field (a random process indexed by a two dimensional parameter). This model relates the image to its manmade (crop type) and natural (crop vigor) components and reflects spatial properties of the two components. By appropriate transformation of the image, contribution of the two components is made additive. Based on the statistical model, a linear estimator is derived in section four which approximates the optimum linear mean square error estimator for the natural component. The filter requires knowledge of field boundaries. For this reason, in section five an algorithm for locating field boundaries is devised. Finally, section six contains a discussion of the implementation and results of the overall enhancement algorithm.

Before going into the filtering method, it is useful to briefly describe the ERTS and its image products

3. ERTS

ERTS-1, launched July 23, 1972, was the primary source of pictures used in the work described below [21]. In order to model the images, as is done in the next section, it is necessary to briefly describe the ERTS imaging equipment. ERTS, which orbits the earth at an altitude between 900 and 950 kilometers, has two kinds of sensors. One is a set of three return beam vidicon tubes, and the other is a multispectral scanner. Each of the vidicon tubes records electromagnetic energy in a different narrow spectral band. The multispectral scanner records the energy in four separate bands from .5 to 1.1 microns. Since the multispectral scanner produced the images used in the following sections, further description of it is required. Essentially, using an array of optical fibers, energy is fed to photomultipliers for the three shortest wavelength bands (.5 to .6, .6 to .7, and .7 to .8 microns) and to silicon photo diodes for the .8 to 1.1 micron band. The outputs of the photomultipliers and photodiodes are analogue signals which are immediately digitized by a digital multiplexer. Output of the multiplexer goes either to a modulator for direct transmission to the earth or is recorded on tape for subsequent transmission. A moving mirror aboard the spacecraft permits the recording of one picture line of approximately 3200 points perpendicular to the vehicles path using only one optical fiber per spectral band. In order to allow for return of the mirror, six lines are swept out at a time using six photosensors in each spectral band. Motion of the ERTS along its flight path makes possible recording of successive picture lines. Each fiber passes to its respective photosensor light coming to it from an imaginary four sided pyramid extending from the fiber at the apex down to the earth at its base. The width of the square base of this pyramid is approximately 79 meters. On the ground, computer compatible tapes are produced for distribution to users. Based on the method of recording, quantizing, and transmitting the image, it has been estimated [21, page A9] that the error in radiance recorded on the user distributed tapes due to causes other than quantization, is comparable with the quantization error.

4. The Model

In order to provide the photo interpreter with an image in which only the natural patterns are displayed, we model the image in terms of the contribution of the manmade component and the natural component. This involves modeling the spatial characteristics of manmade and natural patterns as well as determining how the recorded image brightness is related to the two components.

A narrow band spectral image can be viewed as a raster with a real valued function defined at every point of the raster. Each point (x,y) , of the raster corresponds with a point (or more precisely, a small area) in the target scene of the camera or photodetector, and the value of the real valued function, $\phi(x,y)$, is proportional to the amount of electromagnetic energy (in the narrow spectral band) emanating from the corresponding target point.

For the cases of interest here, wavelengths less than 1.1 microns, the electromagnetic energy is primarily reflected solar energy (10).

Thus $\phi(x,y)$ is the product of the incident energy, $I(x,y)$, the reflectivity, $R(x,y)$, and the atmospheric transmissivity, $T(x,y)$, plus the atmospheric radiance, $N(x,y)$. That is,

$$\phi(x,y) = I(x,y)R(x,y)T(x,y) + N(x,y) \quad (1)$$

It is generally assumed that the percentage of incident energy which is reflected is independent of the amount of incident energy; that is, that $I(x,y)$ and $R(x,y)$ are unrelated.

Now, in order to make further progress, we must cast our problem into a stochastic framework. Consider the following experiment. We pick an area of interest on the earth and place a camera in orbit, aimed such that the camera remains fixed relative to the target. Each trial of the experiment consists of recording the image viewed by the camera. The brightness, $\phi(x,y)$, recorded at each point, (x,y) , is not fixed for all trials but varies according to some probabilistic distribution. Thus, each image (experimental outcome) consists of a set of values of a family of random variables indexed by an order pair (x,y) . Equivalently, each image is a sample function of a random field (a two dimensional process to be distinguished from an agricultural field). We then take ϕ , I , T , R , and N to be random fields. In addition, we allow the possibility of an additive noise, $\eta(x,y)$, effecting the recorded brightness. effecting the recorded brightness. This leads to the form

$$\phi(x,y) = I(x,y)R(x,y)T(x,y) + \eta(x,y) + N(x,y) \quad (2)$$

We next assume that the incident illumination is the same over the entire scene. This approximation is quite good in flat agricultural areas where shadows are minimal. Similarly, we assume $T(x,y)$ and $N(x,y)$ constant in each image. We will operate on sections of ERTS images corresponding on earth to approximate rectangles having sides of length on the order of ten miles. Using other imagery the area covered will be smaller. Hence the assumptions that T and N are constant are reasonable. For the sake of simplicity, we now rescale the reflectivity and the "transmissivity, incident radiation product" in such a way that IRT remains unchanged but IT equals one. This allows us to write

$$\phi(x,y) = R(x,y) + \eta(x,y) + N \quad (3)$$

At this point, we consider the atmospheric radiance, that portion of the light recorded by the sensor which is due to scattering by the atmosphere. It is to a first approximation independent of the ground scene observed by the sensor. Thus, if we assume that the atmosphere is reasonably uniform as a function of horizontal position, then the atmospheric radiance can be considered constant over the entire scene covered by the image. Now, since radiance is always positive (it is a measure of energy), and since atmospheric radiance is assumed constant over an entire image, the atmospheric radiance recorded must be less than or equal to the minimum brightness in an image.

The amount of energy scattered by the atmosphere, as given by Rayleigh's Law, is inversely proportional to the fourth power of the radiation's wavelength. Hence, atmospheric radiance increases substantially as wavelength decreases. In the spectral bands available from ERTS, the amount of atmospheric scatter is small as can be seen from the work done by Horvath, Braithwaite, and Polcyn [15]. Hence, atmospheric radiance will be considered negligible for purposes of the present problem. Thus, the final model we have to deal with is

$$\phi(x,y) = R(x,y) + n(x,y) \quad (4)$$

Now all the information available in the image about the target scene is contained in the $R(x,y)$ term. The reflectivity at any given point in the scene depends on the type and vigor of the ground cover. In order to model the interaction between the "manmade" and "natural" components, it is necessary to first make a number of observations about the two components.

First, it is evident that at approximately 79 meter resolution provided by the ERTS, individual lines of a crop cannot be distinguished. In fact, energy entering each optical fiber corresponds with radiation from many rows of crops. We assume that all other things being equal, a human being will plant his crop uniformly. Hence, were it not for natural disturbances such as variations in soil salinity, the reflectance within a field could be assumed constant.

Second, what is growing in one field, to a first approximation, does not effect what is growing in any other field. Therefore, the contribution of the manmade component to the reflectance in one field is independent of the contribution to the reflectance in another field.

Now we make the assumption that both the manmade and natural contributions can be represented as random fields. Then third, the natural disturbances which affect crop reflectance have no preferred direction and a priori can be expected with equal likelihood anywhere

in the image. More precisely, we assume that the correlation of the natural contribution at two points on the image depends only on the distance between the points. Equivalently, the correlation function of the natural contribution is assumed translation invariant and rotation invariant. This kind of assumption is a commonly made one when digital filtering is applied to imagery [9], [17]. It is used whenever size is a good parameter to describe a scene, and direction and location have little significance.

As a further observation, it may be seen that variations in the reflectance caused by natural phenomena cross boundaries, and, in fact, are independent of the boundaries.

A last observation is that the variations in reflectance between fields tend to be much larger than variations in reflectance within a particular field. The variations within a field represent natural patterns. These natural variations, in turn, are significantly greater than the noise which is only about one quantization level.

Based on the observations of the previous paragraphs, we are now in a position to specify the model. We postulate that $R(x,y)$ can be expressed as

$$R(x,y) = \phi(x,y)\zeta(x,y) \quad (5)$$

where $\phi(x,y)$ contains all information about the type of ground cover, and $\zeta(x,y)$ contains all information about the vigor of the ground cover. This assumption means equivalently that the reflectivity of any given ground cover is proportional to its vigor.

Two experiments were carried out to check the validity of this assumption and appear in reference [29]. While these experiments provide corroboration of the postulate, the ultimate justification must lie in the ability of the resulting image processing method to make the photo interpretation task easier. Hence in the interest of brevity these experiments are not discussed here.

Instead, we present several arguments which motivate choice of the multiplicative model. First, it is well known that both type and vigor of a vegetation canopy contribute to the reflectance of that canopy. Detailed studies for specific crops abound in the literature. A study by Ausmus and Hilty [2] shows that the reduction in reflectance of corn due to two different infections is approximately proportional, at each spectral frequency between .8 and 2.4 microns, to the reflectance of the healthy plant. Similar results for cotton can be found in Gausman et al [12]. For water infiltration into the intercellular spaces of bean leaves, an analogous effect is demonstrated by Knipling [16]. Most of these studies deal with reflectance of individual plants or leaves, although some consider reflectance properties of entire canopies.

Second, in order to apply available analytical techniques, it is desirable to find as simple a model as well reasonably describe the physical facts and/or will lead to a reasonable processing approach.

Third, an additive model violates physical reasoning. Reflectance is a quantity which must always be positive. Suppose the reflectance in a certain spectral region of a given crop at a specific level of vigor is very low. For example, most green vegetation, no matter how vigorous, reflects very little in the red portion of the spectrum. Therefore, such vegetation appears very dark through a red filter. Clearly any decrease in reflectance due to change in vigor must be small, in order that the reflectance remain positive. However, some crops reflect substantially in the red region of the spectrum. A change in their vigor can substantially reduce their reflectivity. Therefore, equal reductions in vigor correspond to different changes in reflectivity in the two types of crops. Therefore, an additive model defies reality in a fundamental way.

Finally, existence of a multiplicative rule would imply that variations in vigor of an essentially dark plant would result in considerably smaller reflectance variations than the reflectance changes resulting from equal changes of vigor in a normally bright plant. As a general rule, this implication of a multiplicative rule conforms with every day experience.

Based on the two experiments and on the motivating arguments above, a multiplicative model is proposed. Hence our model is

$$\phi(x,y) = \theta(x,y)\zeta(x,y) + \eta(x,y) \quad (6)$$

Before describing in further detail the statistical properties of the manmade and natural components, we make some definitions:

$$f'(x,y) \triangleq \log \phi(x,y) \quad (7)$$

$$l'(x,y) \triangleq \log \theta(x,y) \quad (8)$$

$$g'(x,y) \triangleq \log \zeta(x,y) \quad (9)$$

$$n'(x,y) \triangleq \log \left[1 + \frac{\eta(x,y)}{\theta(x,y)\zeta(x,y)} \right] \quad (10)$$

Then we have

$$f'(x,y) = g'(x,y) + l'(x,y) + n'(x,y) \quad (11)$$

Let g , f , l , and n be the expectations of g' , f' , l' , and n' respectively.

Now we define

$$\begin{aligned} g &\triangleq g' - \bar{g} & l &\triangleq l' - \bar{l} \\ f &\triangleq f' - \bar{f} & n &\triangleq n' - \bar{n} \end{aligned}$$

Therefore, by the linearity of the expectations, we have

$$f(x,y) = g(x,y) + l(x,y) + n(x,y) \quad (12)$$

In (23) $g(x,y)$ contains all pertinent information about the natural patterns. We choose to estimate $g(x,y)$ rather than $g'(x,y)$ for two reasons. First, the constant DC term is irrelevant for finding contours corresponding with natural patterns. Second, estimation of g' requires knowledge of \bar{g} , \bar{x} , and \bar{y} , all of which are unavailable.

Now, in order to design a near optimum linear filter, it is necessary to estimate the correlation functions of f , g , l , and n . Some further notation is useful first.

Let $\underline{t} \triangleq (x,y)$

$F(\underline{t}) \triangleq$ field to which \underline{t} belongs

$N \triangleq$ the number of fields in an image raster.

$Q_k(\underline{t}) \triangleq$ 1 when \underline{t} belongs to the k th field
0 otherwise.

First, we consider the correlation function of l , the manmade component. It has already been observed that the manmade component is constant within any field and independent of the manmade component in any other field. Hence

$$E[l(\underline{t}), l(\underline{\tau})] = \overline{l^2} \delta_{F(\underline{t}), F(\underline{\tau})} \quad (13)$$

where δ is the Kroneker delta

and $\overline{l^2}$ is the variance of l

For the natural component, g , the correlation function is translation invariant and rotation invariant based on previous observations. The initial part of the derivation of the filter in the next section does not depend on assuming more about g . We have also observed that natural changes are gradual and aperiodic. Based on these considerations, a correlation function which decays monotonically as a function of distance is an exponentially decaying one.

As exponential correlation function has merit because it depends only on two parameters and makes possible a closed form solution of the problem. Thus we have

$$R_g(\underline{t}-\underline{\tau}) = E[g(\underline{t})g(\underline{\tau})] = Ke^{-\alpha|\underline{t}-\underline{\tau}|} \quad (14)$$

where K is the variance of g and α is the decay constant.

We assume α is unknown for the present.

The correlation function of n is computed as follows:

$$E n(\underline{t})n(\underline{\tau}) = E\{[n'(\underline{t})-\bar{n}][n'(\underline{\tau})-\bar{n}]\} \quad (15)$$

$$= E n'(\underline{t})n(\underline{\tau}) - \bar{n}^2 \quad (16)$$

$$\text{Now } n'(\underline{x}, \underline{y}) = \log \left[1 + \frac{\eta(\underline{x}, \underline{y})}{\theta(\underline{x}, \underline{y})\zeta(\underline{x}, \underline{y})} \right]$$

The noise, $\eta(\underline{t})$, as mentioned before, consists of approximately equal contributions due to sensor noise and quantization error. Therefore, a total error of about one quantization level can be expected. Thus $\theta(\underline{x}, \underline{y})\zeta(\underline{x}, \underline{y})$ is much larger than $\eta(\underline{x}, \underline{y})$ in every image. Therefore

$$n'(\underline{x}, \underline{y}) \approx \frac{c\eta(\underline{x}, \underline{y})}{\theta(\underline{x}, \underline{y})\zeta(\underline{x}, \underline{y})} \quad \text{where } c \text{ is a constant depending on the base of the logarithm} \quad (17)$$

Consequently

$$E n'(\underline{t})n'(\underline{\tau}) = \frac{c^2 E \eta(\underline{t})\eta(\underline{\tau})}{E \theta(\underline{t})\theta(\underline{\tau}) E \zeta(\underline{t})\zeta(\underline{\tau})} \quad (18)$$

By adding an appropriate constant to the original image, any bias in $n(\underline{t})$ due to quantization can be eliminated. Then $n(\underline{t})$ is zero mean and uncorrelated from point to point due to the fact that variations in ϕ tend to be large compared with the size of a quantization level. Hence

$$R_n(\underline{t}-\underline{\tau}) \triangleq E[n(\underline{t})n(\underline{\tau})] \approx \overline{n^2} \delta_{\underline{t},\underline{\tau}} \quad (19)$$

It should be pointed out that in fact the multispectral scanner aboard ERTS had the following difficulty: As previously described, each spectral component was recorded using six photosensors. These photosensors became less uniform in their behavior as the flight progressed. Consequently, error due to the lack of calibration of these sensors became significant. Striping with a six line periodicity occurs in much of the later multispectral scanner imagery. The images used in this work were from the early portion of the life of ERTS and therefore, suffer unnoticeably from sensor nonuniformity. Several methods have been proposed for correcting the streaking a posteriori, with reasonable success. Among these methods is one proposed by V. Algazi [1]. These methods can be applied to imagery before the procedures for enhancing natural patterns is applied, thus maintaining the validity of the model.

5. The Optimum Filter

We now have a model of the image to which we can apply the techniques of filtering theory. The contribution to the image of the natural patterns is represented by the g component. Thus, it is g we wish to estimate.

We consider estimating $g(\underline{t})$ with a linear estimator, $\hat{g}(\underline{t})$, based on $f(\underline{\tau})$ for all $\underline{\tau}$ belonging to T , where T is the set of points in the picture. Thus

$$\hat{g}(\underline{t}) = \sum_{\underline{\tau} \in T} h_{\underline{t}}(\underline{\tau}) f(\underline{\tau})$$

It was with a linear filter in mind that g and ℓ were defined as they were in the previous section. The concept of transforming essentially nonadditive processes into an additive form and applying linear filtering theory is called homomorphic filtering [22]. Because the processes involved are not all stationary, the filter $h_{\underline{t}}(\cdot)$ will be derived for a fixed but arbitrary point \underline{t} . As error criterion we choose mean square error. This is just one of a variety of possible error measures [3], [27], [28]. However, application of linear filtering with mean square error criterion has been effectively applied to many signal processing problems and is at the heart of both Wiener filtering and Kalman-Bucy filtering [23].

Now using the notation developed in the previous section, the estimation problem can be formalized as follows:

$$\text{choose } h_{\underline{t}}(\underline{\tau}) \quad \forall \underline{\tau} \in T \text{ and define } \hat{g}(\underline{t}) \triangleq \sum_{\underline{\tau} \in T} h_{\underline{t}}(\underline{\tau}) f(\underline{\tau}) \quad (20)$$

$$\text{such that } E[g(\underline{t}) - \hat{g}(\underline{t})]^2 \leq E[g(\underline{t}) - \hat{g}(\underline{t})]^2 \quad (21)$$

for any $\hat{g}(\underline{t})$ a linear estimate of $g(\underline{t})$.

In order to determine $\hat{g}(\underline{t})$, we invoke the essential idea basic to all problems of linear mean square error estimation, the orthogonality principle, which states that a necessary and sufficient condition for the optimality of $\hat{g}(\underline{t})$ is that

$$E\{[g(\underline{t}) - \hat{g}(\underline{t})]f(\underline{\xi})\} = 0 \quad \forall \underline{t}, \underline{\xi} \in T \quad (22)$$

(See for example Davenport and Root [7]). At the outset of the derivation, we will make no assumptions about $g(\cdot)$ except that it be wide sense stationary with zero mean and uncorrelated with ℓ and n . For ℓ and n we will assume the correlation functions specified in the last section.

Thus, the derivation which follows will obtain the optimum filter $h_{\underline{t}}(\cdot)$ in terms of $R_g(\cdot)$. We now begin our derivation with Eq. (22).

$$\text{eq. (22)} \iff E[g(\underline{t})f(\underline{\xi})] = \sum_{\underline{\tau} \in T} h_{\underline{t}}(\underline{\tau}) E[f(\underline{\tau})f(\underline{\xi})] \quad (23)$$

$$\iff R_g(\underline{t}-\underline{\xi}) = \sum_{\underline{\tau} \in T} h_{\underline{t}}(\underline{\tau}) R_g(\underline{\tau}-\underline{\xi}) + \ell^2 \sum_{\underline{\tau} \in F(\underline{\xi})} h_{\underline{t}}(\underline{\tau}) \quad (24)$$

$$+ n^2 h_{\underline{t}}(\underline{\xi})$$

where $F(\underline{\xi}) \subset T$ is the set of all points T belonging to the same agricultural field as $\underline{\xi}$. In order to proceed further, at this point we break up $h_{\underline{t}}(\underline{\tau})$ into two components in the following way:

$$h_{\underline{t}}(\underline{\tau}) = \sum_{k=1}^N \mathcal{Q}_k(\underline{\tau}) H_{\underline{t}, F_k} + p_{\underline{t}}(\underline{\tau}) \quad (25)$$

where F_k is the k th field, $k=1, \dots, N$
 A_k is the number of points belonging to F_k

and
$$\sum_{\underline{v} \in F_k} h_{\underline{t}}(\underline{v}) = H_{\underline{t}, F_k} A_k \quad k=1, \dots, N$$

$$\mathcal{Q}_k(\underline{\tau}) = \begin{cases} 1 & \underline{\tau} \in F_k \\ 0 & \underline{\tau} \notin F_k \end{cases}$$

Then returning to Eq. (24), taking two sides, two dimensional z transforms of both sides with \underline{z} as the space domain variable, and taking advantage of convolution property of the 2 sided z transform, we obtain

$$\text{eq. (24)} \iff P_{\underline{t}}(\underline{z}) = \frac{S_g(\underline{z})}{S_g(\underline{z}) + n^2} z_1^{-x} z_2^{-y} \quad (26)$$

$$- \sum_{k=1}^N H_{\underline{t}, F_k} \left\{ \frac{I_k(\underline{z}) S_g(\underline{z})}{S_g(\underline{z}) + n^2} + \frac{(n^2 + 1^2 A_k) I_k(\underline{z})}{S_g(\underline{z}) + n^2} \right\}$$

where $\underline{z} = (z_1, z_2)$ $\underline{t} = (x, y)$

$$I_k(\underline{z}) = \mathcal{Z}[\mathcal{Q}_k(\underline{\tau})]$$

$$S_g(\underline{z}) = \mathcal{Z}[R_g(\underline{\tau})]$$

$$P_{\underline{t}}(\underline{z}) = \mathcal{Z}[p_{\underline{t}}(\underline{\tau})]$$

$$\sum_{\tau \in T} p_{\underline{t}}(\tau) \mathcal{Q}_j(\tau) = \sum_{\tau \in T} h_{\underline{t}}(\tau) \mathcal{Q}_j(\tau) - \sum_{k=1}^N H_{\underline{t}, F_k} \sum_{\tau \in T} \mathcal{Q}_k(\tau) \mathcal{Q}_j(\tau)$$

$$= \check{H}_{\underline{t}, F_j} A_j - H_{\underline{t}, F_j} A_j = 0 \quad (27)$$

for $j = 1, \dots, N$

Therefore, by performing the summation specified on the left side of Eq. (27); substituting for $p_{\underline{t}}(\tau)$ the expression obtained by inverse z transforming (26); we obtain N linear equations with N unknowns, $H_{\underline{t}, F_k}$, $k = 1, \dots, N$. That is, we have to find a solution to the equation $C = DH$ (H unknown) where

$$H = \begin{bmatrix} H_{\underline{t}, F_1} \\ \vdots \\ H_{\underline{t}, F_N} \end{bmatrix} \quad (28)$$

$$C = \begin{bmatrix} \sum_{\tau \in T} \mathcal{Q}_1(\tau) \mathcal{Z}^{-1} \left[\frac{S_g(z)}{S_g(z) + n^2} z_1^{-x} z_2^{-y} \right] \\ \vdots \\ \sum_{\tau \in T} \mathcal{Q}_N(\tau) \mathcal{Z}^{-1} \left[\frac{S_g(z)}{S_g(z) + n^2} z_1^{-x} z_2^{-y} \right] \end{bmatrix} \quad (29)$$

$$D = [d_{ij}], \quad i = 1, \dots, N, \quad j = 1, \dots, N \quad (30)$$

in which

$$d_{ij} = \sum_{\tau \in T} \left\{ \mathcal{Z}^{-1} \left[\frac{I_j(z) S_g(z)}{S_g(z) + n^2} + \frac{(n^2 + 1^2 A_j) I_j(z)}{S_g(z) + n^2} \right] \mathcal{Q}_i(\tau) \right\}$$

There must exist at least one solution of these equations since the equations are by construction mutually consistent. If D is invertible, the solution is unique and is given by

$$H = D^{-1}C \quad (40)$$

Now for a specific correlation function, H can be calculated. Then using (26), $p_t(\tau)$ can be specified, and thus by (25), the filter can be determined.

Up to this point in the derivation of the filter, we have used only one assumption about the correlation function of $g(\cdot)$: that it is solely a function of distance. Now we incorporate our assumption that the correlation function of $g(\cdot)$ decreases exponentially with distance.

The set of points for which we know $f(\underline{\tau})$ has been earlier defined as T . Suppose we want to estimate $g(\underline{t})$ where $\underline{t} = (x, y)$. For reasons given in the paragraphs below, we consider a suboptimal filter.

$$\text{Let } T_x = \{\underline{\tau} | \underline{\tau} = (x, \tau_2), \underline{\tau} \in T\}$$

$$\text{Let } T_y = \{\underline{\tau} | \underline{\tau} = (\tau_1, y), \underline{\tau} \in T\}$$

We consider a suboptimal estimate of $g(\underline{t})$ of the following form

$$\hat{g}(\underline{t}) \triangleq \frac{1}{2} [\hat{g}_1(\underline{t}) + \hat{g}_2(\underline{t})] \quad (41)$$

where $\hat{g}_1(\underline{t})$ is the optimal linear filter given $f(\underline{\tau}) \forall \underline{\tau} \in T_x$ and $\hat{g}_2(\underline{t})$ is the optimal linear filter given $f(\underline{\tau}) \forall \underline{\tau} \in T_y$. Now $\hat{g}_1(\underline{t})$ is determined under the condition that $R_g(\underline{t}, \underline{\xi}) = Ke^{-\alpha|\underline{t}-\underline{\xi}|}$. The same derivation applies to $\hat{g}_2(\underline{t})$.

There are several reasons for limiting ourselves to this suboptimal estimate. First, while it is possible to derive $\hat{g}_1(t)$ and $\hat{g}_2(t)$ (since the one dimensional z transform of $Ke^{-\alpha|t|}$ is calculable in closed form and is a rational function); the two dimensional z transform of $Ke^{-\alpha|t|}$ is not calculable in closed form and therefore makes impossible calculation of a general expression for the optimal two dimensional filter as a function of α . For a given set of boundaries, and for a specific α , the optimum two dimensional filter can be approximated numerically. Based on such an approximation, it is evident that the optimum filter depends on the orientation of each boundary with respect to the square raster of picture elements.

Second, $g_1(t)$ and $g_2(t)$ are themselves optimum estimates for the sets on which they are defined.

Third, implementation of both the optimum and suboptimum filters will depend on knowledge of field boundaries. Finding closed boundaries in two dimensions, however, is a time consuming and formidable task, particularly when the number of fields is large. Unless most of the boundaries are closed, the two dimensional filter cannot be implemented since it requires taking average over entire fields. On the other hand, the one dimensional filter can be implemented if only most of the boundary points are known, independent of closure of the boundaries, since it requires taking averages over only portions of fields.

Fourth, errors caused by overlooking a boundary point are of a very predictable form for the one dimensional filter and can be eliminated. (See section six for further detail.)

Fifth and last, the mean squared error obtained by using $\hat{g}(t)$, as given by (41), as the estimator must be less than the average mean square error obtained by using either $\hat{g}_1(t)$ or $\hat{g}_2(t)$ alone as the estimators. In fact, depending on α and the area of the fields, the mean squared error of $\hat{g}(t)$ can approach half the average mean square error of $\hat{g}_1(t)$ and $\hat{g}_2(t)$. It should be noted here that the squared error for the suboptimal estimate is for most values of α below 10 percent of the variance of g , and in the worst case is 15 percent of the variance of g .

Now, in order to determine the optimum filter, we must find the C vector and the D matrix described above. The details are omitted for the sake of brevity. By making two observations, we can easily obtain close approximations to C and D. These observations depend on the actual values assumed by the following parameters of the model. They are $\frac{\sigma^2}{K}$ (greater than 10); the size of a field, A_k , (approximately 10 samples); the correlation distance, $1/\alpha$, of the natural component (less than 10 samples); and K/n^2 (greater than 3).

Based on these bounds on the parameters, we can make the following two observations:

Observation 1

$$\overline{(n^2 + l^2 A_k)} (e^\alpha + e^{-\alpha} - 2) \gg K(e^\alpha - e^{-\alpha}) \quad (42)$$

Observation 2

$$e^{-A_k \gamma} \ll e^{-\gamma} < 1 \quad (43)$$

where γ is defined as

$$\gamma \triangleq \operatorname{arccosh} \left\{ \left(\frac{1}{2} \right) \left[(K/n^2 + 1)e^\alpha + (K/n^2 - 1)e^{-\alpha} \right] \right\}$$

In order to specify the C vector and D matrix, it is necessary to index the field. For mathematical convenience, we pick the ordering such that

if

$$\underline{\tau}' \triangleq (\tau_1', \tau_2') \quad \underline{\tau}'' = (\tau_1'', \tau_2'')$$

then $F(\underline{\tau}') > F(\underline{\tau}'')$ whenever $\tau_2' > \tau_2''$;

The result of the assumptions and the way we have indexed the fields is that if $C \triangleq [c_m]$ and $D \triangleq [d_{1j}]$

$$\text{then } c_m = K(e^\alpha - e^{-\alpha}) \sum_{\xi=a_m}^{b_m} e^{-\alpha |\xi - t|} \quad (44)$$

where $[a_m, b_m]$ is the set of points belonging to field m and T_x

and

$$d_{ii} = \sqrt{(n^2 + l^2) A_i} \{ (e^\alpha + e^{-\alpha} - 2) (A_i) + 2 \} \quad (45)$$

$$+ \frac{2(e^\alpha + e^{-\alpha} - 2)e^{-2\gamma}}{1 - e^{-\gamma}} + \frac{4e^{-\gamma}}{(1 - e^{-\gamma})^2} \}$$

$$d_{ij} = \sqrt{(n^2 + l^2) A_j} e^{-\gamma(s_{ij} - 1)} \left[1 + \frac{2 - (e^\alpha + e^{-\alpha})}{(1 - e^{-\gamma})^2} e^{-\gamma} \right]$$

for $i \neq j$

$$\text{where } s_{ij} = \min_{\xi \in F_j} \min(|\xi - a_i|, |\xi - b_i|)$$

In order to determine the optimum filter, we need D^{-1} . By observing that the magnitude of elements in the D matrix decreases substantially as one moves away from the main diagonal of the matrix, we are led to the following approximation of D^{-1} based on the binomial expansion.

Let $F = [f_{ij}]$ such that

$$f_{ij} = \begin{cases} d_{ij} & i = j \\ 0 & \text{otherwise} \end{cases}$$

Let $G = [g_{ij}]$ such that

$$g_{ij} = \begin{cases} d_{ij} & |i-j| = 1 \\ 0 & \text{otherwise} \end{cases}$$

$$\text{Then } D^{-1} \approx F^{-1} - F^{-1} G F^{-1}$$

(46)

We are now in a position to obtain a closed form expression for the suboptimal filter. If $e^{-\gamma}$ is sufficiently small, we obtain

$$H_1 = \begin{cases} \frac{K(e^\alpha - e^{-\alpha})}{(n^2 + \lambda^2 A_1^2) [(e^\alpha + e^{-\alpha} - 2)A_1 + 2]} & |1-m| = 1 \\ \frac{K(e^\alpha - e^{-\alpha})}{(n^2 + \lambda^2 A_m^2) [(e^\alpha + e^{-\alpha} - 2)A_m + 2] [(e^\alpha + e^{-\alpha} - 2)A_1 + 2]} & |1-m| = 1 \\ 0 & |1-m| > 1 \end{cases} \quad (47)$$

where $\underline{t} \in F_m$

Therefore, by inverse z transforming (26), and substituting into (25)

$$\underline{h}'_t(\underline{\tau}) \approx \delta_{\underline{t}, \underline{\tau}}$$

$$= \frac{(e^\alpha + e^{-\alpha}) \mathcal{J}_m(\underline{\tau}) - \mathcal{J}_m(\underline{\tau}+1) - \mathcal{J}_m(\underline{\tau}-1)}{[(e^\alpha + e^{-\alpha} - 2)A_m + 2]}$$

$$= \frac{(e^\alpha + e^{-\alpha}) \mathcal{J}_{m+1}(\underline{\tau}) - \mathcal{J}_{m+1}(\underline{\tau}+1) - \mathcal{J}_{m+1}(\underline{\tau}-1)}{[(e^\alpha + e^{-\alpha} - 2)A_m + 2] [(e^\alpha + e^{-\alpha} - 2)A_{m+1} + 2]}$$

$$= \frac{(e^\alpha + e^{-\alpha}) \mathcal{J}_{m-1}(\underline{\tau}) - \mathcal{J}_{m-1}(\underline{\tau}+1) - \mathcal{J}_{m-1}(\underline{\tau}-1)}{[(e^\alpha + e^{-\alpha} - 2)A_m + 2] [(e^\alpha + e^{-\alpha} - 2)A_{m-1} + 2]}$$

for $\underline{t} \in F_m$ and $\underline{1} = (0, 1)$

It should now be pointed out that the filter that has been derived has several desirable properties. The first is that only the first of the four terms depends on \underline{t} itself. The other three terms depend only on $F(\underline{t})$ and hence are constant in any field. This means that the last three terms need to be calculated only once in every field, thus reducing the required computation time. Since the first term is a Kronecker delta, it is evident that the estimate in which we are interested is of the form $\hat{g}_1(\underline{t}) = f(\underline{t}) - k(F(\underline{t}))$. Thus, the filter only requires calculation of one constant in each field and performance of one subtraction at every point in the picture. The optimum two dimensional filter can be approximated by the same form. However, for the optimum filter, $k(F(\underline{t}))$ will depend on the orientation of field boundaries. Furthermore, no closed form expression for k as function of the set of boundaries and of α is possible.

The second nice property of the filter is that it requires information only from five fields to calculate the constant $k(F(\underline{t}))$; that is, the five contiguous fields such that \underline{t} belongs to the middle field. Equivalently, the support of the filter is relatively small. This again reduces the computation time. In fact, by inspection of (48) we can see that $k(\underline{t})$ depends only on the average values of f in each of three fields and the differences in the values of f at four boundaries.

The third desirable property of the filter is that it does not depend on ℓ^2 , K , or n^2 . We have eliminated this dependency essentially by one previous assumption. This assumption is that $\ell^2 \gg K \gg n^2 e^{-\alpha}$. Consequently, in order to specify the filter we need simply to know boundary locations and the value of α .

6. Boundary Location

In the foregoing section, it was shown that implementation of the optimum filter requires knowledge of field boundaries.

Essentially, field boundary location can be viewed as an edge finding problem. Many methods for attacking such problems have been discussed in the literature. (See for example, Rosenfeld [26], Montanari [20], and Underwood and Aggarwal [33].)

There are several approaches to the problem. One alternative is human boundary location. The advantage of this approach is that a human can generally pick out the boundaries quite readily. One of the disadvantages is that the number of boundary points is very large and consequently this method is time consuming. A further disadvantage is the difficulty for a human to specify the exact location of the boundaries.

Another approach to the problem is to specify some known boundary point, then allow a computer program to proceed along the boundary by specifying certain properties that a boundary must satisfy. For the

application of this method to the determination of field boundaries: see Kuehn et al [18]. An advantage of this approach is that it is necessary externally to supply only the location of one boundary point. Also, since a known boundary point is initially specified, it is possible to take advantage of such properties of boundaries as being closed. The disadvantage of this approach is that the necessary complexity of such an algorithm leads to a large computation requirement when a large percentage of points lies on boundaries.

A third approach to boundary finding is to specify certain properties of boundaries and test each point independently to determine if it satisfies these properties. One advantage of this method is that errors do not propagate. That is, if a false boundary point is accepted or a real boundary point is rejected, the decision at neighboring points will not be affected. A further advantage is that such an algorithm can be relatively simple and thus, when a large fraction of points lie on boundaries, can be much faster than a boundary following algorithm. The disadvantage of the third approach is that real boundary points may be missed and false boundary points may be found.

Because of the resolution of ERTS imagery, a large percentage of points lie on the boundaries (on the order of thirty to forty percent in some images). Furthermore, as will be shown in the next section, the lack or surplus of an occasional boundary point can be accounted for in the filter implementation due to the special nature of the filter. For these reasons, and because of the advantages given above, the third approach is taken here.

Two properties are used to define a field boundary. First, it is assumed that at a boundary there will be a sharp change in recorded brightness in at least one spectral band. Second, we assume that in the same spectral band, there will be a large difference in the value of the recorded brightness averaged over several points on one side of a boundary and the value of recorded brightness averaged over several points on the other side of that boundary.

In an image consisting of brightness values specified on a rectangular grid, every point which lies on a boundary is either horizontally adjacent or vertically adjacent to a boundary point in a neighboring field. Hence, a sharp change in recorded brightness at a boundary should occur in either the horizontal or vertical direction. Similarly, there should be a large difference in the average values taken in either the horizontal or vertical direction on opposite sides of a boundary. Thus, the algorithm we specify tests for boundary points that satisfy the conditions in either direction. The union of sets of points satisfying the conditions

It is possible in many cases to compensate for the errors due to inadequacies in boundary detection in one line if the boundary points in the two adjacent lines are found correctly. In most cases, if an error of the type described occurs, the value of the constant which is added will differ slightly from the correct value that the brightness of the filtered image on the set of points where the error occurred will be strictly greater or strictly less than the brightness of the filtered image in the two adjacent lines. That is, if filtering is done in the x direction then either $\hat{g}(x,y) \geq \hat{g}(x,y-1)$ and $\hat{g}(x,y) \geq \hat{g}(z,y+1)$, or $\hat{g}(z,y) \leq \hat{g}(z,y-1)$ and $\hat{g}(z,y) \leq \hat{g}(z,y+1)$ for all z in some interval of line y. Such a condition is unlikely to occur in nature. Consequently, by checking the filtered image for places where this condition occurs and adjusting the constant so that for the new estimate

$$\hat{g}(x,y), \sum_{x \in I} |2\hat{g}(x,y) - \hat{g}(x,y+1) - \hat{g}(x,y-1)|$$

is minimized (where I is the interval over which the error occurs), compensation of boundary detection errors is possible.

The steps involved in implementing the suboptimal filter can now be summarized as follows: 1) take the logarithm of the recorded brightness; 2) find the boundaries; 3) using the boundaries and the logarithm of the image, get horizontal and vertical estimates of the natural component; 4) remove streaks from the horizontal and vertical estimates; 5) average the horizontal and vertical estimates. Because the filtered images occupy only a small fraction of the contrast range of the display device, a nonlinear contrast stretching algorithm proposed by V. Algazi [1] is applied to the estimates for display purposes.

In addition to knowing the boundaries of the fields, the estimator depends on knowing α , the decay constant of the correlation function of the natural component of the image. For ERTS multispectral scanner imagery, the distance between points in the horizontal direction (perpendicular to the satellite's path) is smaller than the distance between points in the vertical direction (parallel to the satellite's path) in a ratio of approximately 5/7. Therefore, the value of α used in the vertical direction should be 7/5 times the horizontal value of α .

An image of an area near Firebaugh, California, where soil salinity is a known problem, was enhanced and is shown in Fig. 1. The height of the image in all the figures is greater than the width due to the fact that for ERTS imagery, the vertical distance between picture elements is greater than the horizontal distance. The imagery is not rectangular because as the satellite travels southward, recording succeeding image lines, the earth rotates eastward, causing each new line to be slightly further west than the last. The original, Fig. 1a, is the red spectral component. Figure 1b is the enhancement with $e^{-\alpha} = .7$. The white splotches

in either direction is the set of accepted boundary points.

We specify a function of the image which can be used to measure whether or not a point lies on a vertical boundary. Let

$$q(x,y) = (1/r)[f(x+1,y) - f(x,y)] \left[\sum_{v=1}^r f(x+v,y) - \sum_{v=0}^{r-1} f(x-v,y) \right]$$

where r is less than the number of samples in one line of one field. It can be shown, based on the model of the image described above, that points not on the boundary of a field generally have values of q close to zero, and that boundary points generally have values of q relatively far from zero. Thus, by picking an appropriate threshold, we can label as boundary points all points having a value of $q(x,y)$ greater than the threshold. All other points can be viewed as non-boundary points. In fact, the threshold level can be chosen interactively by a human.

The technique just described can be used to find points lying on vertical boundaries in one spectral band. By repeating this procedure in the vertical direction, points lying on horizontal boundaries can be found. As has been pointed out previously, the rectangular raster of picture elements implies all boundary points are either horizontally adjacent or vertical adjacent to a boundary point in a neighboring field. By following the same steps in other spectral bands, boundary points not discernible in one spectral band can be found.

Under certain conditions, boundary points can be clustered along lines to improve the boundary finding algorithm [8], [29].

7. Implementation and Results

Before describing the implementation and application of the filter, a refinement should be mentioned.

In section four, it was shown that the optimal one dimensional linear estimate can be approximated by subtracting from the logarithm of the picture a function which is constant between every pair of boundary points. In fact, it was shown that the constant which is subtracted in each field depends on a number of factors. These factors are the average recorded brightness in several contiguous fields and the differences in brightness across several field boundaries. Hence, the determination of the correct value to subtract in each field depends critically on knowing the boundary points. If a boundary point is not detected by the boundary finder, or a point not on a boundary is falsely labelled as a boundary point, the wrong constant value may be subtracted from a set of points, resulting in a streak in the filtered image.

in the original indicate areas of high soil salinity. In the enhancement the white splotches can be followed across field boundaries and the contours are more readily visible. The area in the center of the image was compared with soil maps by Professor G. Huntington of the Soil Science Department of the University of California at Davis, and the contours in the enhancement compared well with those appearing in the map. One particularly interesting portion of the enhancement is the following. Just below the middle of image 1a, on the very right, is a dark field where the natural features are greatly obscured. In Fig. 1b, the field has disappeared and the natural patterns can be easily followed.

Figure 2 shows the dependence of the estimate on various values of α . Figure 2a is the near infrared image of an area in central California. Figures 2b and 2c are enhancements using horizontal values of $e^{-\alpha}$ of .7 and .001 respectively. As α increases ($e^{-\alpha}$ decreases), dependence of the natural contribution on neighboring points becomes less and less. Consequently, patterns extending across field boundaries tend to disappear. Evidence of this phenomenon is particularly pronounced in the upper right corner of the enhancements of Fig. 2. In addition to showing the effect of changing α on the resulting enhancement, Fig. 2 shows some of the other properties of the filter. First of all, the pattern of fields which is striking in Fig. 2a, is all but invisible in the enhancements. Second, a great amount of detail which is barely perceptible in Fig. 2a shows up clearly in Fig. 2b. As an example, compare the areas just above the center and slightly to the left in Figs. 2b and 2c. The increased detail in both the very lower left corner and the very right corner of Fig. 2b is also striking. Figure 2d shows the union of the boundaries of Fig. 2a, found in three spectral bands according to the algorithm in section five.

In concluding this paper, an area for potential extension of these ideas should be mentioned. In this work, the natural patterns in high altitude imagery of agricultural areas have been enhanced. Using similar techniques, the manmade patterns can be estimated. The new image in that case would contain only crop type information. Such an enhanced image may be an ideal input to an automatic crop type classifier. Such classifiers have been studied for several years [11]. However, the variations in reflectance within a particular crop due to soil conditions, hydrological conditions, and so on, lead to a significant percentage of classification errors. Hence the preprocessing suggested above may be valuable. Essentially, use of such filtering allows one to incorporate into the classifier spatial as well as spectral information.

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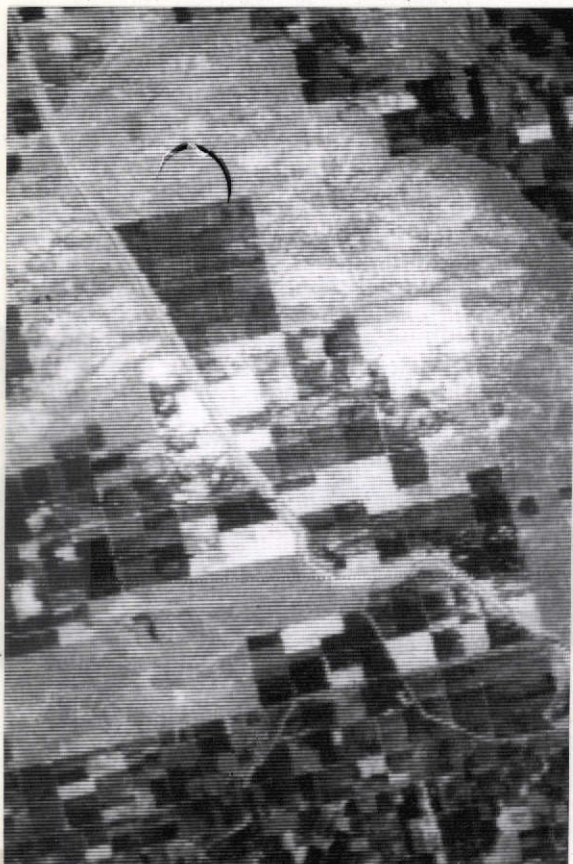


Fig. 1a. Original red component
(MSS 5).



Fig. 1b. Filtered $[e^{-\alpha}]_{\text{horiz}} = .7$



Fig. 2a. Original near infrared component (MSS 6)

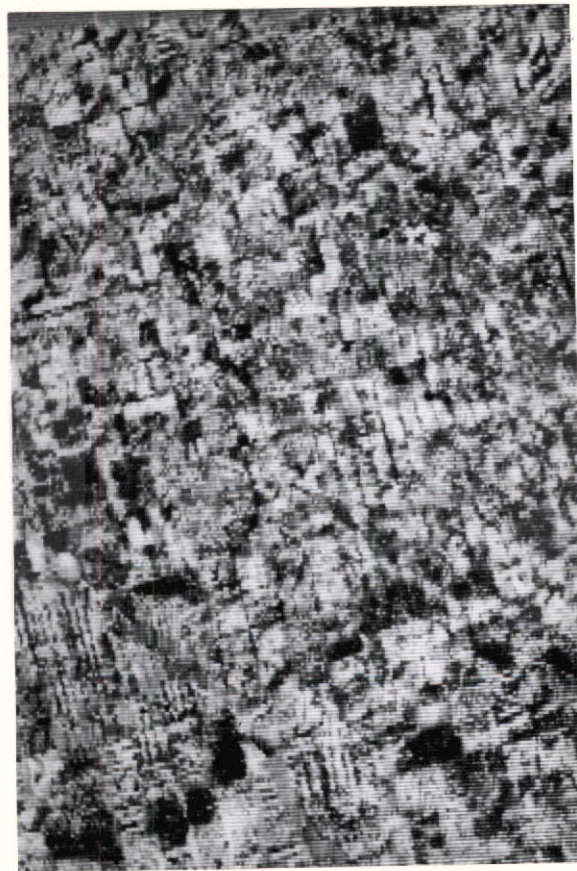


Fig. 2b. Filtered $[e^{-\alpha}]_{\text{horiz}} = .7$

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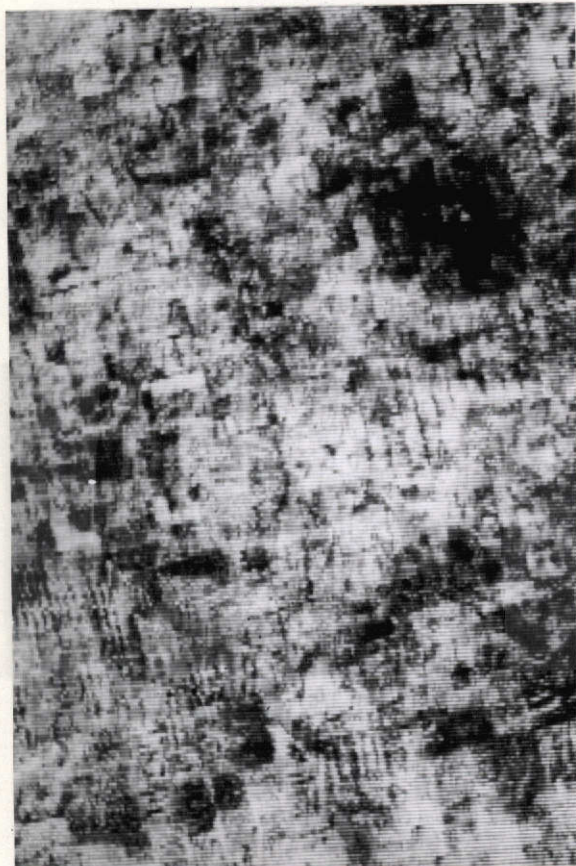


Fig. 2c. Filtered $[e^{-\alpha}]_{\text{horiz}} = .001$



Fig. 2d. Boundaries found using
green, red, and near
infrared components
(MSS 4,5,6)

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ON THE FEASIBILITY OF BENEFIT-COST ANALYSIS
APPLIED TO REMOTE SENSING PROJECTS

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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 than one which looks at a single isolated project².

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, Brinckerhoff-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 Laboratories³ 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

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 total 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. Maunder⁵ 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.

⁴While 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)

⁶Ibid., 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

⁷Willow 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 Budget and the Budget of the United States Government 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 and would 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.

$$B_w = (b_1 + b_2) \left[1 + \frac{1}{1+r} + \frac{1}{(1+r)^2} + \dots + \frac{1}{(1+r)^{T-1}} \right]$$

where r is the selected discount rate.

Reasonable values for r are about 8 percent. If annual benefits vary, then

$$B_w = (b_{11} + b_{21}) + \frac{(b_{12} + b_{22})}{1+r} + \frac{(b_{13} + b_{23})}{(1+r)^2} + \dots + \frac{(b_{1,T} + b_{2,T-1})}{(1+r)^{T-1}}$$

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.

$$\text{Then } B_{\text{grand}} = \sum_{j=w,m,\text{etc}} B_j$$

The net benefits, N , of the remote-sensing alternative would then be

$$N = B_{\text{grand}} - C$$

where C is the cost of the satellite or other alternatives.

$$10. C = K + \phi \left[1 + \frac{1}{1+r} + \dots + \frac{1}{(1+r)^{T-1}} \right]$$

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.

ACTIVITIES OF THE SOCIAL SCIENCES GROUP,
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By

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The activities of the Social Sciences Group have been, to a considerable extent, focused so as to respond to guidelines set forth by Dr. Peter A. Castruccio, President of Ecosystems International, Inc. and consultant to NASA. These guidelines appear in specific and formal terms in his communication of March 12, 1974 to Professor Robert N. Colwell and we have referred to them in the structure of this report. The content of work done, however, reflects the suggestions and advice offered by Dr. Castruccio in his personal conferences of June 22, 1973 and August 6 and 7, 1973.

Before proceeding to the details, we can respond in a synoptic way to the March 12 memorandum, in which the proposal is made that "we synthesize the California project in terms of setting forth whether there is a foreseeable water problem or not." At the risk of sounding oversimplistic, one can state, even without dwelling unduly on a definition of "water problem," that California has not one, but a complex and interrelated network of many water problems. This is a situation that has prevailed, albeit for a kaleidoscope of changing reasons, throughout California's recorded history and can be expected to persist, for one reason or another, in perpetuity. From Spanish Mission days on, water has been central in the life and pattern of development of the State. "Ever since Father Junipero Serra came to what is now California and founded Mission San Diego de Alcalá, people have realized that water would have to be conserved in areas of water surplus and moved to areas of water need." ¹ Water resources planning in California is based on the cardinal principle of "surplus" water in the northern part of the state and "deficiency" of water in the southern part. Thus, at its conception, the problem of water planning was primarily one of transport. It was in direct response to this need that the State Water Project was conceived. One of the most complex and ambitious water development projects ever designed by man, it will carry 4.2 million acre-feet of water per year from the Sacramento Delta to agricultural, urban, and industrial users in the central and southern portions of the State. Operating 444 miles of aqueducts, it will pump 2 million acre-feet of water nearly 2,000 feet over the Tehachapi Mountains into the Los Angeles Basin. Its initial features account for \$2.8 billion.

But, with the Project more than two-thirds completed, can it be said that California has no "foreseeable water problem"? Our research indicates that there is no dearth of problems in sight and that while the Project may have helped overcome some of the inequities of distribution and may

¹ Department of Water Resources, "California State Water Project Annual Report, 1972," p.5.

have solved certain local problems, its total overall effects are not universally regarded as beneficial, nor does its operation solve conclusively all present and foreseeable water-related problems. Quite the contrary. The very operation of the system places certain strains on the environment, creates situations that require vision and judgment in their solution, and by its very existence contributes to basic ecological changes that cannot be ignored.

Indeed, the portion of the Project still to be completed is, perhaps, the most controversial in that it will have irreparable and irreversible effects. This is the proposed Peripheral Canal, a \$220 million project designed to tap the Sacramento River before it enters the Delta and to transport the water to the diversion pumping stations in the Southern Delta. The controversy surrounding the Canal is one that spills over into economics, ecology, and politics and far exceeds the confines of what strictly speaking could be considered water policy. Quite aside from the ongoing debate over the ecological soundness of the Peripheral Canal, there are "foreseeable water problems" on which we will report in greater detail when we discuss quantity, quality, and long range social considerations.

As Dr. Castruccio so properly implies in the suggestion specifically beamed to the "Social Economic Group", California water, present and future, cannot be considered apart from population pressures and manifestation of changing land use, not least among which is the encroachment of urbanization on agricultural areas. We have responded to this portion of the guidelines by consulting the most authoritative sources for data on the pertinent factors. What becomes patently clear is that we are well into a new era in water resources management. No longer is there preoccupation with the mere hydrological aspects of gathering water in areas of surplus and conveying it to areas of deficiency. At present, progress of technology is having its impacts on energy generation, agricultural methods and productivity; concepts of waste water reclamation are becoming more advanced, with groundwater management occupying a position of some priority; public awareness and expectations about something vaguely sensed but generally prized -- viz. the quality of life, are beginning to enter into the decision-making process, -- for better or for worse -- and all these desiderata contribute to making water resource management ever more vital and more complex.

Perhaps to underscore the complexity and, incidentally, to comply with the final request of Dr. Castruccio, we begin the body of this report with a response to the last item on his list, namely, a description of the structure under which California water is managed. Dr. Castruccio's memorandum states, "It would be nice to have a State (and Federal, if significant) organization chart of who is responsible for what and who does what (this could be the task of the Socio Group). In addition to 'overt' responsibilities, define actual functions implemented. Also, role of Water Districts, Private Coops, consumers, etc."²

²P. A. Castruccio, "Comments on Report 'An Integrated Study of Earth Resources in the State of California'," March 12, 1974.

While our construction of the complex organization is nowhere near complete, we have made a significant beginning. The Federal linkages, i.e. laws imposed by Congressional action, role of such agencies as Bureau of Land Management, Army Corps of Engineers, Bureau of Reclamation, Environmental Protection Agency, etc., are still to be clarified and made explicit.

"Private coops, consumers, etc." are, understandably, elusive in the context of both formal and informal organization and can be traced only inferentially. However, some indications may be derived from the agenda of regional meetings of the State Water Resources Control Board, the California Water Commission, and such regional bodies as the Bay Area Sewage Service Agency. What has become evident in our research into organizational structure is the intricate framework for assignment of authority. The result is that venturing beyond the formal charts into functional relationships and allocation of responsibility is fraught with feedback peril. Almost anything outside the "little black boxes" becomes a matter for debate if not dispute.

To try to develop a cohesive picture, we must first locate water management agencies in the context of State Government. The accompanying chart (Chart 1) suggests the relationships and division of authority but omits linkages that, in practical operation, emerge as vital. Department of Water Resources, for example, shares many of the same concerns as Department of Food and Agriculture; State Water Resources Control Board and Solid Waste Management Board unite closely with the Department of Health, and so on. Chart 2 shows the internal structure within the Resources Agency in greater detail and begins to convey some notion of the intricacy of the organizational structure and authorities. What must be kept in mind in interpreting Chart 2 is the deceptive egalitarianism of the little boxes and parallel planes, for while they indicate relationships, they show nothing of relative importance or authority. Since ours is not a study of the life of the bureaucracy and since we are interested in these power lines only as they affect the management of water, we expect to mention them only as they impinge directly on matters coming within our purview.

Because the California Water Project has been the focal point of our research, several specific components of the organizational network are especially pertinent, namely, the Department of Water Resources, (in which primary responsibility for the Project is vested), those sections concerned with quality aspects of California's waters, and those involved in long-range planning vis-a-vis water. Hence, we mentioned earlier in this report that we would follow a tri-part division of "foreseeable problems" -- into quantity, quality, and long range social considerations. These, as can now be seen more clearly, correspond roughly to the formal division of labor in the State's tableau of management for water resources.

The structure of the Department of Water Resources is shown on Chart 3, with distribution of authorized positions (2583 total) for 1973-74. Not unexpectedly, the Division of Operations and Maintenance has the largest contingent of personnel (826), with Division of Design and Construction having the closest number (469), Fiscal Services next (216), and the others variously staffed. For our purposes, it is interesting to note two items on this chart. The first has to do, at least tangentially and potentially, with ultimate utilization of ERTS and other remote-sensing sources of data. As is evident in other sections of this Integrated Study, significant strides are being made in the direction of improving methods

THE EXECUTIVE BRANCH CALIFORNIA STATE GOVERNMENT

MAY 1974

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445-6371

**LIEUTENANT GOVERNOR
ED REINECKE**
445-9533

**STATE CONTROLLER
HOUSTON I. FLOURNOY**
445-0536

**STATE TREASURER
VY BAKER PRIEST**
445-5326

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**ATTORNEY GENERAL
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445-4823
EDWARD H. PEYER
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Deputy Secretary
445-0194
John Jenkins

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Chief Executive Officer**
445-3111

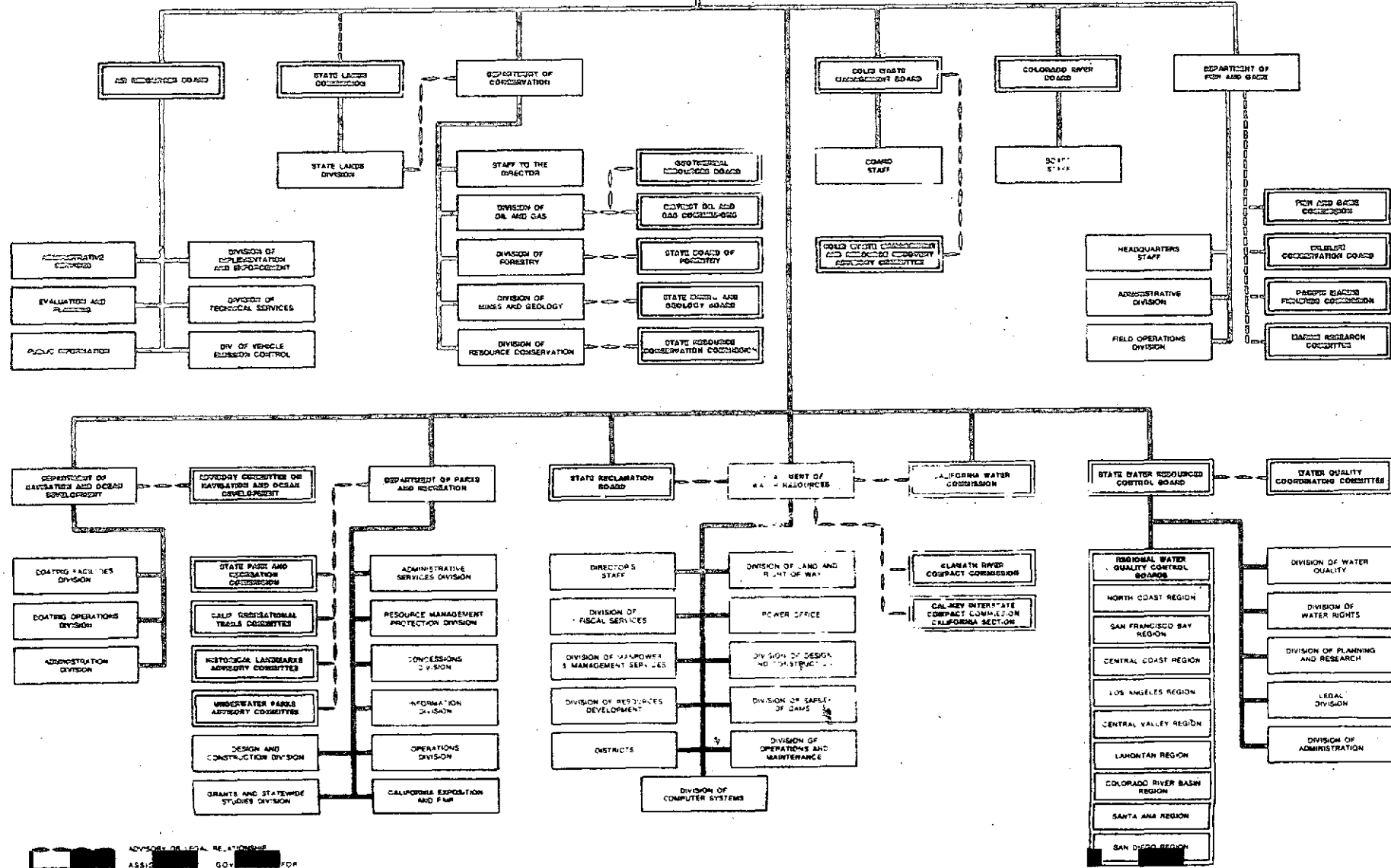
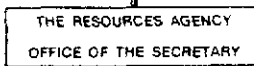
**DEPARTMENT OF COMMERCE
JOHN R. GEORGHIAN
Director**
445-2006

5-50

* Liaison established by Administrative Action.
** Lieutenant Governor serves as Chairman Economic Development Commission and Governor's Representative on Economic and Commerce Policy.
*** Lieutenant Governor serves as liaison to local government for intergovernmental policy.

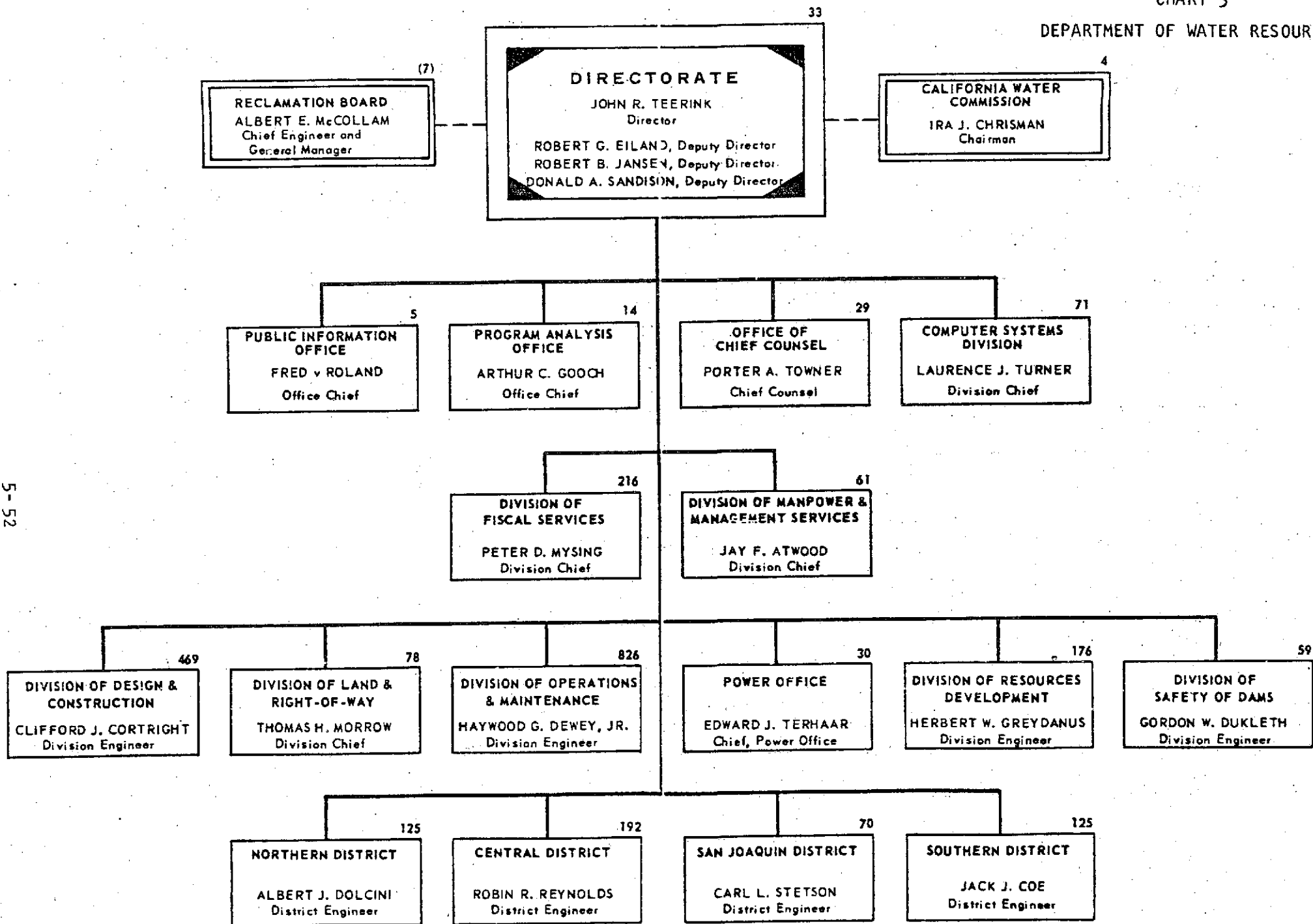
N. B. Liverman Jr.
SECRETARY FOR RESOURCES

October 12, 1973
DATE



5-51

5-52



2583 Authorized Positions
1971-74

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES

APPROVED

John R. Teerink
DIRECTOR

of gathering information needed for operation of the multiple purpose system.

The second item on the chart to which attention is being directed pertains to the California Water Commission. This is a body whose nine members are appointed by the Governor, under Sections 150 and 151 of the Water Code. Its primary function is advisory to the Director of Water Resources, the Commission "confers with, advises, and makes recommendations to the Director with respect to any matters under his jurisdiction." (Section 161, Water Code). Some of the Commission's responsibilities: (a) final approval of all state loans and grants to local agencies for water development purposes under Davis-Grunsby Act (Section 12891.4, Water Code); (b) must concur in the Director's declaration of public interest and necessity before the Department can enter into eminent domain proceedings for acquisition of land for project purposes (Sections 251, 11581, Water Code); (c) must approve all rules and regulations of the Department, except those for purely internal operations (Section 161, Water Code); (d) has the power to name all facilities of the State Water Resources Development System owned by the State (Section 161.5, Water Code); (e) shall conduct an annual review of progress of construction and operation of the State Water Resources Development System and report thereon to the Department and Legislature (Section 165, Water Code); (f) shall hold public hearings on any proposed additions to the State Water Resources Development System (Section 166, Water Code); (g) shall present its views to Congress on appropriations for federal reclamation and flood control projects in California; must consult with other agencies, and may on request represent local agencies before Congress (Section 12602, Water Code); (h) shall advise the Department and the Governor on coordination of planning, construction, and operation of federal water development and flood control projects in California (Section 12604.3 Water Code); and (i) may conduct public hearings and make recommendations annually concerning proposed planning program and other activities of the Department (Section 16634.3, Water Code).

The scope and importance of the Commission's activities are indicated in the accompanying agenda a (pages 8 & 9) of the two most recent meetings. Exemplifying the linkage between Commission and Department of Water Resources is the Director's Report on April 5, 1974. Departing from his prepared statement, he mentioned the growing public resistance to dams and pointed out the difficulties of replacing water if dams are not going to be accepted. He talked about the changing needs of Kern County, where the shift from agricultural to urban-industrial land use constitutes a new kind of demand. This, coupled with the State's urgent interest in new energy sources, since pumping water over the Tehachapis takes more power than drawing it from the Colorado River, has inspired a Legislative Committee to initiate a study on requirements for water for cooling. Mr. Teerink's overall conclusion was that a water shortage exists and that it will become more acute.

His detailed report for the month just past was, understandably, more specific to the current situation and the immediate future, and we report items covered to indicate the ultimate uses which input data such as ERTS or other remote sensing might supply.

The Director of the Department of Water Resources began his formal report with mention of current water conditions, in terms of supply. "This will be a good water supply year although it was accompanied by

State of California
The Resources Agency
Department of Water Resources
CALIFORNIA WATER COMMISSION

Agenda for the Meeting to be Held
9 a.m., Friday, April 5, 1974
Bay Area Rapid Transit District
Board Room
800 Madison Street
Oakland, California

1. MINUTES -- Consideration of the minutes of the meeting held March 1 in Sacramento.
2. STAFF REPORT -- Report of the Executive Officer and Chief Engineer for March.
3. DIRECTOR'S REPORT -- Report of the Director of Water Resources on departmental activities for March.
4. EAST BAY MUNICIPAL UTILITY DISTRICT'S WATER PROGRAMS -- A presentation by John S. Harnett, General Manager, East Bay Municipal Utility District.
5. WATER MANAGEMENT PROGRAMS IN ALAMEDA COUNTY -- A presentation by the Honorable Joseph P. Bort, Chairman, Board of Supervisors.
6. WASTE WATER RECLAMATION ACTIVITIES IN THE BAY AREA -- A presentation by Mr. Robin R. Reynolds, District Engineer, Central District, Department of Water Resources.
7. THE WATER PICTURE -- A report on water conditions by Mr. Robert E. Whiting, Chief, Flood Forecasting and Operations Branch, Department of Water Resources.
8. COBEY-ALQUIST FLOOD PLAIN MANAGEMENT ACT -- Consideration of tentative approval of amendments to rules and regulations for the administration of the Act.
9. DAVIS-GRUNSKY ACT -- Consideration of loan request by American Canyon County Water District.
10. CONDEMNATIONS -- Consideration of declarations of the Director for acquisition of land for project purposes in:
 - a) North Bay Aqueduct
11. OTHER BUSINESS

SUMMARY OF WATER CONDITIONS

APRIL 1, 1974

CALIFORNIA'S WATER SUPPLY POTENTIALS HAVE BEEN ENHANCED CONSIDERABLY DURING THE LAST MONTH IN ALL AREAS OF THE STATE. APRIL 1 SNOW SURVEYS SHOW THE SPRING MELT CYCLE, THAT BEGAN IN MID-MARCH, WAS TEMPORARILY SUSPENDED BY A SERIES OF STORMS FOLLOWED BY COOLER WEATHER WHICH PRODUCED SUBSTANTIAL ACCUMULATIONS OF NEW SNOW.

THE COMBINATION OF ABOVE AVERAGE SNOW WATER CONTENT AND WELL ABOVE AVERAGE RESERVOIR STORAGE ASSURES CALIFORNIA AN EXCELLENT WATER SUPPLY IN 1974. RUNOFF ALREADY THIS YEAR HAS SET NEW RECORDS. FOR EXAMPLE IN THE SACRAMENTO VALLEY RUNOFF HAS EXCEEDED THE RECORD SET IN 1909.

SNOWPACK WATER CONTENT RANGES FROM 115 PERCENT OF NORMAL IN THE LAHONTAN AREA TO 140 PERCENT IN THE NORTH COASTAL AREA. STORMS DURING MARCH REVERSED THE DRY TREND OF FEBRUARY AND BOOSTED SNOW WATER CONTENT TO WELL ABOVE NORMAL IN ALL AREAS EXCEPT THE TULE RIVER BASIN. BECAUSE THE MID-ELEVATION PACK HAD RIPENED AND BEGAN TO MELT IN MID-MARCH, EARLIER THAN USUAL MELT-OFF IS ANTICIPATED THIS SEASON DESPITE THE ADDITIONAL INCREMENT OF NEW SNOW.

PRECIPITATION DURING MARCH WAS ABOVE AVERAGE THROUGHOUT THE STATE EXCEPT FOR A PORTION OF THE SOUTH COASTAL AND DESERT AREAS. NORTHERN CALIFORNIA EXPERIENCED TWICE NORMAL AMOUNTS AT MANY POINTS WITH SOME OBSERVERS REPORTING OVER 300 PERCENT OF AVERAGE. SEVERAL STATIONS HAVE RECEIVED SEASONAL ACCUMULATIONS EXCEEDED ONLY DURING THE 1889-90 WATER YEAR FOR THE CORRESPONDING SIX-MONTH PERIOD.

RUNOFF DURING MARCH REACHED NEAR RECORD VOLUMES IN THE SACRAMENTO VALLEY. NATURAL RUNOFF OF THE SACRAMENTO RIVER SYSTEM, INCLUDING INFLOWS TO SHASTA LAKE AND OROVILLE RESERVOIR, WAS THE SECOND HIGHEST MARCH RUNOFF OF RECORD. FOR THE OCTOBER 1 THROUGH MARCH 31 PERIOD, RUNOFF IN THE SACRAMENTO SYSTEM AMOUNTED TO 22.5 MILLION ACRE-FEET, EXCEEDING THE RECORD ESTABLISHED IN 1909 FOR THIS PERIOD. ON THE NORTH COAST THE SEASONAL RECORD ESTABLISHED IN 1958 WAS ALSO TOPPED AS 22.3 MILLION ACRE-FEET WERE RECORDED. IN THE SAN JOAQUIN VALLEY, RUNOFF FOR THE SIX-MONTH PERIOD SINCE OCTOBER 1 HAS BEEN 140 PERCENT OF AVERAGE. DURING MARCH, RUNOFF WAS ONE-AND-ONE-HALF TIMES NORMAL, RANGING FROM NORMAL ON THE TULE RIVER TO 180 PERCENT ON THE STANISLAUS.

RESERVOIR STORAGE IS EXCELLENT THROUGHOUT CALIFORNIA. IN THE SACRAMENTO VALLEY ONE-FOURTH OF THE RESERVOIRS ARE FULL AND ALL MAJOR RESERVOIRS ARE EXPECTED TO FILL AS FLOOD CONTROL RESERVATION CRITERIA ARE WITHDRAWN. IN THE SAN JOAQUIN VALLEY, STORAGE IS 120 PERCENT OF AVERAGE WITH 1.5 MILLION ACRE-FEET MORE STORAGE THAN LAST YEAR AT THIS TIME.

SUMMARY OF WATER CONDITIONS IN PERCENT OF AVERAGE						
HYDROGRAPHIC AREA	PRECIPITATION OCTOBER 1 TO DATE	SNOW WATER CONTENT	RESERVOIR STORAGE	RUNOFF		
				OCTOBER 1 TO DATE	APR-JULY FORECAST	WATER YEAR FORECAST
NORTH COASTAL	160	140	115	240	160	220
SAN FRANCISCO BAY	130	--	105	165	--	155
CENTRAL COASTAL	130	--	125	175	--	165
SOUTH COASTAL	90	--	120	75	--	85
SACRAMENTO VALLEY	140	135	120	225	135	185
SAN JOAQUIN VALLEY	115	120	120	140	115	120
LAHONTAN	115	115	100	170	120	135
COLORADO DESERT	80	--	--	--	--	--
AVERAGE	130	125	120	220	130	175

considerable flood damage. Nearly all watersheds in the Central Valley are expected to produce near-average or above-average April-July runoff this year. Based on April forecasts of runoff and an above-average amount in storage in most reservoirs, the State and Federal water projects are expected to have sufficient water to meet all scheduled water and power commitments this year." Under "Flood Operations," he reported that the Flood Operations Center had been extremely busy, due to severe storms. Points along the Sacramento River below Shasta Dam reached levels higher than had been the mark during the heavy January storms. Flooding had occurred near Redding and below, although farther down the river, the Sacramento River Flood Control Project handled the flows well.

Mindful of our mandate to identify lines of responsibility in the management of water, we traced the data sources for this supply portion of the Director's report to the Commission. The accompanying document, "Summary of Water Conditions," is a monthly index, compiled from information drawn from the following sources: (see following page)

PUBLIC AGENCIES

BUENA VISTA WATER STORAGE DISTRICT
 CENTRAL CALIFORNIA IRRIGATION DISTRICT
 EAST BAY MUNICIPAL UTILITY DISTRICT
 FRIANT WATER USERS ASSOCIATION
 KAWAIAH DELTA WATER CONSERVATION DISTRICT
 KAWAIAH RIVER ASSOCIATION
 KINGS RIVER WATER ASSOCIATION
 LOS ANGELES COUNTY FLOOD CONTROL DISTRICT
 LOWER TULE RIVER IRRIGATION DISTRICT
 MERCED IRRIGATION DISTRICT
 MODESTO IRRIGATION DISTRICT
 NEVADA IRRIGATION DISTRICT
 OAKDALE IRRIGATION DISTRICT
 OROCKWINE-HARTNELL WATER DISTRICT
 OROVILLE-WYANDOTTE IRRIGATION DISTRICT
 PLACER COUNTY WATER AGENCY
 PORTERVILLE IRRIGATION DISTRICT
 SACRAMENTO MUNICIPAL UTILITY DISTRICT
 SAUCCELITO IRRIGATION DISTRICT
 SOUTH SAN JOAQUIN IRRIGATION DISTRICT
 ST. JOHNS RIVER ASSOCIATION
 TULE RIVER ASSOCIATION
 TURLOCK IRRIGATION DISTRICT

PUBLIC AGENCIES (CONTINUED)

VANDALIA IRRIGATION DISTRICT
 YUBA COUNTY WATER AGENCY

PRIVATE ORGANIZATIONS

ATMOSPHERICS INCORPORATED
 J. G. BOSWELL COMPANY
 KERN COUNTY LAND COMPANY
 LIBERTY FARMS COMPANY
 MT. REBA INC.
 UNION CARBIDE CORPORATION

PUBLIC UTILITIES

PACIFIC GAS AND ELECTRIC COMPANY
 SIERRA PACIFIC POWER COMPANY
 SOUTHERN CALIFORNIA EDISON COMPANY

MUNICIPALITIES

CITY OF LOS ANGELES
 DEPARTMENT OF WATER AND POWER
 CITY OF PORTERVILLE
 CITY AND COUNTY OF SAN FRANCISCO
 PUBLIC UTILITIES COMMISSION

STATE AND FEDERAL AGENCIES

CALIFORNIA DEPARTMENT OF WATER RESOURCES
 CALIFORNIA DEPARTMENT OF PARKS
 AND RECREATION
 U. S. DEPARTMENT OF AGRICULTURE
 FOREST SERVICE (14 NATIONAL FORESTS)
 PACIFIC SOUTHWEST FOREST AND RANGE
 EXPERIMENT STATION
 SOIL CONSERVATION SERVICE
 U. S. DEPARTMENT OF COMMERCE
 NATIONAL WEATHER SERVICE
 U. S. DEPARTMENT OF THE INTERIOR
 BUREAU OF RECLAMATION
 GEOLOGICAL SURVEY, WATER RESOURCES
 DIVISION
 NATIONAL PARK SERVICE (3 NATIONAL
 PARKS)
 U. S. DEPARTMENT OF THE ARMY
 CORPS OF ENGINEERS

OTHER COOPERATIVE PROGRAMS

NEVADA COOPERATIVE SNOW SURVEYS
 OREGON COOPERATIVE SNOW SURVEYS

The specific categories: snowpack, precipitation, reservoir storage, and runoff are explained as follows:

SNOWPACK - APRIL 1 SNOW DATA ARE MAJOR INDEXES OF SPRING AND SUMMER RUNOFF FROM SIERRA WATERSHEDS AND HISTORICALLY REFLECT THE MAGNITUDE OF THE SNOWPACK AT NEAR MAXIMUM SEASONAL ACCUMULATION. AVERAGES ARE BASED ON THE PERIOD, 1931-1970 (40 YEARS).

PRECIPITATION - AVERAGES ARE BASED ON THE PERIOD, 1931-1970 (40 YEARS).

RESERVOIR STORAGE - AVERAGES ARE BASED ON THE PERIOD, 1964-1973 (10 YEARS).

RUNOFF - UNLESS OTHERWISE NOTED, STREAMFLOW DATA USED AS INDEXES OF BASIN OR AREA RUNOFF HAVE BEEN CORRECTED FOR MAJOR UPSTREAM IMPAIRMENTS. FORECASTS OF RUNOFF ASSUME NORMAL PRECIPITATION TO FOLLOW. RUNOFF PROBABILITY RANGES ARE STATISTICALLY DERIVED FROM HISTORICAL DATA; 80 PERCENT PROBABILITY MEANS THAT ACTUAL RUNOFF WILL FALL WITHIN THE STATED LIMITS EIGHT TIMES OUT OF TEN. AVERAGES ARE BASED ON THE PERIOD, 1921-1970 (50 YEARS).

State of California
The Resources Agency
Department of Water Resources
CALIFORNIA WATER COMMISSION

Tentative

Agenda for the Meeting to be Held
9 a.m., Friday, May 3, 1974
Board of Supervisors' Chambers
2555 Mendocino Avenue
Santa Rosa, California

1. MINUTES -- Consideration of the minutes of the meeting held April 5 in Oakland
2. STAFF REPORT -- Report of the Executive Officer and Chief Engineer for April
3. DIRECTOR'S REPORT -- Report of the Director of Water Resources on departmental activities for April
4. AN UPDATE ON SONOMA COUNTY'S WATER DEVELOPMENT -- A report by Gordon W. Miller, Chief Engineer, Sonoma County Water Agency
5. THE GEYSERS POWER PROJECT -- A report by John P. Finney, Project Engineer, Department of Mechanical and Nuclear Engineering, Pacific Gas and Electric Company
6. STATUS REPORT ON SACRAMENTO-SAN JOAQUIN BASIN PLANS -- A report by Bay Valley Consultants
7. OTHER BUSINESS

The forecasts presented in synoptic form by the Director are shown graphically in the accompanying Snowmelt Runoff Map (page 13). A sample copy of the "Summary of Central Valley Water Conditions" is supplied on Pages 13, 14, and 15 as indicative of the information (and its sources) by which the Department of Water Resources conducts its operations at present. It is possible that herein reside clues to the potential usefulness of more advanced technology, such as remote sensing.

Further to exemplify the range of responsibility of the Department of Water Resources were the additional matters reviewed by the Director. Federal Legislation and State Legislation came next and a document compiled by the California Assembly Committee on Water, "Handbook of Federal and State Programs of Financial Assistance for Water Development," provides valuable insights into at least that aspect of California water. Federal construction funds for general water development were tested as coming from the Departments of Agriculture, Housing and Urban Development, Interior and Commerce, as well as from the Environmental Protection Agency and the Army Corps of Engineers. Recreation development appropriations, came from the Department of the Interior and Housing and Urban Development, along with the Army Corps of Engineers, and long range planning and research support from the Departments of the Interior and Housing and Urban Development and Environmental Protection Agency. Other federal legislation of special and current interest, such for example as several dealing with water and power resources, the Colorado River salinity control program for the works upstream from the Imperial Dam, and a proposed overhaul of the U. S. House of Representatives committee system, were reported in this context.

State appropriations paralleled the above categories. An entry of special interest in the study of jurisdictional relationships is the permanent allocation of \$130,000,000.00 administered by the Department of Water Resources, (with the requirement for approval by the California Water Commission) for the "development, control, and conservation of the water resources of the state and the State Water Resources Development System," the purpose being "to provide financial assistance to public agencies for the construction of water projects to meet local requirements in which there is a state-wide interest in making loans." Current state legislation noted again indicated the wide scope of the Department of Water Resource's concerns: AB 2891, to extend the life of the Interstate Compact Commission; SB1614 to repeal and reenact the Natural Disaster Assistance Law and centralize administration in the Office of Emergency Services; SB 1498, to establish the California Wilderness Preservation System; AB 2365, for the exchange of real property needed in connection with development of a state recreation area; AB 1477, requiring a metropolitan water district which has a contract with the state for a water supply and has an additional source of water to serve as large an area as is practicable with a blend of water from the two sources, not less than 50% being state-supplied. Mentioned also were several bills specifically concerned with water quality.

Up to this point in the report, we have concentrated almost exclusively on water quantity-related responsibilities of the state's organization, and then with only several boxes on the chart. This is not to imply that others are unimportant. In fact, a swift visual scan of the graphic breakdown of duties (as shown in charts 5 through 17), to say nothing of our intensive perusal of manuals backed up by personal contact with key officials,

Jim 1200

SUMMARY OF CENTRAL VALLEY WATER CONDITIONS

APRIL 1, 1974

Water supply potentials for the Central Valley have been enhanced considerably during the last month. April 1 snow surveys show the spring melt cycle, that began in mid-March, was temporarily suspended by cooler weather and a series of storms that produced substantial accumulations of new snow. Snow water content is well above average in tributary watersheds, ranging from 120 to 135 percent. Precipitation during March was substantially above average with several stations in the northern Sacramento Valley reporting over 300 percent of average.

Runoff during March reached near record volumes in the Sacramento Valley. Natural runoff of the Sacramento River system, including inflows to Shasta Lake and Oroville Reservoir, was the second highest March runoff of record. Runoff of the Sacramento River system by April 1 had amounted to 22.5 million acre-feet, exceeding a record established in 1909 for an October 1 through March 31 period. Shasta and Oroville Reservoir inflows also set new records for this six-month period.

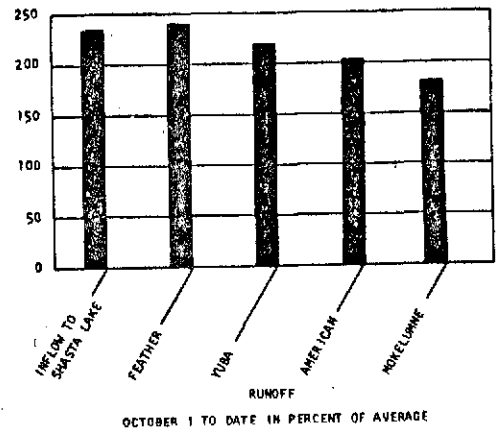
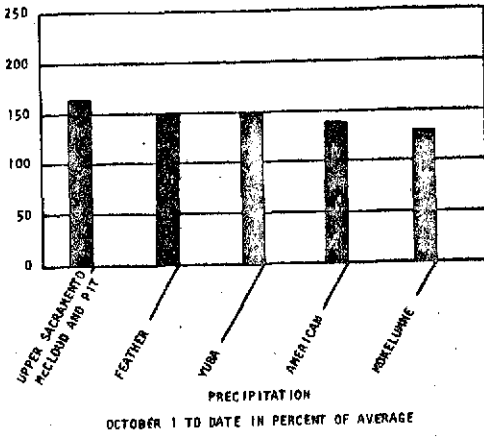
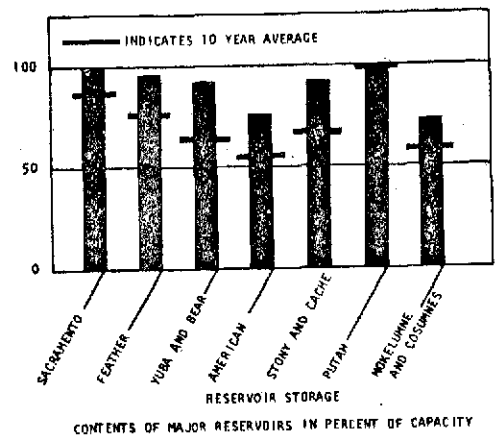
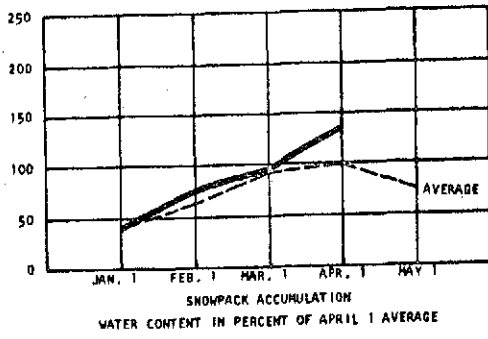
In the San Joaquin Valley runoff during March was almost one-and-one-half times normal, ranging from normal on the Tule River to 180 percent on the Stanislaus. Runoff for the first half of the water year, although not as spectacular as in the Sacramento Valley, was 140 percent of average.

Reservoir storage is excellent throughout the Central Valley with 120 percent of average April 1 supplies now impounded. In the Sacramento Valley one-fourth of the major reservoirs are full and all major reservoirs are expected to fill as flood control reservations are withdrawn. In the San Joaquin Valley there is almost 1.5 million acre-feet more in storage than last year at this time. The new Don Pedro Reservoir on the Tuolumne River is two-thirds full, reaching its highest level to date with 1,353,000 acre-feet in storage on April 1.

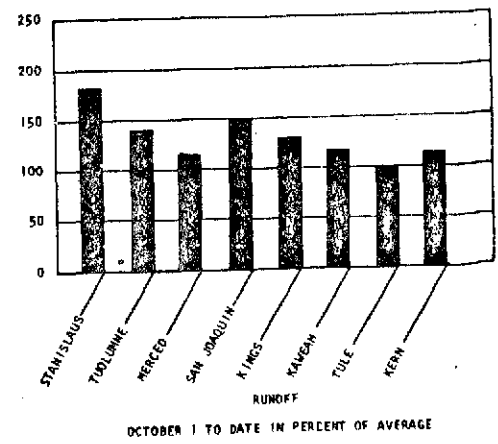
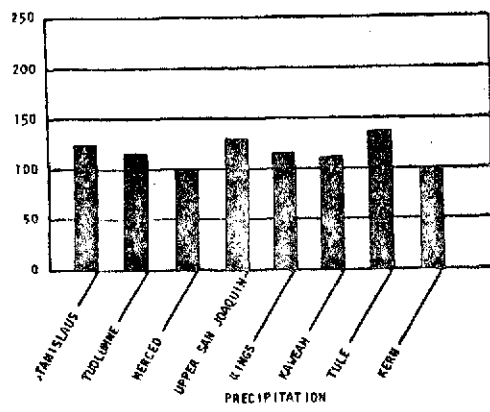
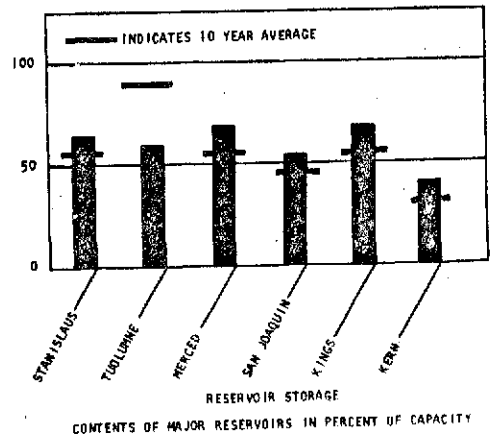
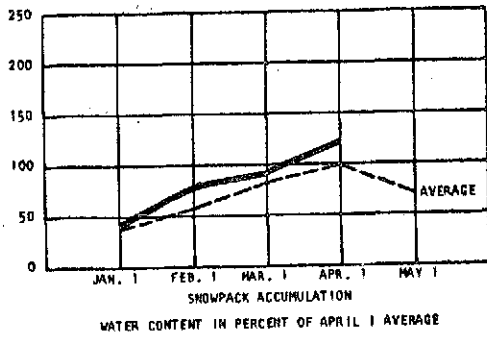
Runoff forecasts for the April through July period have all been increased from those of one month ago. With upper watershed snow conditions much improved as a result of the March storms, runoff forecasts in the San Joaquin Valley have been raised by 15 to 35 percent. Only the Tule River will be below normal at 93 percent. All Sacramento Valley runoff forecasts have been increased by 20 to 40 percent and now range from 115 percent of normal for the American River to 160 percent for the Sacramento River tributary to Shasta Lake.

SUMMARY OF WATER CONDITIONS IN PERCENT OF AVERAGE						
HYDROGRAPHIC AREA	PRECIPITATION OCTOBER 1 TO DATE	SNOW WATER CONTENT	RESERVOIR STORAGE	RUNOFF		
				OCTOBER 1 TO DATE	APR-JULY FORECAST	WATER YEAR FORECAST
NORTH COASTAL	160	140	115	240	160	220
SAN FRANCISCO BAY	130	--	105	165	--	155
CENTRAL COASTAL	130	--	125	175	--	165
SOUTH COASTAL	90	--	120	75	--	85
SACRAMENTO VALLEY	140	135	120	225	135	185
SAN JOAQUIN VALLEY	115	120	120	140	115	120
LAHONTAN	115	115	100	170	120	135
COLORADO DESERT	80	--	--	--	--	--
AVERAGE	130	125	120	220	130	175

SACRAMENTO RIVER BASIN



SAN JOAQUIN RIVER AND TULARE LAKE BASINS



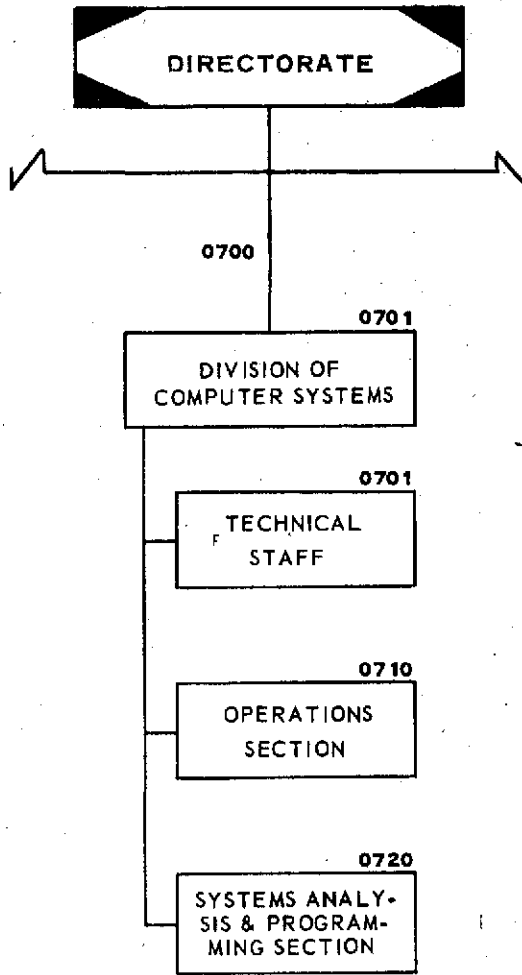
**FORECASTS OF APRIL - JULY AND WATER YEAR RUNOFF
FOR CENTRAL VALLEY STREAMS
AS OF
APRIL 1, 1974**

DRAINAGE BASIN AND WATERSHED	April-July Flow in 1000 Acre-Feet			Water Year Flow --- October Through September --- in 1000 Acre-Feet										
	Historical 50-Year Average	FORECASTS		Historical 50-Year Average	DISTRIBUTION								FORECASTS	
		April-July Forecast	Percent of Average		October Through January	February	March	April	May	June	July	August and September	Water Year Forecast	Percent of Average
<u>SACRAMENTO RIVER BASIN</u>														
Upper Sacramento River Total Inflow to Shasta Lake	1,774	2,550	144	5,481	5,172	695	1,778	1,150	740	410	250	475	10,670	195
Feather River Total Inflow to Oroville Reservoir	1,862	2,800	150	4,286	3,331	442	1,569	1,090	1,010	500	200	258	8,400	196
Yuba River Yuba River at Smartville	1,079	1,350	125	2,266	1,703	182	621	460	530	280	80	54	3,910	173
American River Total Inflow to Folsom Reservoir	1,314	1,530	116	2,570	1,584	209	724	570	570	300	90	43	4,090	159
Cosumnes River Cosumnes River at Michigan Bar	145	200	138	363	222	35	130	105	65	25	5	3	590	163
Hokelumne River Total Inflow to Pardee Reservoir	465	560	120	705	269	37	122	150	230	150	30	12	1,000	142
<u>SAN JOAQUIN RIVER BASIN</u>														
Stanislaus River Total Inflow to Melones Reservoir	718	800	111	1,065	378	50	203	210	310	220	60	19	1,450	134
Tuolumne River Total Inflow to Don Pedro Reservoir	1,193	1,300	109	1,789	499	69	229	340	470	400	90	33	2,130	119
Mercad River Total Inflow to Lake McClure	608	640	105	920	212	38	105	160	270	170	40	15	1,010	110
San Joaquin River Total Inflow to Hillerton Lake	1,193	1,490	125	1,659	328	66	208	290	560	490	150	88	2,180	131
<u>TULARE LAKE BASIN</u>														
Kings River Total Inflow to Pine Flat Reservoir	1,163	1,450	125	1,568	247	53	159	250	490	540	170	81	1,990	127
Kaweah River Total Inflow to Terminus Reservoir	271	300	111	404	72	19	55	80	110	90	20	9	455	113
Tule River Total Inflow to Success Reservoir	59	55	93	133	41	9	26	23	20	10	2	1	132	99
Kern River Total Inflow to Isabella Reservoir	419	440	105	629	105	27	67	100	160	130	50	45	685	109

Monthly Unimpaired Values Are Proportionally Distributed
Based On Historical Years Of Similar Magnitude.

* Unimpaired Flows To Date

CHART 5



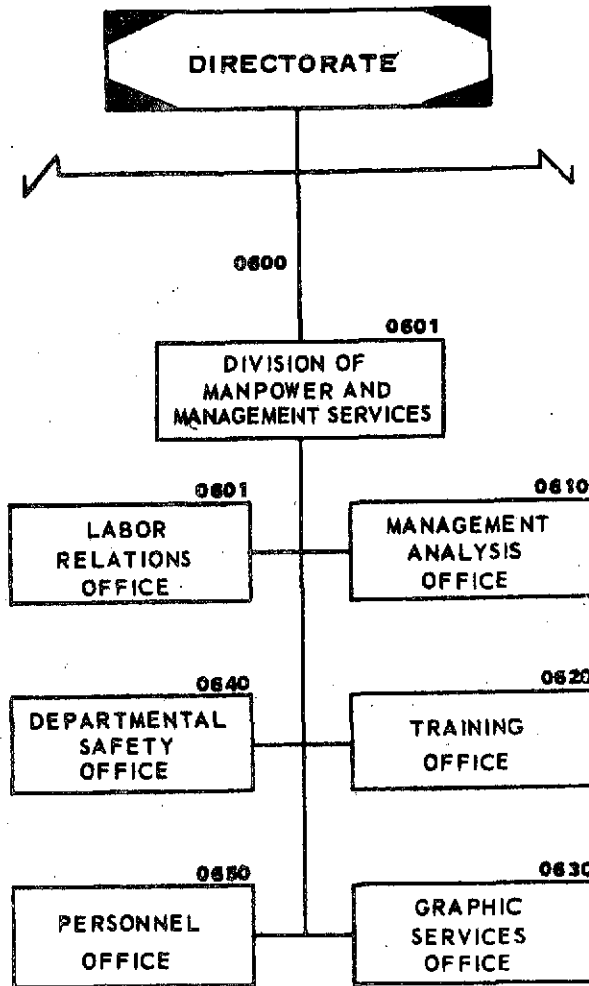
APPROVED Laurence Turner
DIVISION CHIEF

APPROVED Robert B. Eibert
ASSISTANT DIRECTOR

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
DIVISION OF COMPUTER SYSTEMS

JULY 1973

CHART 6



APPROVED Jay J. Atwood
DIVISION CHIEF

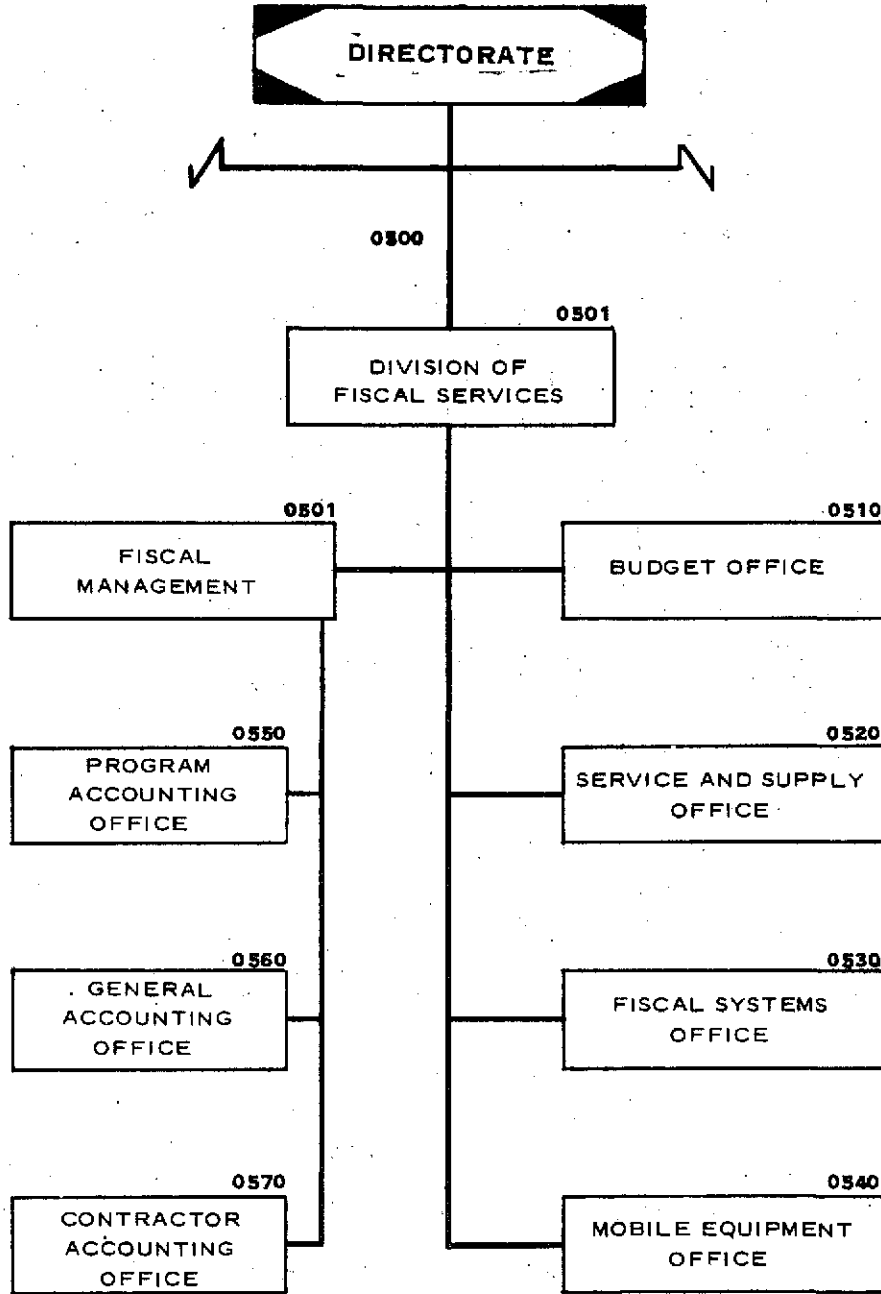
APPROVED Robert B. Eiler
ASSISTANT DIRECTOR

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES

DIVISION OF MANPOWER
AND MANAGEMENT SERVICES

JULY 1973

CHART 7



APPROVED Peter M. Mysing
DIVISION CHIEF

APPROVED Robert S. Eiland
ASSISTANT DIRECTOR

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
DIVISION OF FISCAL SERVICES

JULY 1973

APPROVED *E. J. Terhaar*
CHIEF, POWER OFFICE
APPROVED *Robert D. Gussner*
DEPUTY DIRECTOR

State of California
The Resources Agency
DEPARTMENT OF WATER RESOURCES
POWER OFFICE
July 1972

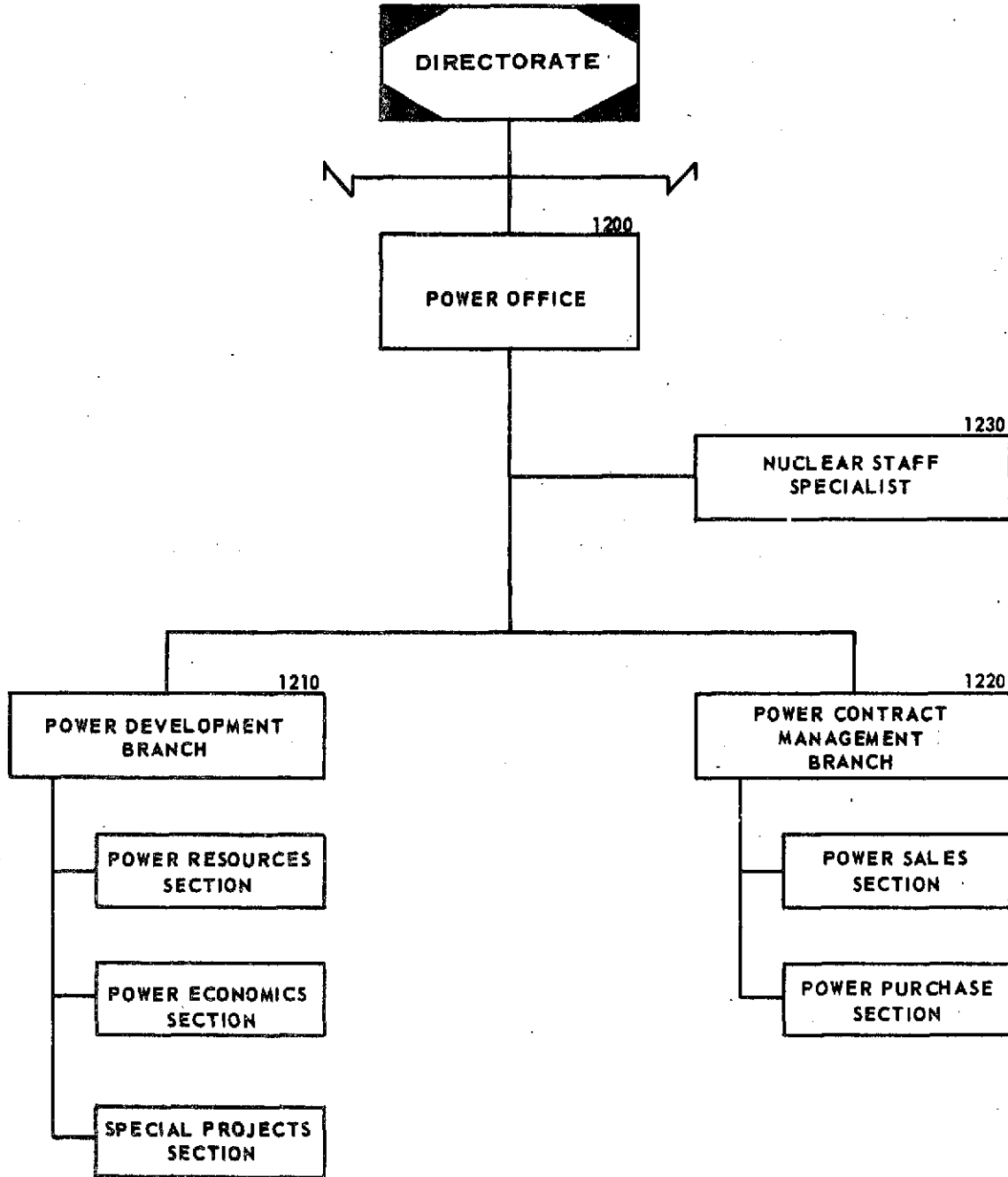
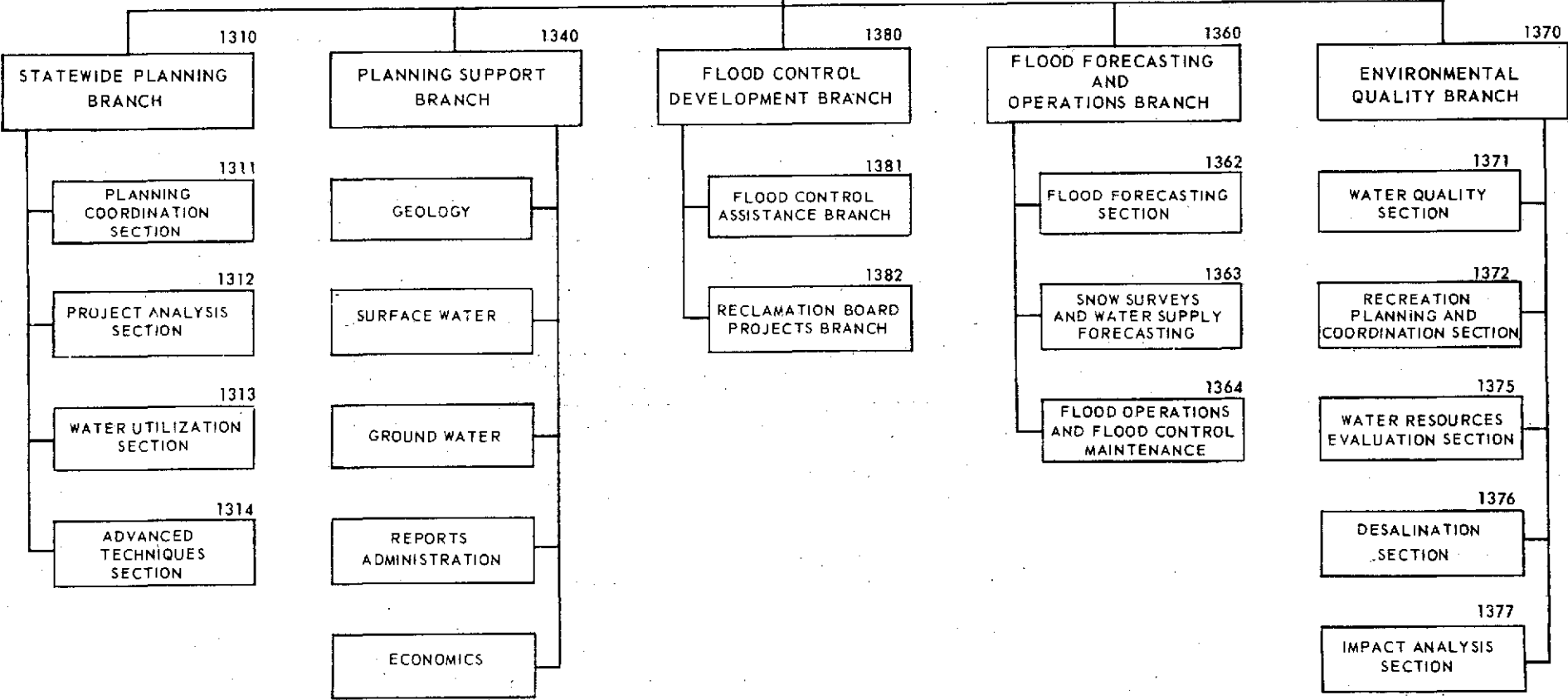
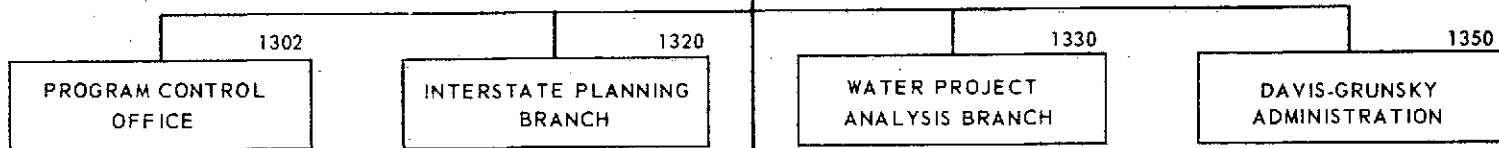
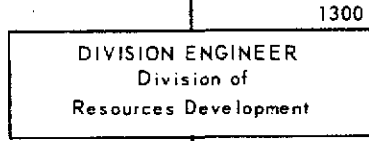


CHART 9

APPROVED *Herbert W. Lynders*
DIVISION ENGINEER

APPROVED *John R. Linnick*
DEPUTY DIRECTOR

State of California
The Resources Agency
DEPARTMENT OF WATER RESOURCES
Division of
Resources Development
November 1972



5-68

CHART 10

State of California
The Resources Agency
DEPARTMENT OF WATER RESOURCES
DIVISION OF DESIGN AND CONSTRUCTION
July 1973

APPROVED *Lloyd E. Shields*
DIVISION ENGINEER
APPROVED *Robert S. Pusem*
DEPUTY DIRECTOR

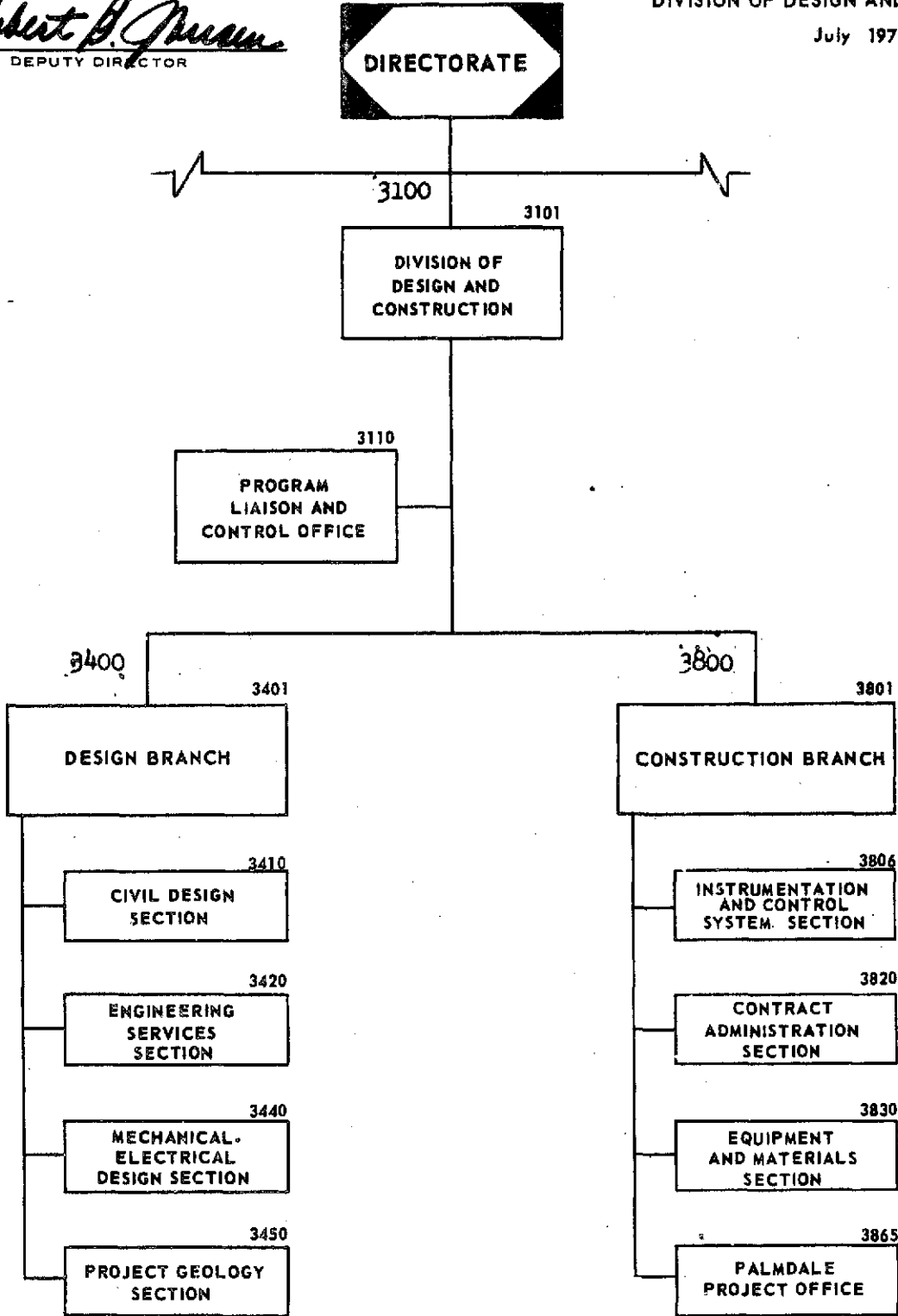
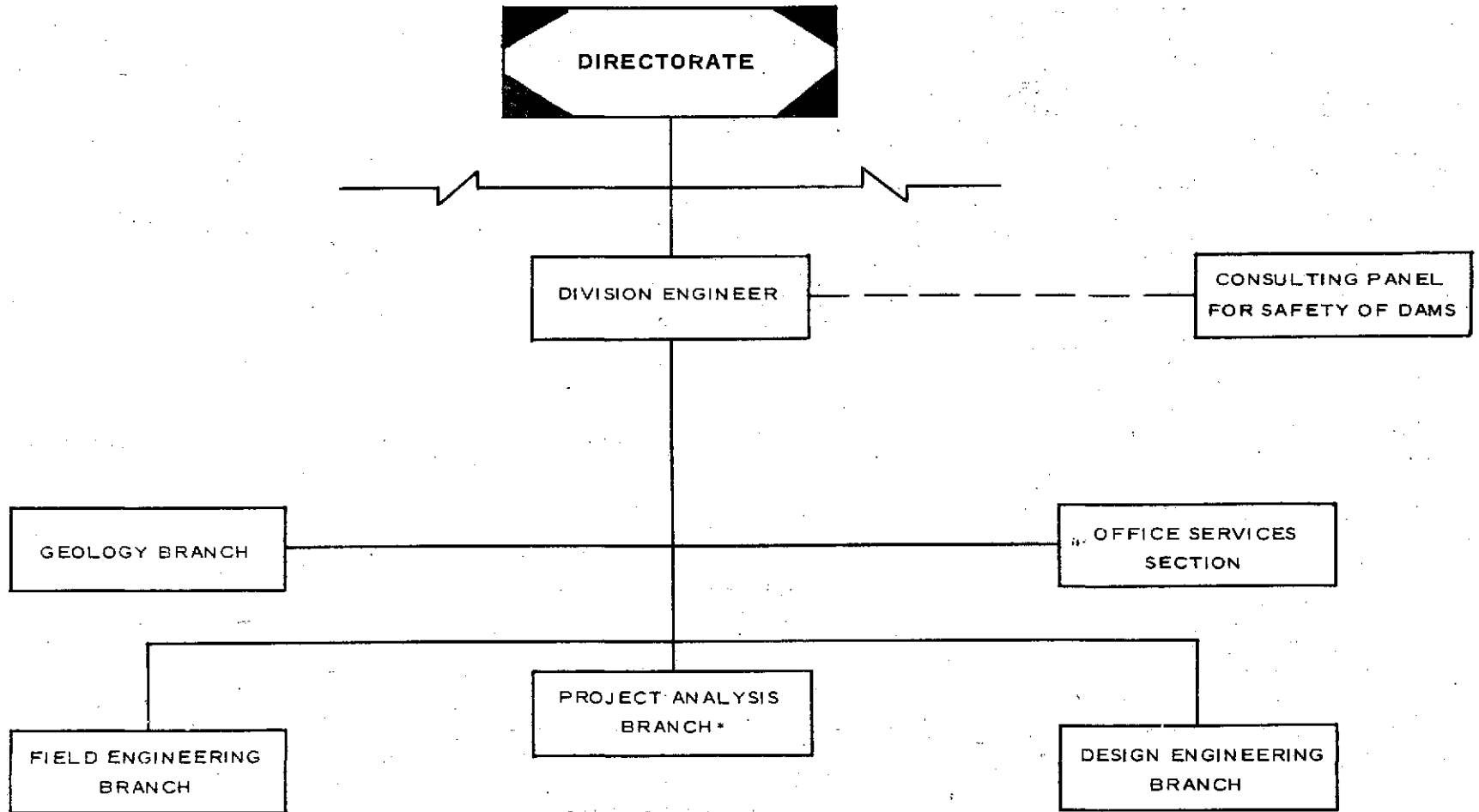


CHART 11



5-70

APPROVED *CJ Contreras*
 DIVISION ENGINEER

APPROVED *John R. Seerink*
 DEPUTY DIRECTOR

STATE OF CALIFORNIA
 THE RESOURCES AGENCY
 DEPARTMENT OF WATER RESOURCES
 DIVISION OF SAFETY OF DAMS

FEBRUARY 1971

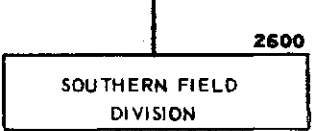
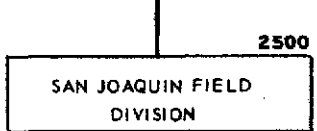
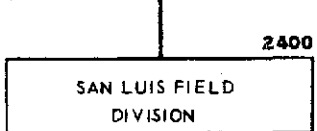
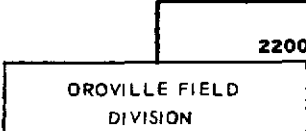
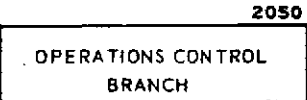
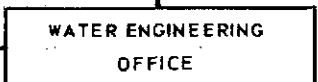
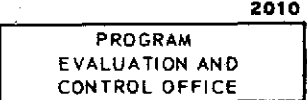
* Chief, Project Analysis Branch also performs the duties of a deputy division engineer as required.

CHART 12

APPROVED *[Signature]*
 DIVISION ENGINEER

APPROVED *[Signature]*
 DEPUTY DIRECTOR

State of California
 The Resources Agency
 DEPARTMENT OF WATER RESOURCES
 Division of
 Operations and Maintenance
 JANUARY 1973



5-71

CHART 13

APPROVED

John M. Staley
DISTRICT ENGINEER

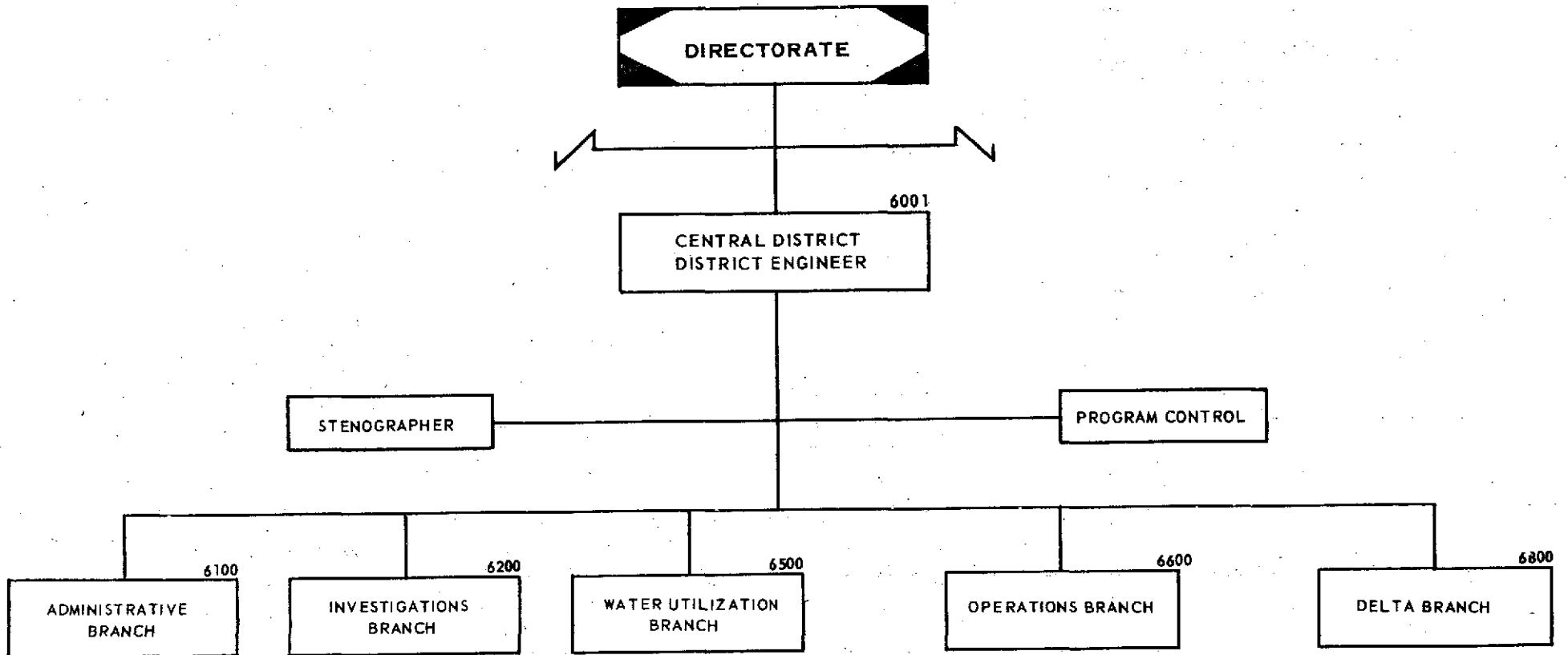
APPROVED

John R. Steerink
DEPUTY DIRECTOR

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES

CENTRAL DISTRICT

JULY 1972



5-72

APPROVED

T. H. Morrison
DIVISION CHIEF

CHART 14

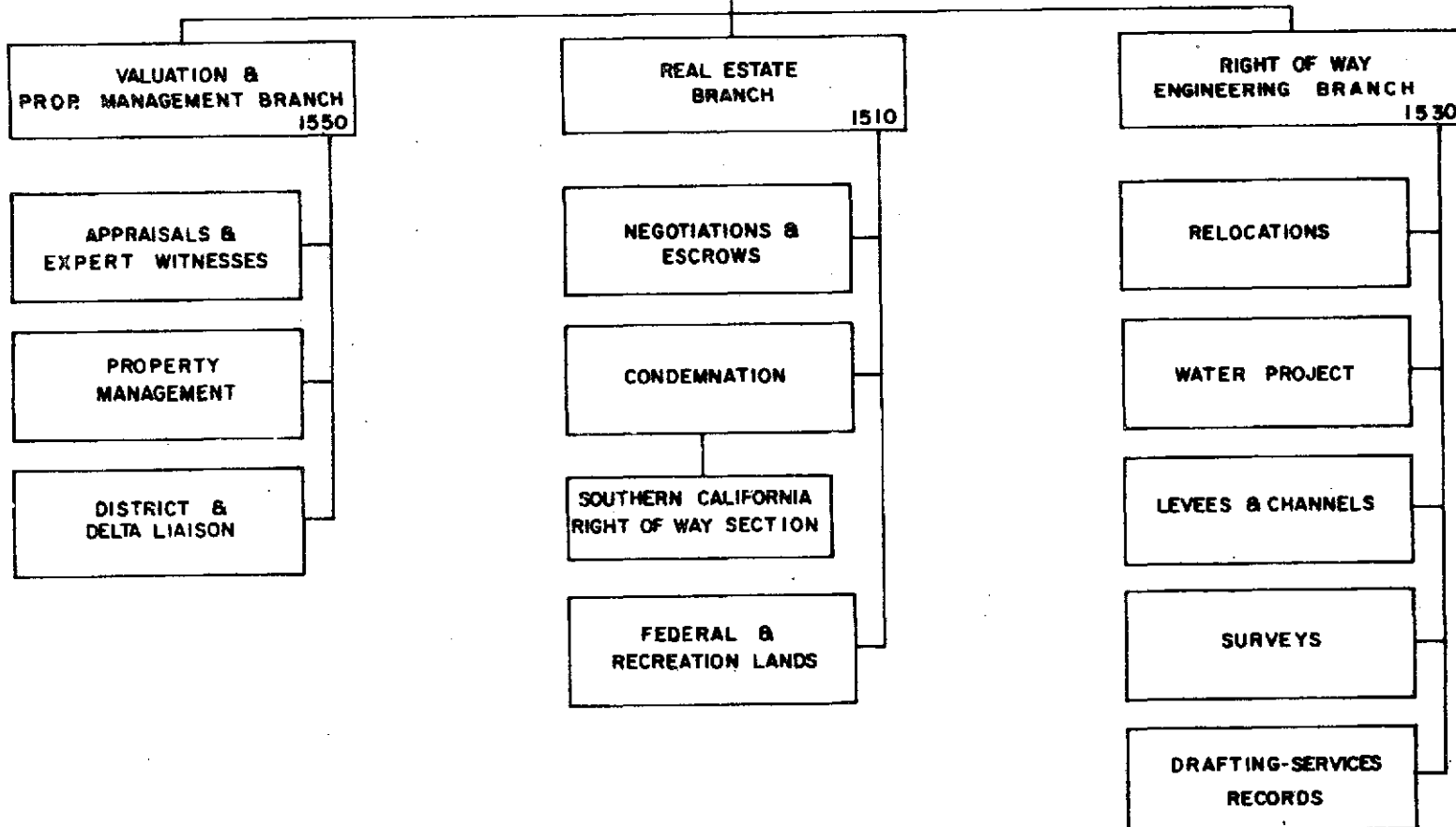
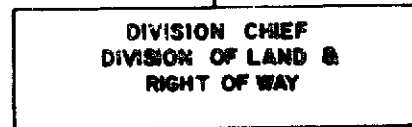
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES

DIVISION OF LAND &
RIGHT OF WAY

JANUARY 1973

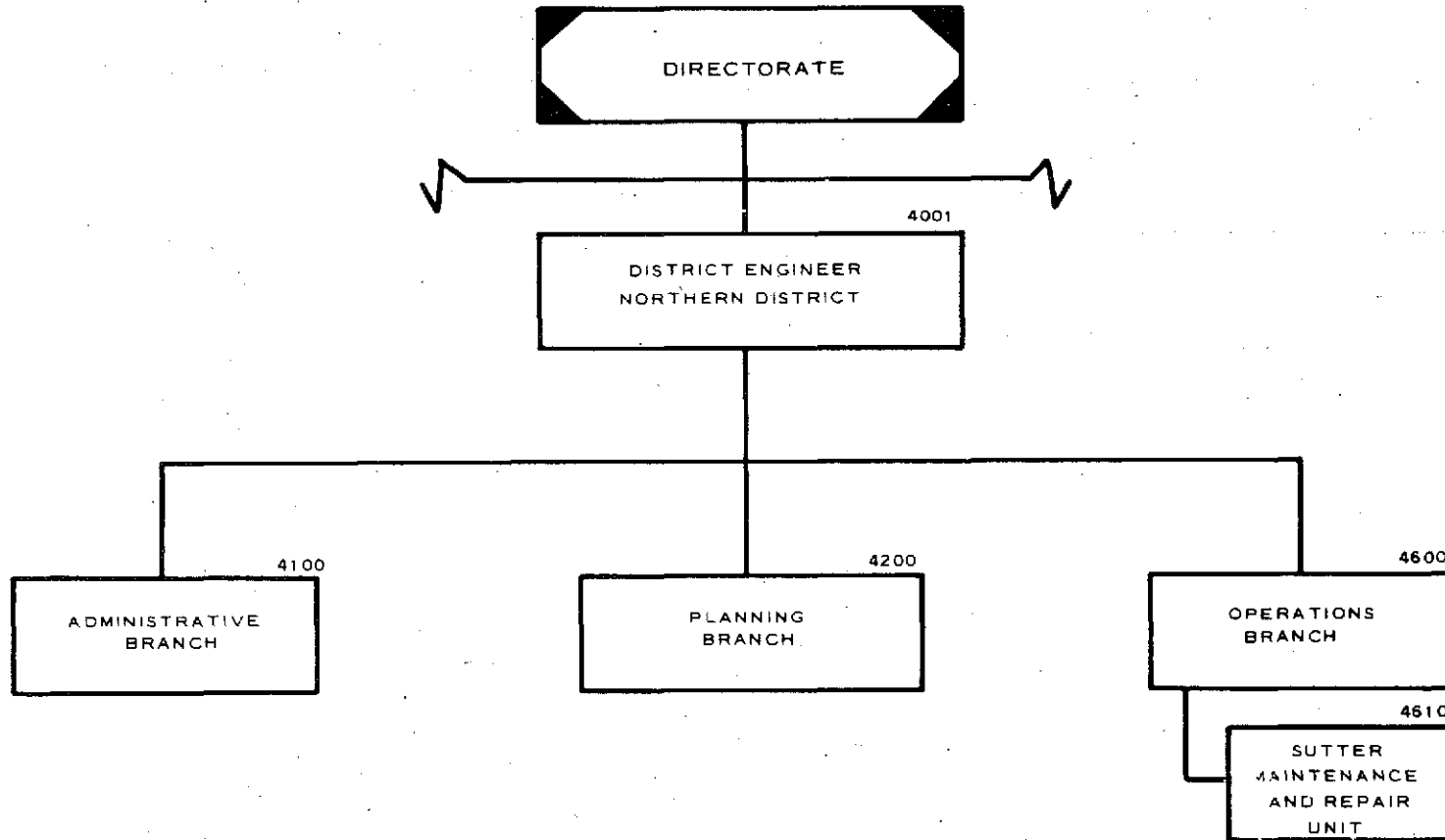
APPROVED

Robert B. Jensen
DEPUTY DIRECTOR



5-73

CHART 15



5-74

APPROVED *G. H. Dubleth*
DISTRICT ENGINEER

APPROVED *John R. Scerink*
DEPUTY DIRECTOR

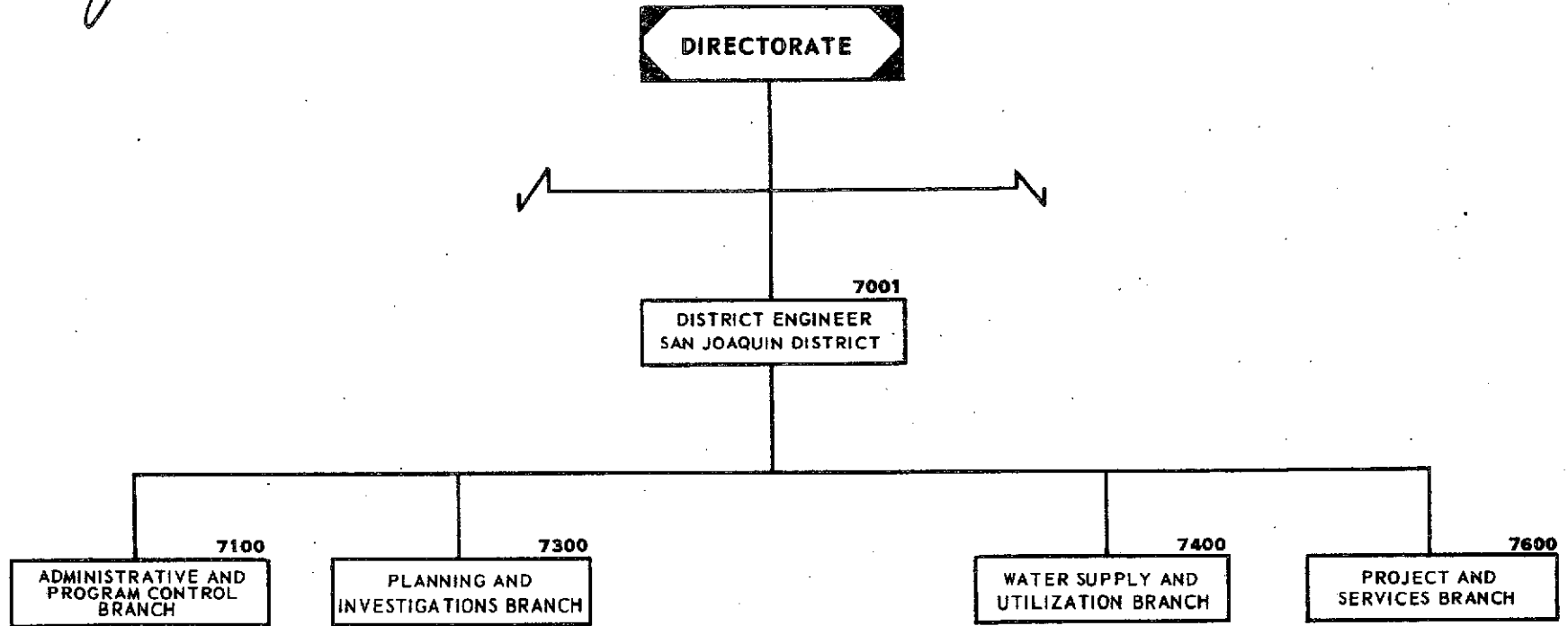
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
NORTHERN DISTRICT
JULY 1971

CHART 16

APPROVED *Carl L. Ottem*
DISTRICT ENGINEER

APPROVED *John R. Teerink*
DEPUTY DIRECTOR

State of California
The Resources Agency
DEPARTMENT OF WATER RESOURCES
SAN JOAQUIN DISTRICT
FEBRUARY 1972



5-75

CHART 17

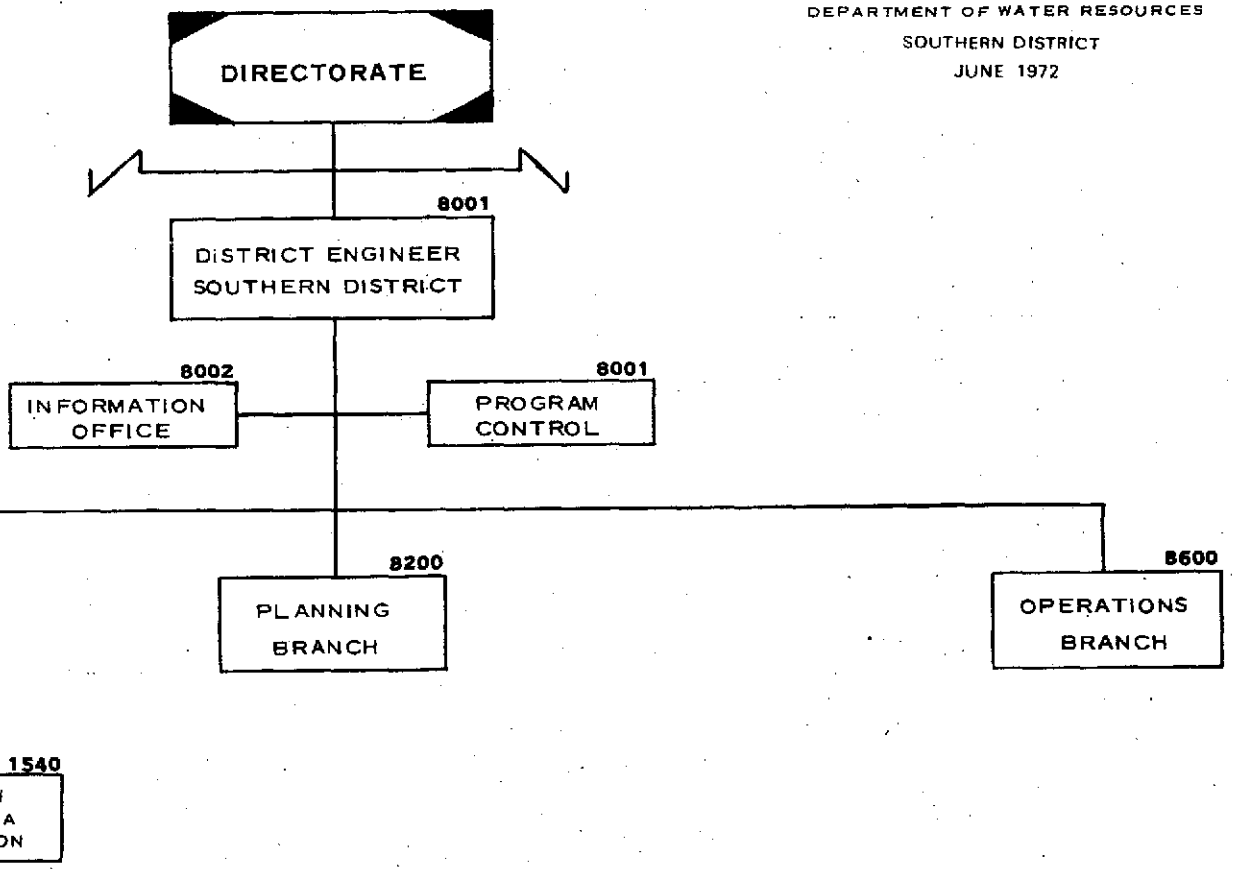
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
SOUTHERN DISTRICT
JUNE 1972

APPROVED

J. Deedy
DISTRICT ENGINEER

APPROVED

John R. Teerink
DEPUTY DIRECTOR



5-76

* Assigned to Southern District for personnel and other administrative support services. The Division of Right-of-Way Acquisition has line responsibility for Right-of-Way activities.

suffices to underscore the immense complexity of water management and the folly with which oversimplification might be fraught. Even fairly close adherence to the lines of relationship shown on the formal charts has, as we have learned through perusal of documents and reports and attendance at important meetings, made it clear that there are many dimensions of interaction that are more crucial to the management of water than any chain-of-command type of drawing could capture or depict.

Moreover, as is shown in the following tables, 1-6, there is no dearth of statistics or supply and demand for California water. To comply ritualistically with the specific suggestions (in the March 12, 1974 memorandum) that, for example, we "describe the present and future water demand schedule in the State of California," or that we "characterize the demand as to specific users and rank them" is to invite a re-hash of records well kept and publicly accessible. From our point of view, the interesting dimension provided by remote-sensing technology has to do with the ways in which new sources of information, and possibly new forms, will impinge on the operation of present systems and perhaps ultimately provide more efficient ways of arriving at long-range decisions about the water resources of the state.

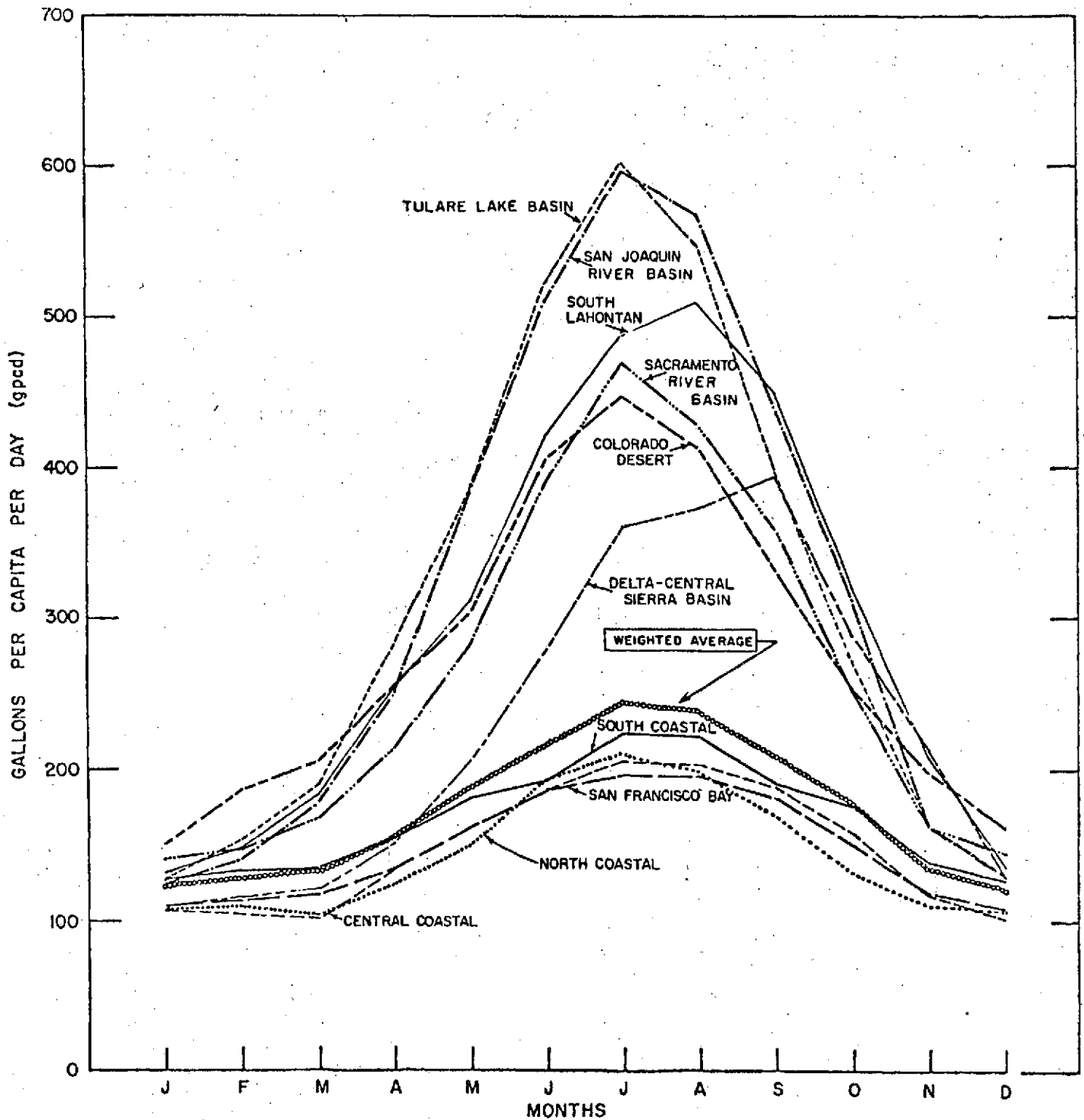
Quality Considerations

Nowhere is the factor of interaction more apparent than in the inextricable relationship between quality and quantity. Reference to Chart 1 will show a separate, but roughly equal, box for the State Water Resources Board, with, however, a line indicating connection with the Department of Water Resources. The interrelationship is considerably more intense functionally than would appear graphically. Problems of quality quickly surface concomitantly with problems of quantity, whether too much or too little, or attributable to natural or man-made causes. In the April 5, 1974 Report of Activities of the Department of Water Resources to the Commission, the Director of the DWR made some of the connections explicit. He discussed several legislative bills that, he said, would have an effect on the State Water Resources Control Board. One was SB 1873, which places restrictions on conditions that can be imposed on releases of water for recreation and fish and wildlife enhancement. Another was AB 3070, which would restrict the SWRCB in requiring release of water from storage for the enhancement of fish and wildlife. During the Assembly Committee on Water Hearings on the bill, the Director testified as follows: "I told the Committee that the Board's Decision 1379 (the Delta Decision), unless modified, would reduce the yield of the State Water Project and Federal Central Valley Project by about 500,000 acre-feet per year for enhancement purposes. About 200,000 acre-feet would be the State Water Project share. Additional yield would also be lost due to other provisions of the Decision dealing with unregulated flows to the Delta. To make up the loss in Project yield resulting from the Decision would require the construction of conservation facilities in the Upper Sacramento Valley, or the North Coast. I pointed out that the cost of the yield lost to the Project would be about \$60 per acre-foot or \$12 million per year for the state's share."³

³ Report presented to the California Water Commission, April 5, 1974, pp.6-7.

TABLE I

AVERAGE MONTHLY PER CAPITA WATER USE
 AGENCY PRODUCED FRESH WATER
HYDROGRAPHIC AREAS



Source: California. Department of Water Resources. Municipal and industrial water use. Sacramento, 1968. (Bulletin 166-1)

6-4

TABLE 2

NET WATER DEMANDS AND WATER SUPPLIES BY HYDROLOGIC
STUDY AREA, 1967. (IN 1,000'S OF ACRE-FEET)

Hydrologic area	Urban per capita water use (gpd)	Net water demands	Dependable water supply	Groundwater overdraft	Total net water supply	Shortage
North Coastal	160 ¹	960	950	0	950	10
San Francisco Bay	170	1,140	1,090	50	1,140	0
Central Coastal	200	940	820	120	940	0
South Coastal	180	2,490	2,490	0	2,490	0
Sacramento Basin	350 ¹	5,560	5,360	140	5,500	60
Delta-Central Sierra	320 ²	1,930	1,830	100	1,930	0
San Joaquin Basin	370	4,370	4,200	170	4,370	0
Tulare Basin	370	6,390	4,590	1,800	6,390	0
North Lahontan	(NA)	410	350	0	350	60
South Lahontan	280	420	180	240	420	0
Colorado Desert	380	3,980	3,890	90	3,980	0
TOTALS		28,590	25,750	2,710	28,460	130

- Notes: 1. Water demands for pulp and paper industry not included.
2. For Valley floor only, recreational and second home use in foothills not included.

Source: California. Department of Water Resources. Bulletin 160-70: Water for California, the California Water Plan outlook in 1970. Sacramento, 1970.

TABLE 3

PRESENT DEVELOPED WATER SUPPLY (1965)
(1,000 acre-feet/yr)

Subregion	Regulated Surface Water		Ground Water Pumpage		Import	Export	Developed Water Supply (1965)
	With conveyance	Without conveyance	Safe yield	Overdraft			
North Coastal	3,345		150			950	2,545
San Francisco Bay	75	(98)	300	70	1,186		1,631
Central Coastal	113		900	70			1,083
South Coastal	180		1,600		1,505		3,285
Sacramento Basin	7,789	(3,315)	1,600	100	807	1,987	8,309
Delta-Central Sierra	2,359		600	150	1,976	2,509	2,576
San Joaquin Basin	3,825		1,750	50	1,675	1,531	5,769
Tulare Basin	2,800		4,200	2,300	1,331		10,631
North Lahontan	379		60		11	9	441
South Lahontan	328		300	300		325	603
Colorado Desert	0		100	200	5,346	1,180	4,466
	(21,193) ^{a/}	(3,413) ^{b/}			(13,837)	(8,491)	(41,339) ^{a/}
California Region	16,693		11,560	3,240	5,346	0	36,839

a/ An estimated 4,500,000 AF/yr. of this amount is local reuse of return flows and is not included as "developed water supply."

b/ Not included in total present developed water supply.

Source: Pacific Southwest Inter-Agency Committee. Comprehensive framework study; California region. 1972.

TABLE 4

SUMMARY OF 1967 NET WATER DEMANDS AND WATER SUPPLIES

(in 1,000's of acre-feet per year)

Hydrologic study areas	Total net water demands	Dependable water supplies								Ground water over-drought	Total net water supplies
		Local surface water developments	Ground water safe yield	Imports by local agencies	Central Valley Project ¹	Other federal developments ¹	State water project ¹	Waste water reclamation ²	Total dependable supplies		
North Coastal	960	550	150	-	-	250	-	-	950	0	950
San Francisco Bay	1140	150	310	430	55	80	60	5	1090	50	1140
Central Coastal	940	40	730	-	0	50	0	-	820	120	940
South Coastal	2490	170	900	1390	-	-	0	30	2490	0	2490
Sacramento	5560	1960	1010	10	2210 ³	170	0	-	5360	140	5500
Delta-Central Sierra	1930	190	570	-	980 ³	90	-	-	1830	100	1930
San Joaquin	4370	2040	580	-	1590	0	0	-	4200	170	4370
Tulare Basin	6390	2290	600	-	1460	240	0	-	4590	1800	6390
North Lahontan	410	290	50	10	-	0	-	-	350	0	350
South Lahontan	420	40	140	-	-	-	0	-	180	240	420
Colorado Desert	3980	-	60	-	-	3830	0	-	3890	90	3980

1. Facilities existing or under construction in 1967.

2. Facilities definitely planned for construction.

3. Includes conveyance of exchange supplies via project facilities.

Source: California, Department of Water Resources. Bulletin 160-70: Water for California, the California Water Plan outlook in 1970. Sacramento, 1970.

TABLE 5

GROUND WATER IN CALIFORNIA
(1,000 Acre-Feet)

Region	Known Ground Water Areas			
	Storage Capacity		Water :in Storage	Annual : Primary ^{1/} : Recharge
	Total	Usable		
North Coastal Area	2,000	700	2,000	150
San Francisco Bay Area	3,000	1,100	1,000	310
Central Coastal Area	20,000	7,600	18,000	730
South Coastal Area	100,000	7,000	95,000	900
Central Valley Area ^{2/}	608,000	102,000	540,000	2,760
Lahontan Area	157,000	700	100,000	190
Colorado Desert	158,000	3,600	100,000	60
Total	1,048,000	122,700	856,000	5,100

^{1/} Includes natural recharge plus recharge from local reservoirs operated to augment natural stream channel percolation.

^{2/} Combined areas of Sacramento Basin, Delta-Central Sierra area, San Joaquin Basin, and Tulare Basin.

Source: California. Department of Water Resources. Water for California, the California Water Plan outlook in 1970. Sacramento, 1970. (Bulletin 160-70)

TABLE 6

SUMMARY OF WATER WITHDRAWN, EXCEPT FOR HYDROELECTRIC POWER,
IN MILLIONS OF GALLONS PER DAY.

Year	Popu- lation (1,000's)	Per capita use (gpd)	Water withdrawn, including irrigation conveyance losses										Convey- ance losses	Fresh water consum- ed
			Groundwater			Surface water			Re- claimed sewage	All sources				
			Fresh	Saline	Total	Fresh	Saline	Total		Fresh	Saline	Total		
1950	10,586				9,977			12,430				22,407		
1955	13,003		11,089	0	11,089	14,392	5,200	19,592	25.3	25,481	5,200	30,706		
1960 ¹	15,717	2,200	11,000	140	11,140	11,000	9,100	20,100	.5	22,000	9,240	31,240	4,000	15,000
1965	18,403	2,300	14,000	140	14,140	17,000	11,000	28,000	400	31,000	11,140	42,540	5,000	17,000
1970	19,953	2,400	18,000	180	18,180	20,000	8,700	28,700	130	38,000	8,880	47,010	4,900	22,000

Notes: ¹ 1. Withdrawal figures for 1960 exclude conveyance losses.

Source: U.S. Geological Survey. Estimated use of water in the United States, 1950, 1955, 1960, 1965 and 1970. (Circulars 115, 398, 456, 556 and 676).

In discussing the SWRCB's basin plans, the Director again alluded to some relationships. He said that of the 16 basins under consideration, four would be developed with the Department of Water Resources as contractor. Following his brief description of the plans, the Director made a statement most germane to our search for clues to the management of water resources. "Although these plans are ostensibly water quality control plans, they get involved in the whole subject of water resources management and will become part of the California Water Plan."⁴

The history of water quality control in California is found legislatively in the Dickey Water Pollution Act of 1949 and amendments in nine subsequent sessions of State Legislature through 1965. The Act's title was changed in 1965 to Water Quality Control Act and represents Decision 7 of the California Water Code. With the State Constitution requiring that the water resources of the state "be put to the fullest beneficial use" and that "the waste or unreasonable use or unreasonable method of use be prevented", the 1965 Act stated that:

It is necessary for the health, safety and welfare of the people of this state to provide means for coordinating the actions of various state agencies and political subdivisions in the control of water pollution and the maintenance of water quality.

. . . it is necessary to provide means for the regional control of water pollution . . .

. . . (the) control of water quality is a matter of statewide interest and concern and that it is necessary to provide for statewide control of water quality and to provide for regional control of water quality where water quality is primarily a matter of regional concern.

. . . the people of the state have a primary interest in the control and conservation of the water resources of the state and the prevention of damage thereto by unreasonable use.

. . . because of the widespread demand and need for full utilization of the water resources of the state for beneficial uses, it is the policy of the state that the disposal of wastes into the waters of the state shall be so regulated as to achieve highest water quality consistent with maximum benefit to the people of the state so as to promote the peace, health, safety and welfare of the people of the state.

One of the principles stipulated in the law calls for regional control of water pollution. Applying the "systems approach" in its most sensible form, the Legislature recognized that California's water pollution problems are regional in nature and dependent on an interacting web of factors

⁴ Report of the Director of Department of Water Resources to the State Water Commission, April 4, 1974, P. 7.

of climate, topography and population, as well as recreational, agricultural, and industrial development probably unique to each region and differing in one from another. In response to the situation created by California's size and enormous internal diversity, a State Water Pollution Control Board and nine Regional Water Pollution Control Boards were established in 1949 (subsequent amendments to the 1949 Act changed the name to State and Regional Water Quality Control Boards).

The State Water Quality Control Board is composed of nine members appointed by the Governor and the directors of the following state departments (or representatives delegated by them): (1) Public Health; (2) Water Resources; (3) Conservation; (4) Agriculture; and (5) Fish and Game. Seven of the Governor's nine appointees must be selected from qualified persons in each of the following fields: (1) production and supply of domestic water; (2) irrigated agriculture; (3) industrial water use; (4) production of industrial waste; (5) public sewage disposal; (6) city government; and (7) county government.

Each regional board is composed of seven members representing the following interests: (1) water supply, conservation, or production⁵; (2) irrigated agriculture; (3) industries producing industrial wastes; (4) municipalities; (5) counties; (6) organization associated with both recreation and wildlife; and (7) public at large. There are no ex-officio state officials on the regional boards. Members of each board are appointed by the Governor for four years on a staggered schedule. Regional board members serve without pay but are reimbursed for their necessary expenses.

Each board is served by a staff of administrative, technical and clerical personnel headed by an executive officer. The executive officers, who must meet technical qualifications set by the State Board, are exempt from civil service and serve at the pleasure of the regional boards.

Principal responsibilities of a regional board are:

to formulate and adopt long-range plans and policies for water pollution and water quality control within the region in conformity with legislative policy and any water quality policy adopted by the State Board.

to conduct public hearings prior to the adoption of water pollution and water quality control policies.

to prescribe requirements relative to any condition of pollution or nuisance existing or threatened including prescribing requirements as to a proposed or existing discharge of sewage or industrial waste into a disposal area or receiving waters; such requirements may be revised at the discretion of the board. (Each regional board may also specify certain conditions and locations where no direct discharge of sewage or industrial waste will be permitted within the region.)

⁵Note here again the direct linkage between quantity and quality concerns.

to obtain coordinated action in water quality control and in the abatement, prevention and control of water pollution and nuisance by means of formal or informal meetings with the persons involved.

to encourage and assist self-policing waste disposal programs.

to request enforcement of laws concerning water pollution or nuisance by appropriate federal, state and local agencies.

to issue an order to cease and desist to a sewage or industrial waste discharger when such discharge is taking place contrary to the prescribed requirements and is threatening to cause or is causing pollution or nuisance; then on the failure of the discharger to comply with the order, to certify the facts to the local district attorney who will seek a superior court injunction order restraining the discharger from continuing the discharge in violation of requirements.

to report to the State Board and appropriate local health officer any case of contamination in the region which is not being corrected.

to investigate any source of water pollution or nuisance within its region and to conduct surveillance.

to recommend to the State Board projects for the reduction of water pollution which the regional board considers eligible for any financial assistance which may be available through the State Board.

As regulatory agencies, their work until recently was limited to the formulation and adoption of long-range plans and policies for water pollution control, establishment and enforcement of discharge requirements, and to conduct surveillance and coordinate the interests of other agencies. The 1965 amendments to the Water Quality Control Act gave the regional boards additional authority in the development of water quality control policies that are not limited, as are water pollution control policies, to the consideration of man-made waste discharges only.

In formulating long-range plans and policies, even in setting waste discharge requirements, the regional boards first must consider and determine the beneficial water uses to be protected.

A regional board does not establish water uses, but it must identify water uses which it intends to protect. Any use may affect other uses and the problem becomes a matter of overall benefit to the area concerned. Prior to making a policy declaration, or establishing waste discharge requirements, the board considers established water uses, planned future uses, and the need for waste disposal. The Statewide Policy for the Control of Water Quality, adopted by the State Board in March, 1967, continues to recognize that waste disposal, dispersion and assimilation are economic beneficial uses of water but declares, in accordance with Section 1300.2 of the Water Quality Control Act, that such uses shall be regulated as

required to protect the beneficial uses of, but not limited to, domestic, municipal, and industrial supplies, the propagation, sustenance and harvest of fish, aquatic life and wildlife, recreation, esthetic enjoyment and navigation.

Before determining the beneficial water uses to be protected, the views of all interested parties are solicited and considered. Cooperation and assistance are sought from other agencies having water pollution and water quality control or water contamination control responsibilities. Use is made of the planning, investigative, technical and advisory services of federal, state, and private agencies whenever practicable.

Informal meetings and discussions and formal public hearings are held. After weighing the findings, the board acts upon the matter at a public meeting. Thus, the board acts as arbiter with the duty to hear all interested parties, to evaluate all factors, and then, to enunciate the water uses which it intends to protect.

Until recently, the regional control boards were primarily concerned with establishing and enforcing waste discharge requirements for the control of water pollution. Waste discharge requirements are regulations specifying the quality level at which the waste discharge or the receiving waters or both are to be maintained to preclude unreasonable harm to other water users.

The boards must set requirements on every existing, proposed, new (or materially changed) waste discharge, and they may establish new requirements on existing discharges if necessary. The reporting of a discharge from a family dwelling may be waived by the regional boards. In keeping with the legislative policy of maintaining highest water quality consistent with maximum benefit, prescribed requirements need not authorize utilization of the full waste assimilative capacity of the receiving waters.

Requirements may not specify the design, location, type of construction or particular manner in which pollution may be corrected, but a regional board may specify certain conditions under which, and locations where, no direct discharge of waste will be permitted.

The boards also specify water-contact sports areas for which rules and regulations as to water quality established by the State Department of Public Health are applicable.

A regional board may investigate any source of water pollution or nuisance within its region and may require waste dischargers to furnish such technical reports as the board directs. Using this authority, the boards may require a waste discharger to supply necessary technical data or to conduct a monitoring program to assure that the prescribed discharge requirements are being met. The boards themselves conduct check-sampling programs on waste discharges.

Proceedings to establish or revise waste discharge requirements are generally initiated on the filing, as required by law, of a report of a proposed discharge or change in an existing discharge. The discharger is usually required to file only one report consisting of either a simple form or a letter with accompanying map. A regional board forwards copies of the report and any other pertinent data to all interested and affected parties, thus starting the process of coordination. Where facts are lacking in regard to the discharge or proposed discharge, the board asks state or local agencies to make special technical investigations or may ask the discharger to make such investigations.

Before forwarding tentative discharge requirements to the discharger, comments and recommendations from interested agencies are sought and hearings may be held to develop additional facts. All parties concerned are notified when the board meets to make its decisions.

After determining the beneficial uses of water to be protected, the board at a public meeting establishes limits on physical, chemical and bacteriological characteristics (or concentrations) beyond which the quality of the waters become impaired for the beneficial uses enunciated. Existing state and regional water pollution and water quality control policies serve as guidelines in determining specific water quality objectives. A regional board customarily consults with agencies and individuals expert in particular fields of water use. This consultation, although not mandatory, is the normal procedure. However, the final decision in all cases rests with the regional board.

In summary, the four major steps which a regional board follows in prescribing or revising and enforcing discharge requirements are:

1. Enunciation of the beneficial water uses which the board intends to protect.
2. Definition of water quality criteria to protect beneficial uses.
3. Prescribing of discharge requirements, and
4. Checking and enforcing compliance with requirements.

Similar steps are taken by the boards in establishing water pollution control policies. State Board policy encourages a rational long-range approach to an effective water pollution control program by the establishment of waste discharge requirements on major hydrographic units. However, the boards are empowered to consider, on a case-by-case basis, the beneficial uses and water quality objectives in the area of a waste discharge. The urgency of specific situations requires that this frequently be done, making the prescription or revision of waste discharge requirements almost a daily task of the regional boards.

As previously stated, water quality control has far broader implications than the consideration of man-made wastes only as the causative factor in water pollution. Water quality control policies provide the basis for maintaining water quality to protect designated beneficial uses in a given basin, stream or reach, bay, lagoon and the ocean, and provide guidance to all whose actions may affect the quality of the water. The policies also provide the basis for establishing or revising waste discharge requirements and programs of surveillance and enforcement, and for directing coordinated efforts in water quality control by federal, state and local public agencies and private industry.

In addition to enunciating the beneficial water uses that are to be protected and delineating the precise water concerned, the control boards, in formulating and adopting water quality control policies, also:

1. Select the water quality indicators (water constituents or characteristics) to be used to measure and define water quality.

2. Delineate water quality objectives (limits or levels prescribed for water quality indicators) to protect the designated beneficial uses.
3. Define the controlling principles and underlying reasons for the above actions, including the evaluation of the practicality of achieving the established water quality objectives.
4. Delineate the program by which the established water quality objectives will be attained and maintained.

Obviously, the formulation of long-range plans and policies and the setting of waste discharge requirements require extensive preparatory work. This is the task of a regional board staff. The staff conducts informal meetings and discussions with all interested parties, often with board members in attendance. The staff also secures with the board's approval the special investigative, technical and advisory services deemed necessary to complement those of the staff itself.

The board relies heavily on information and recommendations from its staff and on evidence presented at public hearings and formal meetings conducted by the board. In all cases, the decisions are the prerogative and judgment of the board.

The board's staff conducts other activities such as inspection, surveillance and enforcement tasks, public information, and the processing of applications (including analyzing and recommending projects) for sewerage and waste treatment plant construction grants administered or approved by the State Board. The staff is also responsible for liaison with other regional board staffs and the State Board, and for coordinating with other state, federal and local agencies at the regional level.⁶

In their water pollution control activities, the regional boards have a high degree of autonomy. They have been delegated the primary responsibility of controlling water pollution within their respective regions. In this capacity they are basically local agencies governed by local people representing local interests, yet agencies of the state government. They act in accordance with state law and are guided by statewide policies established by the State Water Quality Control Board, which may review the action or inaction of a regional board. This particular regional concept is unique in the executive department of the state government.

A second concept, that of providing a balance of interests in considering economical waste disposal practices and preserving the beneficial uses of water, is one of the strongest aspects of the water pollution control legislation. This necessary balance of interests of the water user with those of the waste discharger is achieved through broad and varied representation on both the state and regional boards.

A third significant concept expressed in the Water Quality Control Act is that, in setting waste discharge requirements, the regional boards may prescribe end results only. This provision eliminates the previous

⁶This information is derived from the document, "A History of Water Pollution Control in California, 1949-1967," itself a reprint from "Useful Waters for California," final report of the former State Water Control Quality Control Board.

system of issuing permits and reviewing plans for sewerage works. Under the present law, the regional boards prescribe and revise waste discharge requirements only in relation to conditions existing from time to time in the disposal area or receiving water. The law clearly states that the boards may not specify the design, location, type of construction, or particular manner of correcting pollution. Persons ordered to correct or prevent pollution may do so by any lawful means.

Likewise, in formulating and adopting water quality control policies, the boards are concerned with the end results. As in setting waste discharge requirements, the boards first enunciate the beneficial water uses which they intend to protect, and then define the water quality objectives to protect such uses. But further, water quality control policies, unlike waste discharge requirements, delineate the program by which the established water quality objectives will be attained and maintained.

Finally, it should be noted that the Act does not limit the power of a local governmental agency to act on its own behalf to abate nuisances or to adopt restrictions or regulations as to sewage or industrial waste disposal more stringent than those adopted by a regional board, nor does the Act limit the right of any person to seek an action for relief against any private nuisance as defined in the Civil Code or seek relief against contamination or pollution. The Act, which specified that the water quality boards are the agencies to control water pollution and water quality, also recognizes the duties and responsibilities of other state and local agencies with regard to water pollution control. Thus, coordinated action is required between all agencies concerned.

To return to the recommendation made by Dr. Castruccio that we provide an organization chart of "who is responsible for what and who does what", our research into the decision network would be grossly inadequate without mention of the Porter-Cologne Water Quality Control Act, universally regarded as the basis for the way in which responsibility has been allocated.

Early in 1968 the new State Water Resources Control Board created a Study Project, Water Quality Control Program, for the purpose of reviewing, and to make recommendations toward improving, California's 20-year water quality control laws. The Study Project consisted of a blue ribbon panel of seven members supported by a small staff. The Project was assisted by representatives of 23 statewide organizations and 12 concerned state agencies. Use was made of testimony heard during nearly five years of legislative hearings on water quality.

After nearly a year of workshop-type meetings followed by public hearings, the Study Project issued its report titled "Recommended Changes in Water Quality Control". The recommendations proposed both legislative and administrative changes.

Assemblyman Carley V. Porter, Chairman of the Assembly Water Committee, immediately introduced AB 413 based on the recommendations of the Study Project and the State Board. The Governor gave full support to the bill which was subsequently passed without a dissenting vote. AB 413 repealed Division 7 of the Water Code (the Water Quality Control Act) and substituted entirely new language. AB 413 also amended related sections in other Codes. Division 7 of the Water Code is now known as the

Porter-Cologne Water Quality Control Act, and became effective January 1, 1970.⁷

Some concepts of the old law were retained and refined and new concepts added. In short, the authority of the State Board and the nine Regional Water Quality Control Boards was greatly strengthened thus enabling these regulatory agencies to administer an effective water quality control program for California.

The new law clearly identifies the relationships between water quantity and water quality.⁸ For example, the State Board may approve appropriation by storage of water to be released for the purpose of enhancing the quality of other waters which are put to beneficial uses. Also, the State Board shall take into account, whenever it is in the public interest, the amount of water required for recreation and the preservation and enhancement of fish and wildlife resources. In addition, the new law adds esthetic enjoyment to the list of beneficial uses to be protected.

Practically, the addition of these beneficial uses enables more stringent regulation of water use and waste disposal to better protect and enhance water quality. The inclusion of esthetic enjoyment recognizes a new environmental awareness and the growing public concern over the water environment.

The Porter-Cologne Act strengthens the powers of the State Board to make it one of the most effective regulatory agencies in state government. The State Board is directed to adopt (after a public hearing) a new, broader state policy for water quality control which must be complied with by all other government entities.

In accordance with the Act, the State Board has initiated a public education program, established a filing fee on reports of proposed discharges or a material change in an existing discharge, adopted interim regulations governing the licensing and use of oil spill cleanup agents and has set up a procedure for emergency oil spills.

The Act also affects the regional boards, increasing each board's membership from seven to nine members, "each of whom shall represent and act on behalf of all the people of the region". Duties undertaken by the regional boards are similar to those previously assigned but are greatly broadened. A board can now regulate land use practices which affect water quality and stress is placed on areawide solutions to water pollution problems.

Prior to the enactment of the Act, some of the most frequent criticism of the 20-year-old existing California water quality law centered on the complaint that enforcement provisions were not adequate.

Under the Porter-Cologne Act, the regional boards now will be able to enforce waste discharge requirements without showing the existence of a condition of pollution or nuisance. If a discharge is violating requirements or threatening to cause pollution, a regional board may issue a cease and desist order and require compliance. The board may order the discharger to clean up the effects of pollution at the discharger's expense.

⁷The legal ramifications for the Porter-Cologne Act are ably discussed in an article by Ronald B. Robie, "Water Pollution: An Affirmative Response by the California Legislature", in The Pacific Law Journal, Vol. 1, No. 1, January, 1970, pp. 2-35.

⁸Note again the quantity-quality relationship.

If a discharger does not comply with a cease and desist order, the regional board may request enforcement by the Attorney General, who will bring action in the appropriate Superior Court. In an emergency, the board can request the Attorney General to abate a discharge even though no discharge requirements have been adopted.

Violation of a regional board cease and desist order could result in a maximum fine of \$6,000 for each day of the violation.

Other provisions of the Act include the establishment of a State Water Pollution Cleanup and Abatement Account which provides funds for cleaning up pollution; the creation of a program to train sewage plant operators; and the establishment of procedures for the regulation of discharges from houseboats. The Act also greatly strengthens the 18-member Water Quality Advisory Committee.

In implementing administrative recommendations, the State Board has established a Division of Planning and Research. The division determines water quality research needs, conducts research programs, or coordinates such programs being conducted by other state agencies. Planning efforts are directed toward protecting and enhancing the water environment and achieving clean water for California.

Chart 18 "Major Water Quality Problems -- California Region" portrays graphically and in useful detail many of the areas of concern of the Regional Board.

The incidence of high mineral content, a problem of growing importance, is shown on the map on the following page, Charter 19.

Under the Porter-Cologne Water Quality Control Act, the State Water Resources Control Board reviews and evaluates state agencies' proposed planning and investigatory activities relating to water quality. Tabulations for 1973-74 provide valuable clues as to "who does what" within a given fiscal year.

Of the various program categories of material concern to the State Water Control Board's Division of Planning and Research, the one entitled "Environmental Surveillance and Data Management" merits particular attention within the framework of the University of California Integrated Study. Here are included programs for data collection, storage and retrieval analysis, reporting, and operation of models for water quality control and water resources management. State agencies' proposed expenditures in this category for fiscal year 1973-74 are approximately \$1.6 million, which is 9 percent of the total water quality related expenditures for that year. Major programs are listed as follows:

Groundwater Quality Data

Surface Water Quality Data

D-1379 Delta Water Quality Monitoring

San Joaquin Valley Drainage Monitoring

Bay-Delta Environment Protection Study

California-Nevada-Federal Joint Water Quality Investigation of Lake Tahoe.

CHART 18
 MAJOR WATER QUALITY PROBLEMS
 CALIFORNIA REGION

Subregion/Area	Problem	Cause
North Coastal		
(1) Crescent City & Humboldt Bay	Bacteriological contamination	Improper waste treatment and vessel wastes dumped in coastal waters.
(2) Klamath Lake	Eutrophic conditions and nuisance	Natural conditions and irrigation return flows.
(3) Klamath River	Fish kills	Algae concentrations from Klamath Lake
(4) Most drainage basins	Siltation and turbidity	Erosion.
San Francisco Bay		
(5) San Francisco Bay	Depressed oxygen levels Elevated coliform bacteria Fish kills	Discharge of MGI waste water. Discharge of MGI waste water. Accidental oil spills and deliberate toxic waste discharge.
	Nuisance, algal growths Bacterial pollution	Discharge of several kinds of wastes. Sewer overflows.
(6) Russian River	Turbidity Algal blooms	Improper land use and imported water from Eel River. Improper waste treatment.
Central Coastal		
(7) Monterey and Carmel Bays	Pollution	Massive oil spills and inadequately treated waste discharges.
(8) Lower Salinas Valley	Sea-Water Intrusion into ground water	Overdumping of groundwater.
South Coastal		
(9) Ground-water basins	Sea-water intrusion	Overdraft.
(10) Coastal areas	Adverse effects on kelp beds	Ocean disposal of municipal waste waters.

CHART 18
 MAJOR WATER QUALITY PROBLEMS
 CALIFORNIA REGION
 (cont'd)

Subregion/Area	Problem	Cause
South Coastal		
(11) Near shore areas	High coliform bacteria concentrations	Floating material of waste water origin.
(12) Coastal lagoons-estuaries	Excessive algal growth, oxygen depression and odors	Runoff carries enriching nutrients from urban and irrigated lands and wastes from military, commercial and pleasure craft.
Sacramento Basin		
(13) Keswick Reservoir	Fish kills	Occasional mine drainage discharge.
(14) Clear Lake	Algal concentrations, odors	Natural and man made causes.
Delta Central		
(15) San Joaquin River Delta	Eutrophication - depressed oxygen levels	Unnatural flora patterns from pumping and waste discharge during low flows.
(16) Delta system	Turbidity	Continual dredging for ship channels.
(17) Western Delta	Fish kills	Toxic waste discharges.
San Joaquin		
(18) Stanislaus River	Algae, aquatic plants, fish kills	Large salt loads, nutrients from municipal, industrial and agricultural sources. Diversion of natural flow from San Joaquin River and its tributaries.
(19) Tuolumne River	"	"
(20) San Joaquin River	"	"

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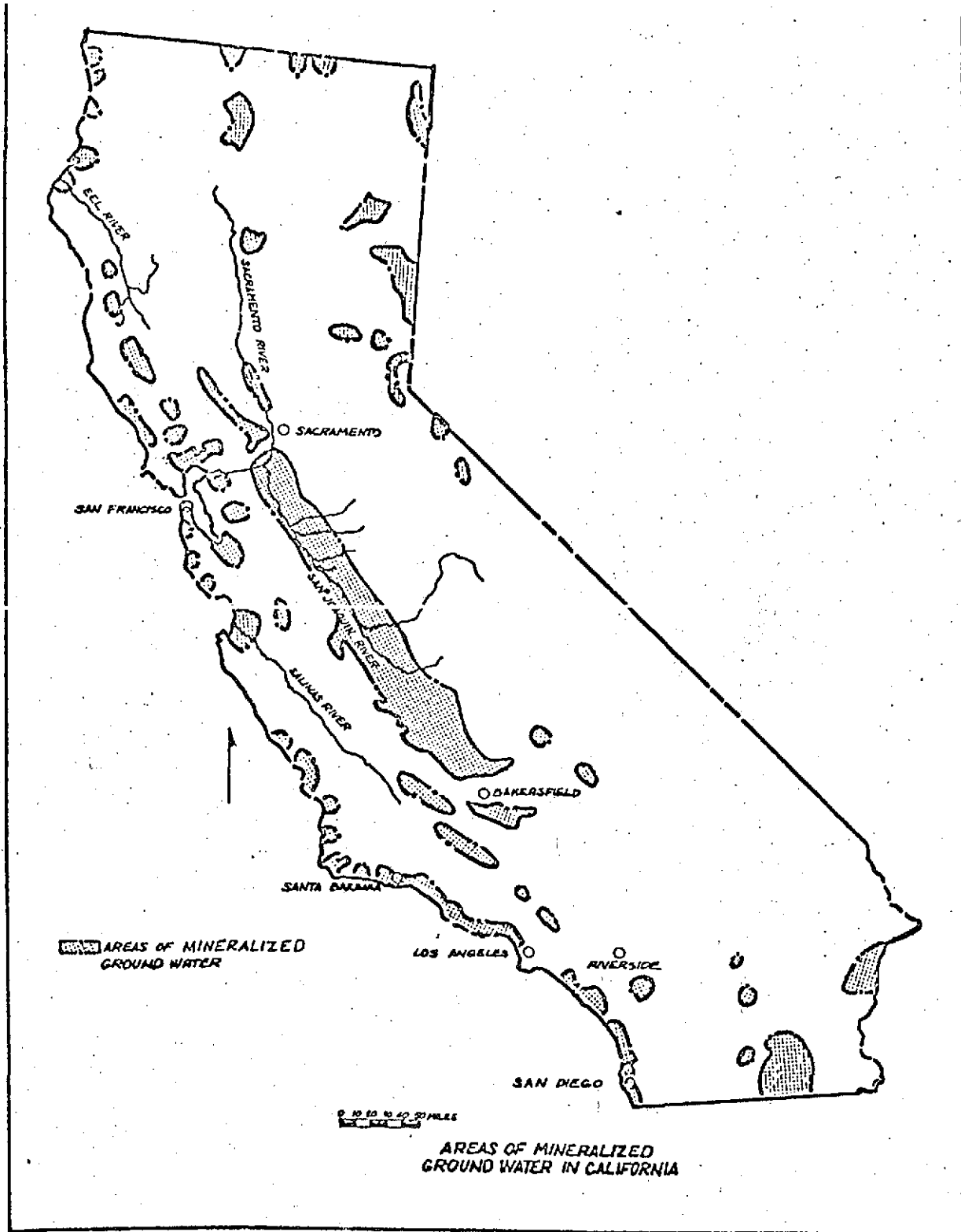
CHART 18
 MAJOR WATER QUALITY PROBLEMS
 CALIFORNIA REGION
 (cont'd)

Subregion/Area	Problem	Cause
San Joaquin		
(21) Lower San Joaquin River	High salt content	Saline water from abandoned gas wells.
(22) Ground-water basins	High salt content	Increasing drainage problems.
Tulare Basin		
(23) Ground-water basins	Ground water exceeds recommended maximum total dissolved solids and nitrate concentrations exceed maximum levels recommended.	Worsening adverse salt balance conditions near the inland sink formed by Tulare Lake.
North Lahontan		
(24) Lake Tahoe	Degradation of quality and increase in turbidity	Solid wastes and surface runoff from land development and installation of shoreline structures.
(25) East Fork Carson River	Waters of tributary have become toxic	Acid wastes from abandoned mine.
South Lahontan		
(26) Mono Lake	Water quality is being degraded	Diminishing inflow
(27) Various recreation areas	Minor water quality problems	Failing septic tanks.
Colorado Desert		
(28) Agricultural areas	Adversely affected	Application of high mineral content water from Colorado River.
(29) Salton Sea	Eutrophic and increasing salinity	Agricultural waste discharges.
(30) Salton Sea	Fish kills	Decreasing oxygen from decomposition of algal blooms and waste discharges from Mexicali into New River.

Source: Pacific Southwest Inter-Agency Committee.
 Comprehensive framework study: California region. 1972.

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AREAS OF MINERALIZED GROUND WATER IN CALIFORNIA



Source: Fuhriman, Dean K. and James R. Barton. Ground water pollution in Arizona, California, Nevada and Utah. Washington, D.C., 1971. (EPA Water pollution control research series 16060 ERU 12/71)

CHART 20
PROPOSED STATE AGENCIES' WATER QUALITY RELATED ACTIVITIES FOR 1973-74

AGENCY	PROGRAM OR PROJECT TITLE	ESTIMATED EXPENDITURES (\$ in Thousands)																
		Total 1973-74 Proposed	Source of Funds	AREAS OF WATER QUALITY RELATED WORK							PROGRAM CATEGORIES							
				Inland Surface Waters	Ground- waters	Coastal Waters	Agric. Wastes	Municipal Industrial Wastes	Wastewater Reclamation and Reuse	Others	Planning and Management	Monitoring and Data Management	Research, Development and Demon- stration	Enforcement Activities	Services to Other Agencies			
<u>Agriculture</u> <u>Dept. of</u>	Dairy Water Pollution Inspection	75	GF				75										75	
<u>Colorado River</u> <u>Board</u>	Protection of California's Colorado River Rights and Interests	68	GF	68								50	3	15				
<u>Conservation,</u> <u>Dept. of</u>	Watershed and Fire Protection	275	GF	275								92		92			91	
	Regulation of Oil, Gas and Geothermal Operations	76	P&GF		75			1				19	19		19		19	
	Mineral Resources and Environmental Geochemistry	10	GF	10								10						
	SUBTOTAL	361																
<u>Public Health,</u> <u>Dept. of</u>	Sludge Disposal and Reclamation	15	GF						15					15				
	Shellfish Protection	15	GF			15							15					
	Wastewater Reclamation Component	15	GF							15				15				
	Wastewater Reclamation - Standard Setting	10	GF							10				10				
	Water Quality Investigations	50	GF	50										50				
	Support RWQCB	55	GF	10	5	15			25									55
	Sewage Disinfection	10	GF						10						10			
SUBTOTAL	170																	

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CHART 20 (cont'd)

PROPOSED STATE AGENCIES' WATER QUALITY RELATED ACTIVITIES FOR 1973-74

ESTIMATED EXPENDITURES (\$ in Thousands)

AGENCY	PROGRAM OR PROJECT TITLE	Total 1973-74 Proposed	Source of Funds	AREAS OF WATER QUALITY RELATED WORK							PROGRAM CATEGORIES					
				Inland Surface Waters	Ground- Waters	Coastal Waters	Agric. Wastes	Municipal Industrial Wastes	Wastewater Reclamation and Reuse	Others	Planning and Management	Monitoring and Data Management	Research, Development and Demon- stration	Enforcement Activities	Services to Other Agencies	
<u>Fish and Game Dept. of</u>	General Water Quality Investigations	75	F&GSP	38		37							50		25	
	Fish Kill Investigations & Pollution Regulation Enforcement	186	F&GSP	93		93					62			62	62	
	Water Pollution Control Laboratory	150	F&GSP	30		80	10	30					50	100		
	Evaluation of Annual Unexplained Fish Mortalities in San Francisco Bay-Delta	22 129 22	SWRCB-BF EPA F&GSP			173								173		
	Technical Support to Regional Water Quality Control Boards	7 63	SWRCB-GP F&GSP	18		17	17	18			16			32	15	7
	Study of Factors Controlling Algae Growth	50	SWPF	50												
	Wildlife Disease Control	12 12	F&GSP Fed.Aid				12	10	2		12			50		
	Pesticides Investigation	5 2	Fed.Aid F&GSP	4		3								7		
	Pesticide Residue Monitoring of Fish and Wildlife	15 6 44	F&GSP EPA Fed.Aid	34		31							65			
	Standardized Toxicity & Threshold Response Bioassay Test for Monitoring Wastewaters	50	SWRCB-BF					50						50		
	Inshore Fisheries Habitat Evaluation and Monitoring	50	F&GSP			50					10	20	10	10		
	SUBTOTAL	900														

CHART 20 (cont'd)

PROPOSED STATE AGENCIES' WATER QUALITY RELATED ACTIVITIES FOR 1973-74

ESTIMATED EXPENDITURES (\$ in Thousands)

AGENCY	PROGRAM OR PROJECT TITLE	Total 1973-74 Proposed	Source of Funds	AREAS OF WATER QUALITY RELATED WORK							PROGRAM CATEGORIES				
				Inland Surface Waters	Ground- waters	Coastal Waters	Agric. Wastes	Municipal Industrial Wastes	Wastewater Reclamation and Reuse	Others	Planning and Management	Monitoring and Data Management	Research, Development and Demon- stration	Enforcement Activities	Services to Other Agencies
<u>Water Resources</u> <u>Dept. of</u>	Basin Water Quality Planning	100	SWRCB-BF							100	100				
	Groundwater Quality Data	166	GF		166							166			
	Calif-Nevada-Federal Joint Water Quality Investigation of Lake Tahoe	18	GF	18								18			
	D-1379 Delta Water Quality Monitoring	457	SWPF	457								457			
	San Joaquin Valley Drainage Monitoring	69 10	SWPF USBR	25			54					79			
	Planned Utilization of Water Resources (Development of Groundwater Quality Model)	40 80	GF OWRR		120								120		
	Surface Water Quality	428	GF	428								428			
	Water Quality Investigations	525	GF	165	210			150			200		25		300
	Wastewater Reclamation	375 69 30	GF SWPF Local						474		417	57			
	Saline Water Conversion	253 85	GF SWPF							338	113		225		
	Groundwater Basin Protection	176	GF		176						176				
	Environmental Impact Analysis	40	GF	20	20						40				
	Bay-Delta Environment Protection Study	184	SWPF	184								184			
	Geothermal Resources	7	GF							7	7				
	Groundwater Basin Resources	47	GF		47						24	23			
	Western States Water Planning	27	GF							27	27				
	Coordinated Statewide Planning	100	GF							100	100				
	Planned Utilization of Water Resources	60	GF							60	60				
	San Diego County Coastal Lagoons	20	GF			20					20				
	Land Development Impact Studies	16 16	GF Local							32	32				
SUBTOTAL	3,398														

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CHART 20 (cont'd)

PROPOSED STATE AGENCIES' WATER QUALITY RELATED ACTIVITIES FOR 1973-74

AGENCY	PROGRAM OR PROJECT TITLE	ESTIMATED EXPENDITURES (\$ in Thousands)															
		Total 1973-74 Proposed	Source of Funds	AREAS OF WATER QUALITY RELATED WORK							PROGRAM CATEGORIES						
				Inland Surface Waters	Ground- waters	Coastal Waters	Agric. Wastes	Municipal Industrial Wastes	Wastewater Reclamation and Reuse	Others	Planning and Management	Monitoring and Data Management	Research, Development and Demon- stration	Enforcement Activities	Services to Other Agencies		
<u>University of Calif.</u>	Saline Water Conversion Research (UC-Water Resources Center)	411 472	State Fed.									883			883		
	Soils and Plant Nutrition (UC-Davis)	40	UC		10		10	20							40		
	Water Science and Engineer- ing - Water Quality & Pollution (UC-Davis)	160	Fed., State & Local	70	46		22			22					160		
	Water Science & Engineer- ing - Water Utilization & Management (UC-Davis)	40	CSRS & GF	10			30								40		
	Soils & Plant Nutrition (UC - Berkeley)	20	UC	20											20		
	Research Program in the Lake Tahoe Basin - National Science Foundation	561	NSF	390	171										561		
	Sanitary Engineering & Public Health (UC-Berkeley- SERL)	134 31 40 124	UC Private SWRCB-BP Fed.					306		23					329		
	Environment Engineering (UC-Davis)	50 100	UC Fed	46		8	30	27		39					150		
	Kearney Foundation of Soil Science (Nitrogen in the Environment)(UC-Riverside, Berkeley & Davis)	590 180	Fed-NSP UC Kearney Foundation				710			60					770		
	Environmental Toxicology (UC Davis)	160 65	Fed UC				225								225		
	Water Resources Research (UC Water Resources Center)	90 70 50	Fed GF UC	53	42	19	34	13		13	36				210		
	Soil Science & Agricultural Engineering (UC-Riverside)	200	Fed & State				200								200		

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PROPOSED STATE AGENCIES' WATER QUALITY RELATED ACTIVITIES FOR 1973-74

AGENCY	PROGRAM OR PROJECT TITLE	ESTIMATED EXPENDITURES (\$ in Thousands)														
		Total 1973-74 Proposed	Source of Funds	AREAS OF WATER QUALITY RELATED WORK							PROGRAM CATEGORIES					
				Inland Surface Waters	Ground- Waters	Coastal Waters	Agric. Wastes	Municipal Industrial Wastes	Wastewater Reclamation and Reuse	Others	Planning and Management	Monitoring and Data Management	Research, Development and Demon- stration	Enforcement Activities	Services	
University of Calif. Continued	Pest Control Related to Water Quality (UC-Riverside)	100	Fed & State	100										100		
	SUBTOTAL	3,688														
State Water Resources Control Board & Regional Boards	Regional Boards Laboratory and Field Services	300	GF	80		20		200								300
	Regional Boards Studies and Investigations	177	BF	50	50	50	27							177		
	State Board Research Program	807	BF	135	60		44	240	120		462			1091		
	144	GF														
	130	EPA														
	1005	BF								1005	1005					
State & Regional Board's Water Quality Control Programs	3404	GF								7290	4860				2430	
250	BF															
1413	EPA															
223	Reim- burse- ment															
	Total SWRCB Programs (1)	9853														
	(1) SWRCB Funded Activities listed under other state agencies (\$219,000) are not included in this amount															
TOTAL EXPENDITURES		18,513		2,931	1,218	631	1,500	3,115	778	10,340	7,452	1,634	5,957	2,836		

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ABBREVIATIONS
 AES - Agricultural Experiment Station
 BF - Bond Fund
 EPA - Environmental Protection Agency
 F&GSP - Fish and Game Support Funds
 GF - General Fund
 OWRR - Office of Water Resources Research
 SWPF - State Water Project Fund
 SWRCB - State Water Resources Control Board
 UC - University of California
 CSRS - Coop. States Research Service
 NSF - National Science Foundation

Source: California State Water Resources Control Board, Division of Planning and Research and Interagency Planning Committee, "California Agencies Water Quality Related Activities Proposed for Fiscal Year 1973-74", December, 1972 pp. 19-23.

Mentioned specifically in the Interagency Planning Committee's 1973-74 evaluation was the Department of Water Resources' Groundwater Quality Data Program.

"Much of the data is collected from contributing sources. The amount and type of data is often inadequate to assess general trends in water quality and has mostly been collected in response to specific problems. The present programs are being reoriented to the more environmentally significant constituents, but in many cases the numbers and frequency of analyses are too few for meaningful studies." The following four steps were proposed by a subcommittee established to study the groundwater quality data problem:

- (1) Summarize existing groundwater data programs.
- (2) Develop objectives of a program of groundwater monitoring.
- (3) Evaluate existing programs.
- (4) Develop program improvements and make recommendations for changes.

Especially noteworthy from our point of view was the proposal submitted by the Department of Fish and Game for the purpose of obtaining baseline information on the marine habitat in Southern California. In specifying that surveys under the \$50,000 program would include such techniques as remote sensing, the Department related their activities to the State Board's project, "Cooperative Study to Test Effectiveness of Aerial Surveillance and Remote Sensing for Water Quality Monitoring".⁹

Under the category "Research, Development, and Demonstration", four areas of endeavor were spelled out. While all of them contain elements of direct interest in connection with our study of water resource management processes and of potential interest with respect to our own emphasis on remote sensing techniques, one of them merits special attention here. Identifying the need for a statewide monitoring system "to fulfill the needs for planning and implementing water quality management programs in the waters of the state", the State Water Resources Control Board proposed an expenditure of \$200,000 in fiscal year 1973-74 for the development of a statewide water quality monitoring system and \$266,000 for the development of data management systems.¹⁰ The first concerned a combination of remote sensing from aircraft and possibly satellites, automatic recording monitors and systematic grab sampling. In the biological environment, techniques still require development. Indicators of pollution in coastal waters represent the least well-defined areas. Monitoring programs need to provide a basis to forecast pollution problems from materials such as

⁹ Division of Planning and Research and Interagency Programming Committee, California State Water Resources Control Board, "California State Agencies Water Quality Related Activities Proposed for Fiscal Year 1973-74", December 1972, p. 10.

¹⁰ Ibid., p. 15

heavy metals and pesticides. During the design of the statewide water quality monitoring system, close coordination with existing water quality data collection programs, such as the Department of Water Resources' ground and surface water quality data programs, will be necessary. The "information management system" was deemed necessary so as to achieve "effective utilization from the monitoring program. The following specific projects were then proposed:

Design of Statewide Water Quality Monitoring System

Wastewater Treatment Plant Data Acquisition and Management

Data Storage and Retrieval for Water Quality

Data Management for Water Rights

Application of Remote Sensing to Water Quality Control

Cooperative Study to Test Effectiveness of Aerial Surveillance and Remote Sensing for Water Quality Monitoring with Emphasis on Eutrophication Problems

Especially significant from the point of view of the ongoing Integrated Study of Remote Sensing at the University of California is the fact that the water quality control agencies of the state are cognizant of the need for water quality surveillance, aware of the inadequacy of conventional sampling techniques, and receptive to remote sensing as a tool in water quality inventory, monitoring, and enforcement. In fact, the State Water Resources Control Board concluded from a report, performed under contract by North American Rockwell Corporation (Space Division), that "with appropriate interpretation, qualitative information from water surfaces can be obtained for significant physical and biologic water quality factors and that water temperature can be measured quantitatively. Additional potentials for aerial remote sensing appear to be the discovery of unknown or illegal waste-water discharges and inventory of land use or construction projects that can affect water quality".¹¹

If, in our research during the past year and, consequently, in our report, we may seem to have moved away from the stricture of supply and demand¹², it is because, in the more comprehensive and realistic picture of California water, concerns about, and quest for promising utilization of remote sensing technology such as ERTS and similar devices, water

¹¹ North American Rockwell Space Division, "Study to Evaluate the Utility of Aerial Surveillance Methods in Water Quality Monitoring", Forward in Final Report, SD 70-565, September, 1970.

¹² P. A. Castruccio op. cit.

quality seems to take precedence. In fact, now that we have documented the close administrative, bureaucratic, and functional relationships between quantity and quality, we consider emphasis on quality to be proper, legitimate, and desirable. If there is need for an engineering base for a water quality operations plan, the state has already had the benefit of presumably competent advice through contracts negotiated by the Department of Water Resources. Reports submitted by Metcalf & Eddy, an engineering firm in Boston, New York, and Palo Alto, suggest that the state has already accepted and implemented recommendations emanating from contracts culminating in May, 1965¹³ and September, 1966¹⁴. In a 1970 contract, Metcalf & Eddy presented a report¹⁵ incorporating the elements of a water quality operations plan for the State Water Project. Detailed in it was a listing of the water quality goals and constraints under which the Project will be operated and maintained as well as recommendations for a monitoring network. After review of these and many documents issued by and in connection with the management of water resources in California, one cannot but be impressed with the necessity to exercise care not to devote energies to rediscovering America, re-inventing the wheel, or otherwise re-treading old paths. Many of the routines are long established; many of the procedures presented by law and hallowed by custom. Even to attempt to depict them in summary form is to court distortion through oversimplification. Certainly, there appears to be little value in pursuing sophomoric dichotomies and recompiling data already digested.

Far more challenging, now that we have achieved a better grasp of water resource management in the state, is the possibility of moving boldly into the functioning planning system as conceived by the state itself to ascertain where, how, and with what effect remote sensing could be used. Chart 21 provides a graphic portrayal of this process and even cursory review suggests a number of exciting prospects. Some of these are elucidated in finer detail in a valuable document prepared by the State Water Resources Control Board and entitled, "Research Needs for Water Resources Control in California".¹⁶ Useful for our purposes in its entirety,

¹³ Metcalf & Eddy, Engineers, "Program for the Development of an Operations Plan for Water Quality Control for the State Water Project", Palo Alto, California, May, 1965.

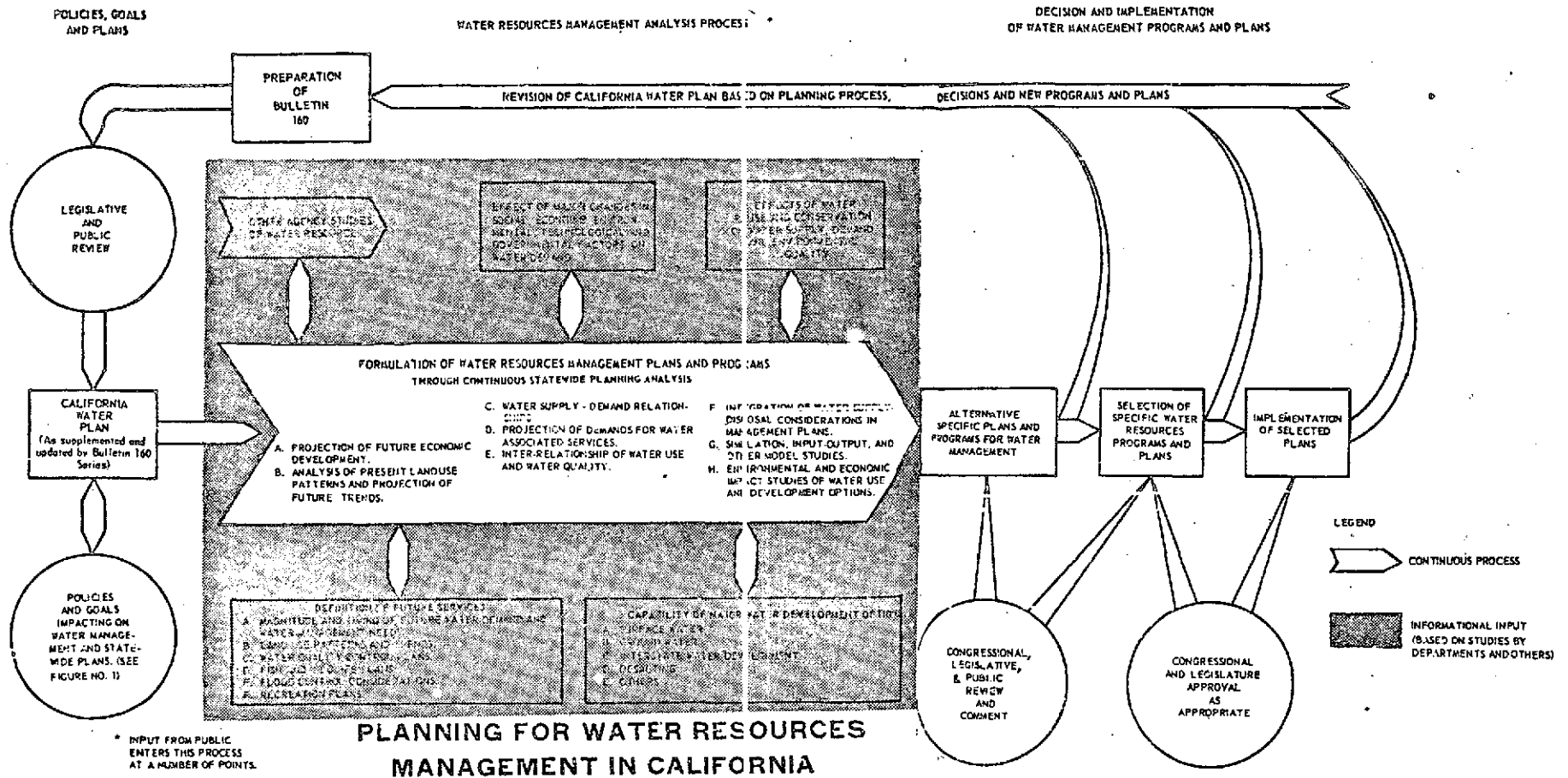
¹⁴ Metcalf & Eddy, Engineers, "Program for the Development of Biological Control Procedures for Water Quality Control for the State Water Project", Palo Alto, California, September, 1966.

¹⁵ Metcalf & Eddy, "A Water Quality Operations Plan for the State Water Project", May, 1970.

¹⁶ Publication No. 48, April, 1973.

CHART 21
 PLANNING FOR WATER RESOURCES
 MANAGEMENT IN CALIFORNIA

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Source: State of California, Department of Water Resources, Water for California The California Water Plan Outlook in 1970, December, 1970, pp. 28-29

expediency requires that we content ourselves with pertinent excerpts. Under the section, "Research and Guidelines"; a set of priorities is enunciated as follows:

a. Priority I

The following research needs are of greatest importance to the Board:

- Design of water quality control data management system;
- Design of basinwide and statewide comprehensive water quality monitoring program for surface and groundwaters;
- Determination of impact on groundwater by wastes particularly from total dissolved solids, toxicants, nitrates and hardness, and development of criteria and means to control those substances;
- Determination of surface water impacts of wastes particularly from toxicants and biostimulants, dissolved, suspended, floatable and settleable solids, pathogenic organisms, and development of criteria and means to measure and control those substances;
- Development of methods and data for immediate implementation in the analysis of water right applications;
- Evaluation of nontoxic disinfection methods and development of design criteria and guidelines for reliable disinfection systems;
- Determination of feasibility of utilization of wastewater solids for recycling on land and effects on groundwater quality and the environment;
- Determination of long-range environmental effects of the use of reclaimed water and treatment requirements and criteria for various uses of reclaimed water;
- Improvement of methodology used by State and Regional Boards, particularly in the water quality-water rights relationship;

- Investigation of methods and techniques to control water pollution or quality degradation from irrigated agriculture;
- Development of standardized methods, techniques and equipment for monitoring waste discharges, surface waters, groundwaters and aquatic biota;
- Study of appropriate California Water Law for effective water quality-quantity control and management.

b. Priority II

- Evaluation and demonstration of methods for improving efficiency and reliability of conventional treatment processes including processing of wastewater solids;
- Development and demonstration of new processes or improved technology to remove dissolved nutrients, dissolved solids, dissolved organics, acute and chronic toxicants and viruses from wastewater;
- Development of hydrologic water quality models;
- Evaluation of institutional structures for effective water quality planning and control;
- Development of methods to predict social and economic impacts of water quality control and water quantity decisions;
- Development of ecological models for defining and predicting primary productivity;
- Assessment of impact of dredging and spoil disposal on water quality and development of criteria for the protection of the aquatic resources.

c. Priority III

- Identification and evaluation of the impact of irrigated agriculture on water quality;
- Identification of stationary sources of accidental spills of hazardous substances and development of guidelines for spill control;
- Development of a program to protect waters of the State from pollution by spills from ruptured pipelines;
- Development of improved techniques for handling animal wastes;

- Evaluation of methods and techniques to protect water quality from solid waste landfills.¹⁷

The California State Water Resources Control Board has, to use the vernacular, "done its homework" with respect to identifying and articulating its research needs. In Publication 48, to which reference has already been made, there is a section spelling out in detail data needs for effective water resources management and water quality control. Mentioned as urgent are new or improved methods of water quality data collection, development of a comprehensive, statewide water quality monitoring system, design of a data management system, and environmental modeling. Each problem area is clearly specified:

a. Design of Statewide Comprehensive Water Quality Monitoring Program

A coordinated program is needed to provide water quality related information to resources planners and decision makers.

The objectives of the proposed monitoring program are to provide essential information to resource managers, establish a water quality and environmental baseline and historical trends, and develop an understanding of the relationship between resource occurrence, use and response to various factors.

System elements needed to meet those objectives and to promote the most effective management decisions include:

- Resource demand determinants - measures of population, economic, sociological and technological conditions that influence water use and quality required in various uses.
- Use and control activities - records of water quantity and quality needs for various beneficial uses and of actions necessary to maintain flow and quality at required levels.
- Hydrologic, physical and chemical conditions - quantity and quality observed at selected points in the aquatic environment at appropriate times.
- Primary biologic effects - biological conditions that are directly affected by any resource use, such as increased growth of algae, presence of coliforms or death of fish due to environmental stress.

¹⁷ California State Water Resources Control Board, "Research Needs for Water Resource Control in California", Publication No. 48, April, 1973, pp. 4, 5, 6.

- Higher biological effects - indirect effects that occur in the food web as a result of primary biologic effects. These may extend beyond the aquatic organisms to wild fowl, agricultural crops and man.

Existing water quality monitoring activities of other state, federal and local agencies need to be evaluated and, if feasible, integrated into the comprehensive monitoring program.

b. Development of Techniques for Water Quality Monitoring

Once criteria have been established for the various beneficial uses of the waters of the State, the next step is the measurement of substances involved in contamination, pollution or degradation of the aquatic resources. To determine the quality of the aquatic environment, areal extent of pollution, and sources of natural and man-caused pollution, monitoring instruments, equipment and special techniques are required. Research is needed to develop and demonstrate these necessary tools and techniques for reliable and efficient data collection. Activities under this research component must be closely coordinated with the development of the proposed statewide, comprehensive water quality monitoring system and should be responsive to the specific needs for development of monitoring techniques required or desirable for this system.

The following priority areas are identified:

- Develop better biological monitoring techniques, including a standardized biological measurement to indicate the acute, chronic, and residual effects of waste disposal on the aquatic environment.
- Demonstrate the utility of various remote sensing techniques for comprehensive water quality monitoring. Much technology from defense and space industries is available. However, its applicability to water resources control has not been demonstrated.
- Evaluate the utility of in-situ monitoring. Determine those parameters, besides the routinely applied ones, that can be monitored reliably under field conditions.
- Develop an effective, statewide laboratory quality control program to augment or replace the existing state laboratory certification program.
- Standardize bioassay techniques and evaluate use of standard reference organisms such as benthic organisms, zooplanktons and algae. Also evaluate use of continuous flow bioassay versus static testing.

- Develop sampling techniques for monitoring groundwater quality at specified depths. Much of the existing groundwater quality data cannot be related to a specific depth or aquifer.

c. Design of a Data Management System

A data management system needs to be designed that will provide the Board and other agencies with the means to store and analyze data on a timely basis to determine changes in water quality and to assess the effectiveness of water quality control programs.

Elements of the proposed system are: (a) waste treatment facilities information file, including information on enforcement actions; (2) statewide water quality information; (3) data acquisition and management for waste discharge regulation; and (4) data management for water resources control plans.

d. Development of Methods of Data Management

A considerable amount of research has been devoted to methods of handling and analyzing data, and much of the Board's effort in data management is devoted toward the application of data handling techniques. However, in the analysis of water quality data there is still a considerable amount of research that is necessary to develop useful techniques.

The statistical methods of analysis of water quality data are not as simple as those that have been applied in the other areas because the water quality problem is multivariate in nature. Applied research is necessary to transfer developments in multivariate statistical analysis to evaluation of water quality data. Particular emphasis is required in the handling of information for regulatory actions. The relative effort in quality control of the data base that is desirable for the various uses of water quality information in the State and Regional Boards' programs will require definition as the Board's data management methods mature. The need for a rapid response to pollution potential and development pressures requires that the long-term solutions used in the past be supplemented by automated simulation and analysis methods that can quickly utilize larger masses of data to predict effects of alternative actions and decisions.

There will be increasing demand for coordination and integration of environmental activities, not only among water-related agencies, but also with land use, solid waste and air resources agencies.

There will also continue to be a significant federal involvement, requiring information exchanges that will persist and grow in their demands on the state agencies. The most effective forms of interaction and coordination will be given early study.

The present methods of water rights administration for appropriation provide a minimum satisfaction of the legal requirements for the program. However, the data management methods must be improved if the Board is to pursue the goal of assuring optimum beneficial use of the waters of the State.

The application of optimization methods and other techniques from operations research to water quality regulatory activities also requires further study. Related to the statistical evaluations of water quality data is the determination of the value of a

particular set of data or a group of sampling stations in terms of their statistical information content and their economic value to the Board's programs. Strategies will be developed out of these programs to guide the improvement of routine monitoring programs.

The extensive use of self-monitoring data provided by waste dischargers leads to the study objective of comparing the value of data from dischargers to that collected directly by the State.

Effort is also to be directed toward development of methods of assembling data on land use, economic development, and waste production for use in effective water quality management planning. The basic data for many of these activities are not maintained by the Board but are maintained by other agencies. A tradeoff exists between the frequency of the Board querying the other agencies for their data and the use of inventory for input and output models to update the existing summaries of information that the Board has received from previous queries.

Some of the items accorded priority status by the SWRCB are consonant with those mentioned by Dr. Peter A. Castruccio in his letter of March 12, 1974 to Professor Robert N. Colwell. Specifically, he alluded to demographic trends as one and agriculture for the other, "since agriculture is the major consumer of California's water, it might be useful to forecast its evolution in terms of demand". It is with these items as our focus that we intend to move ahead in the coming months.

Long-Range Social Considerations

The item of first priority will be land use planning and management, for it has become increasingly evident that plans with respect to water cannot be divorced from the way in which land is used. Indeed, there is strong interaction here, with cause and effect blurred. As noted above, pressure, concentration, dispersion, and movement of population must be taken into account. Patterns of industrialization are factors of importance.

Perhaps the most pressing matter is that of urbanization. As viewed by E. L. Hendricks, Chief Hydrologist, U. S. Department of the Interior, "Urbanization -- the concentration of people in urban areas and the consequent expansion of these areas -- is a characteristic of our time. It has brought with it a host of new or aggravated problems that often make new demands on our national resources and our physical environment. Problems involving water as a vital resource and a powerful environmental agent are among the most critical. These problems include the maintenance of both the quantity and quality of our water supply for consumption, for recreation, and general welfare and the alleviation of hazards caused by floods, drainage, erosion, and sedimentation".¹⁸

Not only does advancing urbanization generate new water problems; agriculture contributes many as well. For example, the state's Blue Ribbon Committee on Agriculture calls for a 25-year master plan to guide farming to an \$18 billion industry by the year 2000, with farm acreage predicted to increase from the present 8 million to 9.7. But how about ample water to irrigate the additional cropland? The lower East Side of the San Joaquin Valley is an area, for example, that already has a groundwater overdraft of 1 1/4 million acre-feet annually. The Bureau of Reclamation's East Side Canal Project might solve this problem, but it would cost over a billion dollars and is seen by experts as not possible of achievement or completion during this century. Moreover, just as the Peripheral Canal has stirred up public opposition in the San Francisco Bay Area, especially from environmentalists, this East Side Canal could create gigantic controversy. Even though a cross-valley canal represents only a partial solution at best, with an estimated half million acre-feet the total amount deliverable (in face of an overdraft of one and one-quarter million), already agricultural development is proceeding on the East Side, with the resultant even greater groundwater overdraft. According to Don Ragee, of The California Farmer, some areas are likely to run out of water, a situation that calls for the wisdom of a Solomon, in that the Department of Water Resources must make judgments and choices. "Do you go rescue these operations? Part of the problem is that it may not be the newer developments that suffer. It may be operations that have been there 25 years or more. How do you share what you haven't got among oldtimers and the new arrivals?"¹⁹

Charts No. 22, 23 and 24 ("Irrigated Land in Farms by County," "Irrigated Acreage Planted and Harvested By Crop," and "Water Used for Irrigation" respectively) suggest the magnitude, growing complexity, and heightened urgency of the interrelated problems of land use and water. Taking the Bay-Delta counties alone over a period of time, as shown on Chart 25 ("Irrigated Land in Farms by Bay-Delta Counties"), one begins to perceive certain patterns that bear closer scrutiny.

¹⁸ Foreward, William J. Schneider, David A. Rickert, and Andrew M. Spieker, "Role of Water in Urban Planning and Management", U. S. Geological Survey Circular 601-H, 1973.

¹⁹ Don Ragee, "State Water Needs Must Be Met", California Farmer, January 5, 1974, pp. 1-2.

Still ahead of us is the task of studying the OBERS Projections, the multi-volumed series of statistics developed under the aegis of the U. S. Water Resources Council. Covering economic activity in the entire country, with divisions as to states, economic areas, water resources regions and subareas, and spanning the years from 1929 to 2020, the information has been prepared by the U. S. Department of Commerce: Social and Economic Statistics Administration, Bureau of Economic Analysis, and Regional Economics Division and the U. S. Department of Agriculture: Economic Research Service and Natural Resources Economics Division. Herein lies an authoritative foundation of facts and figures that will serve as useful background as we move into the next phase of our research, and the one in which ERTS and related remote sensing techniques may enjoy the most cordial welcome and make the most significant contribution -- in providing new dimensions for land use management.

CHART 22

IRRIGATED LAND IN FARMS, BY COUNTY (ACRES)

County	1930	1940	1945	1950	1954	1959	1964	1969
Alameda	8,494	20,403	14,901	24,919	22,599	29,656	24,227	17,788
Alpine	1,925	8,327	6,087	3,541	2,118	3,210	2,692	(NA)
Amador	678	1,403	398	810	1,290	2,196	3,815	5,495
Butte	67,038	79,885	91,186	125,209	161,628	159,476	170,433	177,490
Calaveras	1,996	1,832	1,824	2,623	5,580	5,434	4,393	5,144
Colusa	58,369	82,890	79,794	97,347	138,929	128,340	163,606	171,754
Contra Costa	53,159	32,386	28,277	51,444	50,117	55,717	56,407	38,793
Del Norte	(NA)	(NA)	176	1,906	2,833	3,013	4,494	3,476
El Dorado	10,134	7,535	8,301	7,234	7,008	7,208	5,796	8,539
Fresno	533,992	561,068	628,139	836,335	905,433	980,030	1,060,314	1,045,173
Glenn	60,306	101,557	86,013	102,557	136,511	136,228	151,298	148,295
Humboldt	1,506	2,205	3,615	12,997	18,027	19,269	19,184	19,175
Imperial	432,240	422,834	417,891	451,847	418,682	416,133	429,594	450,216
Inyo	27,488	11,889	16,759	13,361	29,674	29,458	19,552	26,921
Kern	180,106	259,038	307,613	478,571	569,293	596,785	603,659	680,719

CHART 22 (cont'd)
IRRIGATED LAND IN FARMS, BY COUNTY (ACRES)

(CONTINUED)

County	1930	1940	1945	1950	1954	1959	1964	1969
Kings	269,994	315,618	241,206	348,937	416,787	415,622	436,037	351,135
Lake	1,916	3,281	4,148	9,174	12,498	14,854	15,322	19,744
Lassen	39,893	62,243	66,165	48,662	53,018	60,422	61,991	76,132
Los Angeles	205,837	185,380	175,528	183,824	147,288	101,102	78,813	65,078
Madera	140,637	104,522	126,298	187,851	193,804	207,626	212,052	209,974
Marin	86	(NA)	75	510	974	892	688	500
Mariposa	26	(NA)	730	1,453	3,083	4,510	1,305	3,097
Mendocino	3,663	5,904	5,511	9,237	13,246	16,851	14,614	16,069
Merced	318,244	273,886	257,876	348,738	336,542	361,854	377,817	349,955
Modoc	70,025	92,419	86,804	133,869	124,772	118,488	133,759	146,903
Mono	29,542	42,676	8,873	20,495	20,402	15,003	11,386	17,520
Monterey	80,981	105,344	112,322	139,934	148,941	172,598	177,906	174,765
Napa	1,886	2,630	1,900	4,376	8,390	10,141	10,909	8,169
Nevada	6,255	7,557	6,121	7,390	10,530	12,942	7,797	3,613
Orange	112,025	119,274	125,440	125,444	101,140	91,613	54,893	34,076

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CHART 22 (cont'd)
IRRIGATED LAND IN FARMS, BY COUNTY (ACRES)

(CONTINUED)

County	1930	1940	1945	1950	1954	1959	1964	1969
Placer	30,041	30,071	26,132	34,190	43,415	35,360	28,571	23,104
Plumas	16,774	29,481	12,528	24,516	22,001	19,974	31,320	21,362
Riverside	135,617	122,040	126,659	159,364	194,997	215,779	228,673	178,841
Sacramento	98,667	81,655	69,813	132,341	147,150	171,049	169,237	125,514
San Benito	20,237	21,937	22,145	31,962	31,770	42,918	38,820	34,414
San Bernardino	108,482	111,041	88,984	106,970	101,981	97,678	81,173	53,260
San Diego	42,510	51,664	41,733	56,117	62,779	57,706	52,436	56,083
San Francisco	585	294	86	25	(NA)	22	38	(NA)
San Joaquin	281,629	317,790	245,598	388,326	430,565	497,720	496,948	447,544
San Luis Obispo	12,013	13,453	29,789	18,775	26,634	31,856	30,357	41,484
San Mateo	8,362	9,635	6,887	6,057	6,623	6,103	5,517	7,107
Santa Barbara	36,418	42,200	39,719	58,471	68,984	65,039	65,079	62,635
Santa Clara	96,130	95,959	110,600	105,721	114,776	98,830	78,665	63,889
Santa Cruz	5,136	10,868	10,486	18,118	17,982	22,202	23,175	16,007
Shasta	41,173	37,273	37,311	39,992	44,961	46,213	56,797	43,478

CHART 22 (cont'd)
IRRIGATED LAND IN FARMS, BY COUNTY (ACRES)

(CONTINUED)

County	1930	1940	1945	1950	1954	1959	1964	1969
Sierra	9,104	7,307	(NA)	16,682	14,201	11,006	10,741	5,692
Siskiyou	58,655	91,783	101,877	100,525	93,552	107,128	113,788	121,639
Solano	30,370	53,694	32,519	55,150	79,971	109,287	112,355	105,790
Sonoma	2,530	4,267	1,955	9,285	20,231	25,272	27,985	22,397
Stanislaus	241,712	286,151	299,386	317,064	336,755	355,423	349,694	306,866
Sutter	98,771	102,119	124,333	168,868	192,534	203,891	195,572	201,138
Tehama	32,110	34,453	29,850	38,440	50,766	57,717	72,613	72,138
Trinity	5,263	4,753	2,241	3,734	3,664	3,937	2,432	1,052
Tulare	410,683	366,542	374,205	481,503	535,500	558,657	585,361	554,622
Tuolumne	1,596	3,008	2,234	2,041	3,885	2,581	2,272	3,621
Ventura	88,519	86,134	80,584	107,699	112,306	116,786	103,161	91,928
Yolo	84,856	115,301	102,771	139,483	172,218	205,961	252,184	232,169
Yuba	30,248	24,538	22,423	36,310	56,810	52,904	68,981	67,259
Totals	4,746,632	5,069,568	4,952,819	6,438,324	7,048,049	7,395,570	7,598,698	7,240,131

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Source: U.S. Bureau of the Census. Census of agriculture, 1930, 1940, 1945, 1950, 1954, 1959, 1964 and 1969.

CHART 23

IRRIGATED ACREAGE PLANTED AND HARVESTED, BY CROP

(1,000's of acres)

Crop	Irrigated acreage planted				Irrigated acreage harvested				Irrigated acreage harvested as % of total acreage harvested			
	1950	1960	1965	1968	1950	1960	1965	1968	1950	1960	1965	1968
Field crops									%	%	%	%
Sugar beets	218	216	323	264	209	207	310	254	100	100	100	100
Wheat	138	84	92	130	124	76	83	117	19	22	30	31
Rice	245	297	337	445	238	288	327	432	100	100	100	100
Dry beans	248	210	199	207	233	197	187	195	75	89	91	91
Potatoes	129	110	114	98	121	103	107	92	100	100	100	100
Safflower	6	103	176	102	6	97	165	96	60	58	58	58
Alfalfa seed	99	147	116	103	93	138	109	97	81	98	99	99
Cotton	593	965	740	701	581	946	725	687	100	100	100	100
Corn	38	138	152	196	34	124	137	176	81	95	95	95
Oats	24	26	24	22	22	23	22	20	11	15	20	24
Barley	647	881	857	859	582	793	771	773	33	50	55	55
Grain sorghum	73	243	337	384	66	219	303	346	58	94	96	96
Alfalfa hay	1,024	1,179	1,188	1,164	973	1,120	1,129	1,106	92	94	96	96
Other hay	247	379	408	451	222	341	367	406	26	46	54	57
Miscellaneous	164	168	131	138	154	158	123	30	100	100	100	100
Total	3,893	5,146	5,194	5,264	3,658	4,830	4,865	4,927	57	73	77	78
Vegetables	643	767	690	878	604	721	649	825	100	100	100	100
Tree fruits, nuts, grapes	1,238	1,345	1,436	1,518	1,213	1,318	1,407	1,488	79	90	92	92
Irrigated pasture	998	1,203	1,044	1,046	978	1,179	1,023	1,025	100	100	100	100
Double-cropped acreage	-330	-330	-330	-355	-330	-330	-330	-355				
Total	6,442	8,131	8,034	8,351	6,123	7,718	7,614	7,910	66	80	83	84

Source: Dean, G.W., et al. Projections of California agriculture to 1980 and 2020. Berkeley, 1970. (California Agricultural Experiment Station Bulletin 847).

CHART 24

WATER USED FOR IRRIGATION

(million gallons per day)

Year	Acres irrigated (1000's)	Water delivered to farms				Conveyance loss	Consumptive use
		Surface water	Ground water	Other water	Total		
1950	6,438*	11,605	8,927		20,532		
1955	7,048*	10,713	7,856	20	18,589	5,008	
1960	8,000	9,400	8,500	430	18,000	4,500	14,000
1965	8,500	14,000	11,000	400	25,000	5,000	15,000
1970	8,700	17,000	16,000	120	33,000	4,900	20,000

* Acreage figures from U.S. Bureau of the Census. Census of Agriculture, do not include non-agricultural irrigated lands.

Source: U.S. Geological Survey. Estimated use of water in the United States, 1950, 1955, 1960, 1965 and 1970. (Circulars 115, 398, 456, 556 and 676).

IRRIGATED LAND IN FARMS BY BAY-DELTA (ACRES)

County	1930	1940	1945	1950	1954	1959	1964	1969
Alameda	8,494	20,403	14,901	24,919	22,599	29,656	24,227	17,788
Contra Costa	53,159	32,386	28,277	51,444	50,117	55,717	56,407	38,793
Marin	86	(NA)	75	510	974	892	688	500
Napa	1,886	2,630	1,900	4,376	8,390	10,141	10,909	8,169
Sacramento	98,667	81,655	69,813	132,341	147,150	171,049	169,237	125,514
San Francisco	585	294	86	25	(NA)	22	38	(NA)
San Joaquin	281,629	317,790	245,598	388,326	430,565	497,720	496,948	447,544
San Mateo	8,362	9,635	6,887	6,057	6,623	6,103	5,517	7,107
Santa Clara	96,130	95,959	100,600	105,721	114,776	98,830	78,665	63,889
Solano	30,370	53,694	32,519	55,150	79,971	109,287	112,355	105,790
Sonoma	2,530	4,267	1,955	9,285	20,231	25,272	27,985	22,397
Yolo	84,856	115,301	102,771	139,483	172,218	205,961	252,184	232,169

Source: U.S. Bureau of the Census. Census of agriculture, 1930, 1940, 1945, 1950, 1954, 1959, 1964 and 1969.

INVESTIGATION OF ATMOSPHERIC EFFECTS IN IMAGE TRANSFER

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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 polynomials that describe a set of modified scattering functions.

The scattering functions take the form:

$$R^{(j)}(x, m, \theta) = \sum_{k=1}^m L_k^{(j)}(x, m) P_{k-1}(\cos \theta)$$

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 $R^{(j)}(x, m, \theta)$, 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:

$$R^{(j)} = \sum_{k=1}^m \Lambda_k^{(j)}(r_e) P_{k-1}(\cos \theta)$$

where $P_{k-1}(\cos \theta)$ are the Legendre polynomials. The coefficients are integrated over a given range of radii ($r_{min} \rightarrow r_e$) as follows:

$$\Lambda_k^{(j)}(r_e) = \frac{\lambda^2}{\pi B_s(r_e)} \int_{r_{min}}^{r_e} L_k^{(j)}(x, m) n(r) dr$$

where $n(r)$ is a size-distribution function that may be of the form of a discontinuous 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, $M(\mu, \varphi; \mu', \varphi')$, the elements of which Dave (1972) has expressed in a Fourier series. The even functions, $ij = 11, 12, 21, 22, 33, 34, 43, \text{ and } 44$, are given by:

$$M_{ij}[\mu, \mu', (\varphi' - \varphi)] = \sum_{n=1}^{m(\mu, \mu')} M_{ij}^{(n)}(\mu, \mu') \cos(n-1)(\varphi' - \varphi)$$

while the odd functions, $ij = 13, 14, 23, 24, 31, 32, 41, \text{ and } 42$ are given by:

$$M_{ij}[\mu, \mu', (\varphi' - \varphi)] = \sum_{n=1}^{m(\mu, \mu')} M_{ij}^{(n)}(\mu, \mu') \sin(n-1)(\varphi' - \varphi)$$

The elements $M_{ij}[\mu, \mu', (\varphi' - \varphi)]$ 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:

$$F_n^{(j)}(\mu, \mu') = (2 - \delta_{2n}) \sum_{k=n}^K \Lambda_k^{(j)} Y_{k-1}^{n-1}(\mu) Y_{k-1}^{n-1}(\mu')$$

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 $\theta' = 0^\circ(2^\circ)180^\circ$ and $\theta = 0^\circ(2^\circ)90^\circ$, 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 $M_{ij}^{(n)}(\theta', \theta)$ 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:

$$\underline{P}(\tau; \mu, \varphi; \mu', \varphi') = T(\tau) \underline{M}(\mu, \varphi; \mu', \varphi') + [1 - T(\tau)] \underline{R}(\mu, \varphi; \mu', \varphi')$$

where $T(\tau)$ is the turbidity factor

$\underline{M}(\mu, \varphi; \mu', \varphi')$ is the 4x4 normalized matrix for a unit volume of Mie scatterers

$\underline{R}(\mu, \varphi; \mu', \varphi')$ is the Rayleigh scattering matrix

When expanded in series form, the matrices \underline{M} and \underline{R} can be expressed as follows:

$$\underline{M}_{ij}(\mu, \varphi; \mu', \varphi') = \sum_{n=1}^{N(\mu, \mu')} M_{ij}^{(n)}(\mu, \mu') f_{n-1}(\varphi' - \varphi)$$

where $M_{ij}(\mu, \mu')$ and $N(\mu, \mu')$ are given by the third sub-program.

$$\underline{R}_{ij}(\mu, \mu') = \sum_{n=1}^3 R_{ij}^{(n)}(\mu, \mu') f_{n-1}(\varphi' - \varphi)$$

where $R_{ij}^{(n)}(\mu, \mu')$ 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

$$P_{ij}^{(n)}(\tau; \mu, \mu') = T(\tau) M_{ij}^{(n)}(\mu, \mu') + (1 - T(\tau)) R_{ij}^{(n)}(\mu, \mu')$$

The basic transfer equation is

$$\mu \frac{dI(\tau; \mu, \mu')}{d\tau} = \underline{I}(\tau; \mu, \mu) - \omega(\tau) \underline{J}(\tau; \mu, \mu)$$

where $\underline{J}(\tau; \mu, \mu')$ is the source matrix expressed as

$$\begin{aligned} \underline{J}(\tau; \mu, \mu') &= \frac{1}{4} e^{-\tau/\mu_0} \underline{P}(\tau; \mu, \mu'; -\mu_0, \mu_0) \cdot \underline{E} \\ &+ \frac{1}{4\pi} \int_{-1}^1 \int_0^{2\pi} \underline{P}(\tau; \mu, \mu'; \mu', \varphi') \cdot \underline{I}(\tau; \mu', \mu') d\mu' d\varphi' \end{aligned}$$

If we expand the intensity matrix, $I(\tau; \mu, \mu')$, and the source matrix, $\underline{J}(\tau; \mu, \mu')$, we obtain the relations

$$\begin{aligned} I_y(\tau; \mu, \mu') &= \sum_{n=1}^{N(\mu_0)} I_y^{(n)}(\tau; \mu) f_{n-1}(\mu_0 - \mu) \\ J_y(\tau; \mu, \mu') &= \sum_{n=1}^{N(\mu_0)} J_y^{(n)}(\tau; \mu) f_{n-1}(\mu_0 - \mu) \end{aligned}$$

where $y = e, r, u, \text{ or } v$ in the Stoke's notation.

The values given above for $I_y(\tau; \mu, \mu')$ and $J_y(\tau; \mu, \mu')$ are then substituted into the transfer equation resulting in a set of uncoupled integro-differential equations:

$$\begin{aligned} \mu \sum_{n=1}^{N(\mu_0)} \frac{dI_y^{(n)}(\tau; \mu)}{d\tau} f_{n-1}(\mu_0 - \mu) &= \sum_{n=1}^{N(\mu_0)} I_y^{(n)}(\tau; \mu) f_{n-1}(\mu_0 - \mu) \\ &- \omega(\tau) \sum_{n=1}^{N(\mu_0)} J_y^{(n)}(\tau; \mu) f_{n-1}(\mu_0 - \mu) \end{aligned}$$

With the proper boundary conditions, the set of uncoupled equations is solved for $y = e, r, u, \text{ and } v$ 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:

$$\underline{P}(\tau; \mu, \varphi; \mu', \varphi') = T(\tau) \underline{M}(\mu, \varphi; \mu', \varphi') + [1 - T(\tau)] \underline{R}(\mu, \varphi; \mu', \varphi')$$

which can be expanded in closed form giving the following:

$$\underline{P}(\tau; \mu, \varphi; \mu', \varphi') = \sum_{\substack{l, m \\ l', m'}} \underline{P}_{l, m; l', m'} Y_{l, m}(\theta, \varphi) Y_{l', m'}^*(\theta', \varphi')$$

where $Y_{lm}(\theta, \varphi)$ are spherical harmonics.

If we write the intensity and source matrices in the form:

$$\underline{I}(\tau; \mu, \varphi) = \sum_{l, m} \underline{I}_{l, m}(\tau) Y_{l, m}(\theta, \varphi)$$

$$\begin{aligned} \underline{I}(\tau; \mu, \varphi) &= \frac{1}{4} e^{-\tau/\mu_0} \underline{P}(\tau; \mu, \varphi; -\mu_0, \varphi_0) \cdot \underline{F} \\ &+ \frac{1}{4\pi} \int_{-1}^1 \int_0^{2\pi} \underline{P}(\tau; \mu, \varphi; \mu', \varphi') \underline{I}(\tau; \mu', \varphi') d\mu' d\varphi' \end{aligned}$$

and introduce the expanded forms of $\underline{P}(\tau; \mu, \varphi; \mu', \varphi')$ and $\underline{I}(\tau; \mu', \varphi')$ into the equation for the source matrix we obtain:

$$\begin{aligned} \underline{J}(\tau; \mu, \varphi) &= \frac{1}{4} e^{-\tau/\mu_0} \sum_{\substack{l, m, \\ l', m'}} P_{l, m}(\tau) F Y_{l, m}(\theta, \varphi) Y_{l', m'}^*(-\theta_0, \varphi_0) \\ &+ \frac{1}{4} \int_{-1}^1 \int_0^{2\pi} \left[\sum_{\substack{l, m, \\ l', m'}} P_{l, m}(\tau) Y_{l, m}(\theta, \varphi) Y_{l', m'}^*(\theta', \varphi') \right] \\ &\quad \left[\sum_{l'', m''} I_{l'', m''}(\tau) Y_{l'', m''}(\theta', \varphi') \right] d\mu' d\varphi' \end{aligned}$$

Simplifying the expression for $\underline{J}(\tau; \mu, \varphi)$ yields

$$\begin{aligned} \underline{J}(\tau; \mu, \varphi) &= \frac{1}{4} e^{-\tau/\mu_0} \sum_{\substack{l, m, \\ l', m'}} P_{l, m}(\tau) \cdot F Y_{l, m}(\theta, \varphi) Y_{l', m'}^*(-\theta_0, \varphi_0) \\ &+ \frac{1}{4} \sum_{\substack{l, m, \\ l', m', \\ l'', m''}} P_{l, m}(\tau) \cdot I_{l'', m''}(\tau) Y_{l, m}(\theta, \varphi) \\ &\quad \cdot \int_{-1}^1 \int_0^{2\pi} Y_{l', m'}^*(\theta', \varphi') Y_{l'', m''}(\theta', \varphi') d\mu' d\varphi' \end{aligned}$$

But

$$\int_{-1}^1 \int_0^{2\pi} Y_{l', m'}^*(\theta', \varphi') Y_{l'', m''}(\theta', \varphi') d\mu' d\varphi' = \delta_{l', l''} \delta_{m', m''}$$

and therefore

$$\begin{aligned} \underline{J}(\tau; \mu, \varphi) &= \sum_{l, m} \left[\frac{1}{4} e^{-\tau/\mu_0} \sum_{\substack{l', m', \\ l'', m''}} P_{l, m}(\tau) \cdot F Y_{l', m'}^*(-\theta_0, \varphi_0) \right. \\ &\quad \left. + \frac{1}{4} \sum_{\substack{l', m', \\ l'', m''}} P_{l, m}(\tau) \cdot I_{l'', m''}(\tau) \right] Y_{l, m}(\theta, \varphi) \end{aligned}$$

To simplify further we let

$$\begin{aligned} \underline{J}_{l, m}(\tau) &= \frac{1}{4} \sum_{\substack{l', m', \\ l'', m''}} \left[e^{-\tau/\mu_0} P_{l, m}(\tau) \cdot F \cdot Y_{l', m'}^*(-\theta_0, \varphi_0) \right. \\ &\quad \left. + P_{l, m}(\tau) \cdot I_{l'', m''}(\tau) \right] \\ \underline{J}_{l, m}(\tau) &= \frac{1}{4} \sum_{\substack{l', m', \\ l'', m''}} P_{l, m}(\tau) \left[e^{-\tau/\mu_0} Y_{l', m'}^*(-\theta_0, \varphi_0) F + I_{l'', m''}(\tau) \right] \end{aligned}$$

We can therefore write the source matrix in the form:

$$\underline{J}(\tau; \mu, \varphi) = \sum_{l, m} \underline{J}_{l, m}(\tau) Y_{l, m}(\theta, \varphi)$$

The transfer equation is:

$$\mu \frac{dI(\tau; \mu, \varphi)}{d\tau} = I(\tau; \mu, \varphi) - \omega(\tau) \bar{I}(\tau; \mu, \varphi)$$

If we substitute in the appropriate expressions:

$$\sum_{l,m} \frac{dI_{lm}(\tau)}{d\tau} \mu Y_{lm}(\theta, \varphi) = \sum_{l,m} I_{lm}(\tau) Y_{lm}(\theta, \varphi) - \omega(\tau) \sum_{l,m} \bar{I}_{lm}(\tau) Y_{lm}(\theta, \varphi)$$

But

$$\begin{aligned} \mu Y_{lm} &= \frac{1}{\sqrt{2l+1}} \left[\sqrt{\frac{l^2-m^2}{2l-1}} Y_{l-1,m} + \sqrt{\frac{(l+1)^2-m^2}{2l+3}} Y_{l+1,m} \right] \\ &= \alpha_{l,m} Y_{l-1,m} + \beta_{l,m} Y_{l+1,m} \end{aligned}$$

Substituting this equation into the lefthand term of the equation of transfer we get

$$\begin{aligned} \sum_{l,m} \frac{dI_{lm}(\tau)}{d\tau} \left[\alpha_{l,m} Y_{l-1,m} + \beta_{l,m} Y_{l+1,m} \right] &= \\ \sum_{l,m} \frac{d}{d\tau} \left[I_{l+1,m}(\tau) \alpha_{l+1,m} + I_{l-1,m}(\tau) \beta_{l-1,m} \right] \cdot Y_{lm}(\theta, \varphi) & \end{aligned}$$

Then the equation of transfer takes the final form:

$$\begin{aligned} \frac{d}{d\tau} \left[I_{l+1,m}(\tau) \alpha_{l+1,m} + I_{l-1,m}(\tau) \beta_{l-1,m} \right] &= \\ I_{lm}(\tau) - \omega(\tau) \bar{I}_{lm}(\tau) & \end{aligned}$$

where

$$J_{\ell m}(\tau) = \frac{1}{4} \sum_{\ell' m'} P_{\ell m, \ell' m'}(\tau) \left[e^{-\tau/\mu_0} Y_{\ell' m'}(-\theta_0, \varphi_0) \underline{F} + \underline{I}_{\ell' m'}(\tau) \right]$$

$$\underline{F} = \begin{bmatrix} 1/2 \\ 1/2 \\ 0 \\ 0 \end{bmatrix}$$

$$P_{\ell m, \ell' m'}(\tau) = T(\tau) M_{\ell m, \ell' m'} + [1 - T(\tau)] R_{\ell m, \ell' m'}$$

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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 tradewind 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

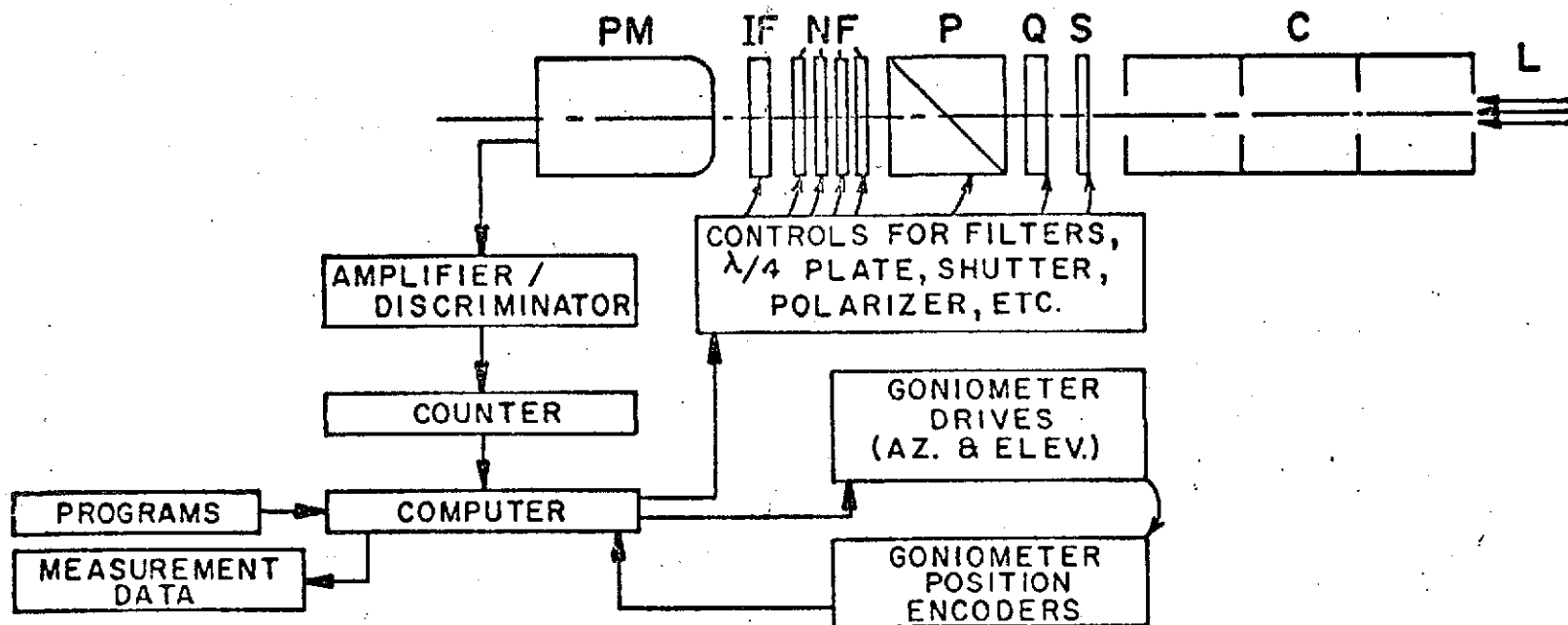
The instrument used for the polarization measurements is the computer-controlled polarizing radiometer which was developed during the previous periods of this project. It has been briefly described in previous reports, and in somewhat more detail by Coulson and Walraven (1972) and Coulson et al (1974). 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.



L : INCIDENT LIGHT

P : ROTATING POLARIZER

C : COLLIMATOR TUBE

NF : NEUTRAL FILTERS

S : OPAQUE SHUTTER

IF : INTERFERENCE FILTER

Q : QUATER-WAVE PLATE

PM : PHOTOMULTIPIER

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

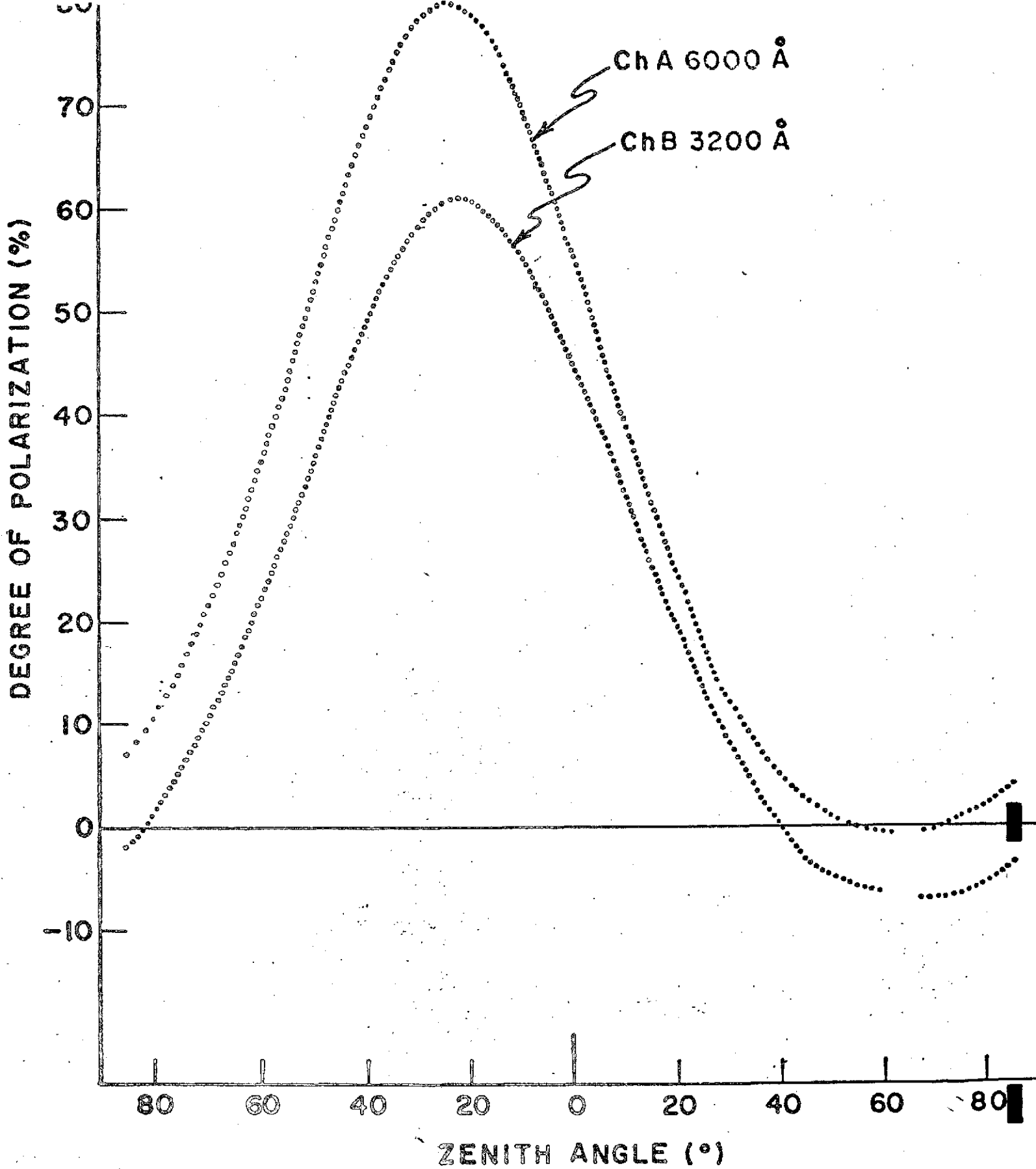


Fig. 2 Typical data on the degree of linear polarization of skylight, as measured by the photon-counting polarizing radiometer. The two channels of the instrument are operated simultaneously for measuring the intensity, degree of polarization, and angle of the incoming radiation. The curves shown are for wavelengths of 0.32 and 0.60 μ m, 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 $\lambda = 0.60\mu\text{m}$.

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_0 of the sun, as expected from theory (Coulson, 1952). However, P_{max} for a Rayleigh atmosphere reaches a slight minimum at about $0_0 = 50^\circ$ to 60° , and no such minimum is seen here at $\lambda = 0.32\mu\text{m}$. There is a tendency for it at $\lambda = 0.60\mu\text{m}$, 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 $\lambda = 0.60\mu\text{m}$ is only 70% or less in Fig. 3, whereas it is 80% in Fig. 2. Similarly, P_{max} at $\lambda = 0.32\mu\text{m}$ is lower in Fig. 3 than in Fig. 2, although by a smaller absolute amount than for $\lambda = 0.60\mu\text{m}$. A similar difference in atmospheric conditions can be deduced from the disappearance of the neutral points at $\lambda = 0.60\mu\text{m}$ 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 $0.90\mu\text{m}$) 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 $\lambda = 0.90\mu\text{m}$ 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 $0.90\mu\text{m}$ than at $0.50\mu\text{m}$. 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

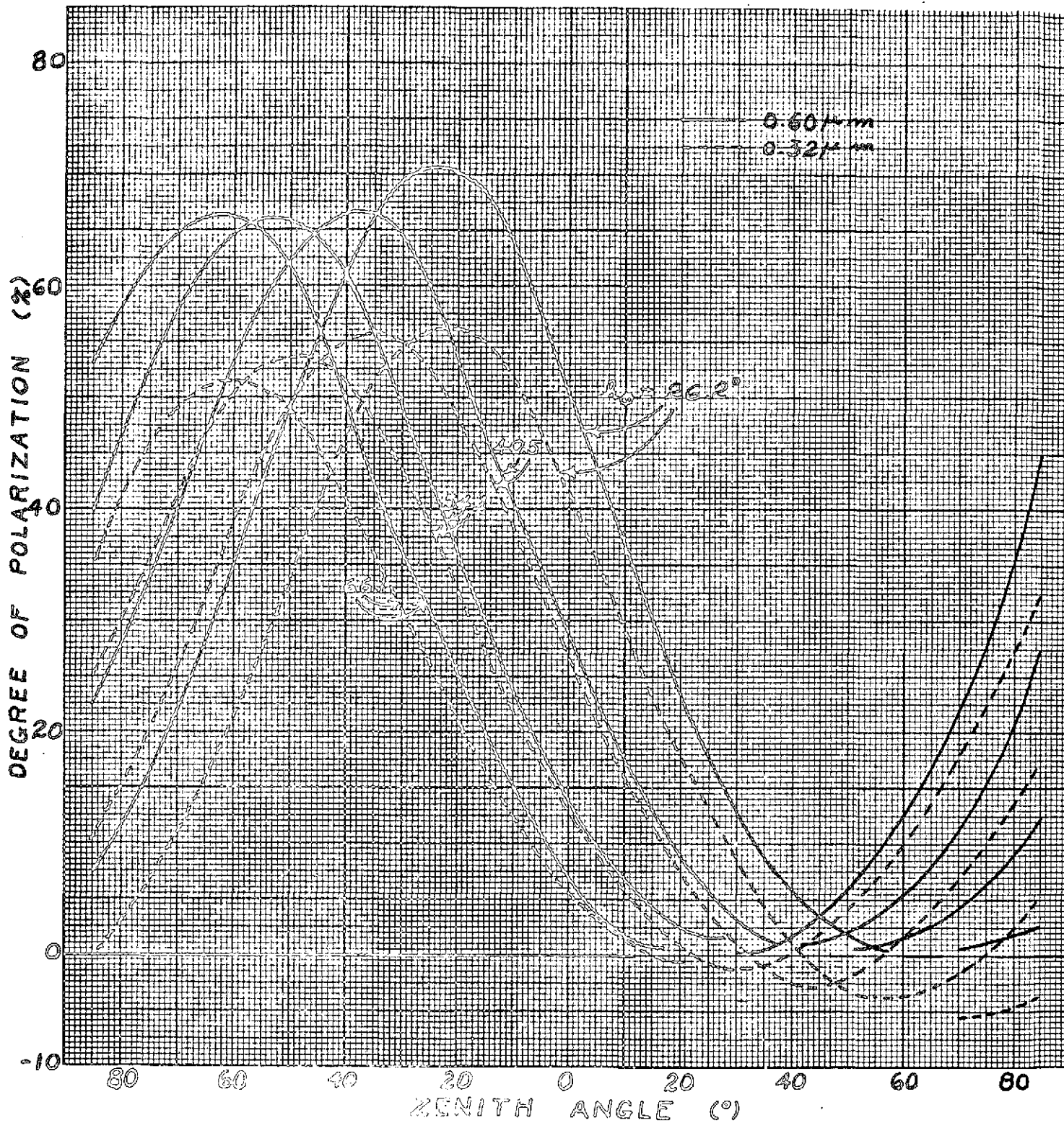


Fig. 3 Degree of polarization as a function of zenith angle in the principal plane as observed on Mauna Loa on March 25, 1973, during four different scans of the sky. The two sets of curves were obtained simultaneously with the two channels of the polarizing radiometer. The sun elevation for the mid-point of each scan is indicated.

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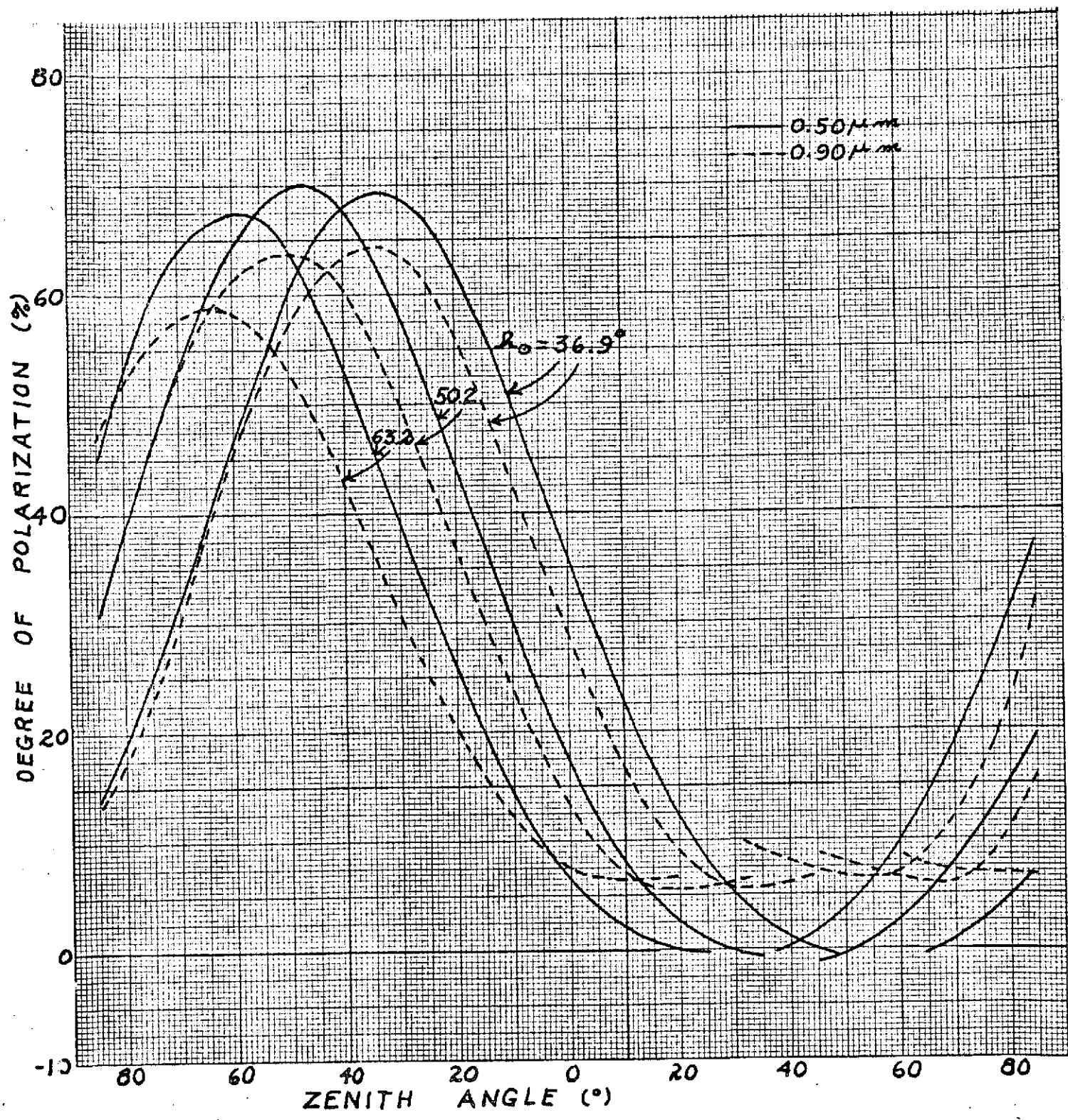


Fig. 4 Degree of polarization as a function of zenith angle in the principal plane as observed on Mauna Loa on March 25, 1973, during three different scans of the sky.

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 0.60 μm ; 0.365 and 0.70 μm ; 0.40 and 0.80 μm ; and 0.50 and 9.90 μm . 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 0.60 μm 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 $\lambda = 0.60\mu\text{m}$, 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.

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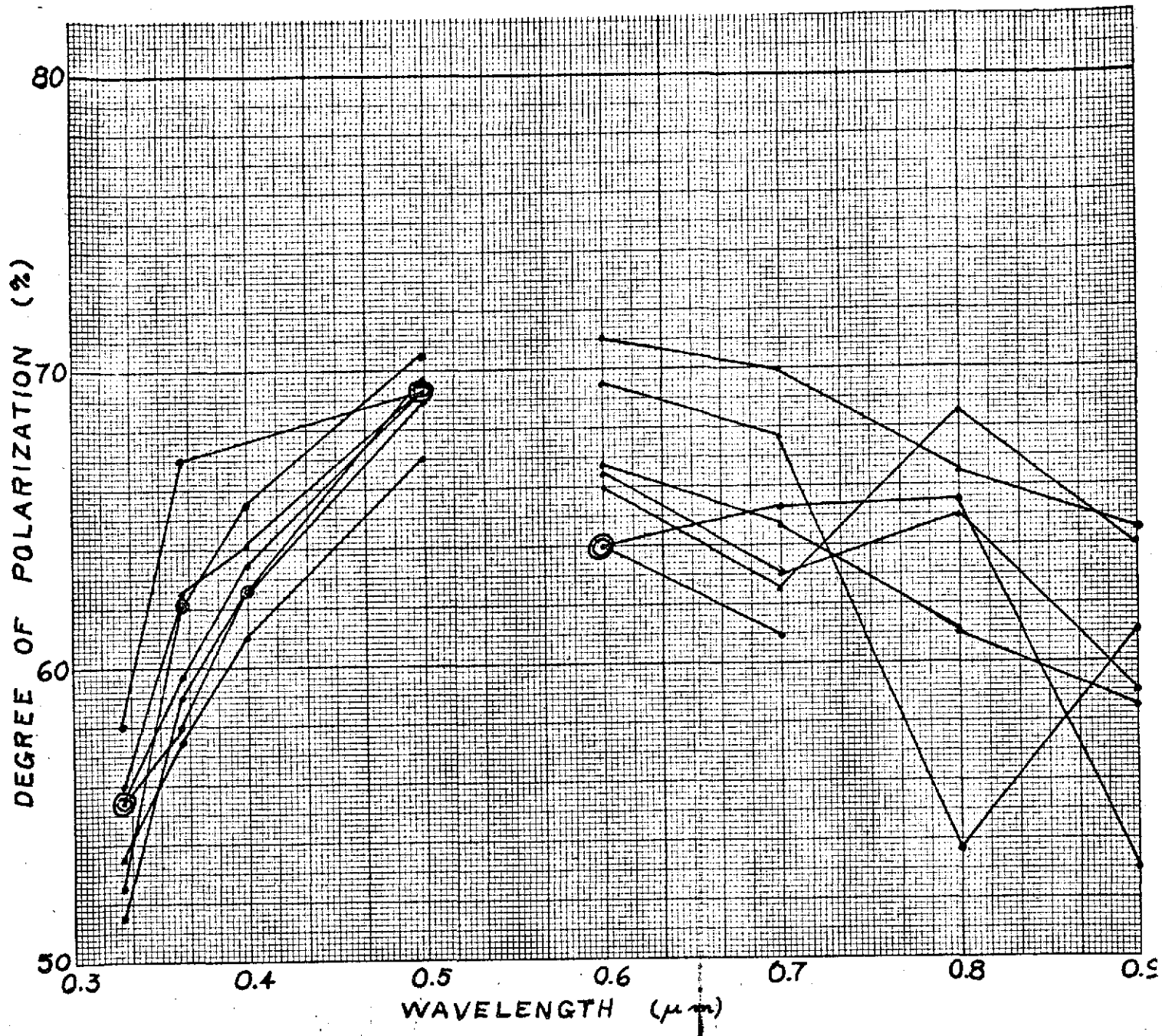


Fig. 5 Magnitude of the polarization maximum as a function of wavelength for approximately 25 scans of the sky on Mauna Loa on March 25, 1973.

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

$$P(\theta) = A + A_2 \left[\frac{\sin^2 \theta}{(1 + \cos^2 \theta)} \right] + A_3 \sin 2\theta + A_4 \sin 4\theta$$

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 $\lambda = 0.60\mu\text{m}$ in Fig. 6 and for $\lambda = 0.32\mu\text{m}$ 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.

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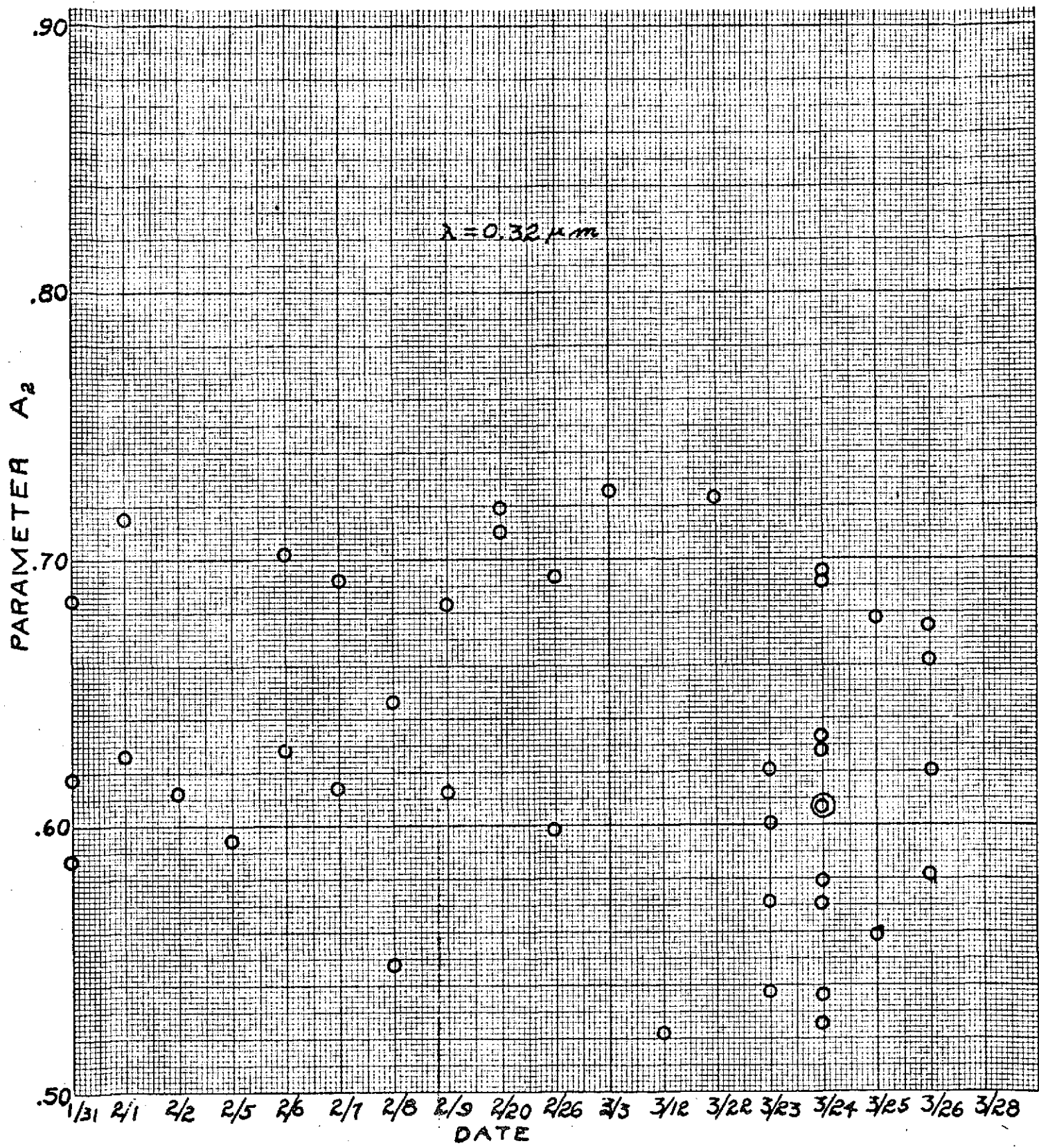


Fig. 6 Magnitude of the coefficient A_2 on different days as observed at $\lambda = 0.32 \mu m$ on Mauna Loa during the period January-March, 1973.

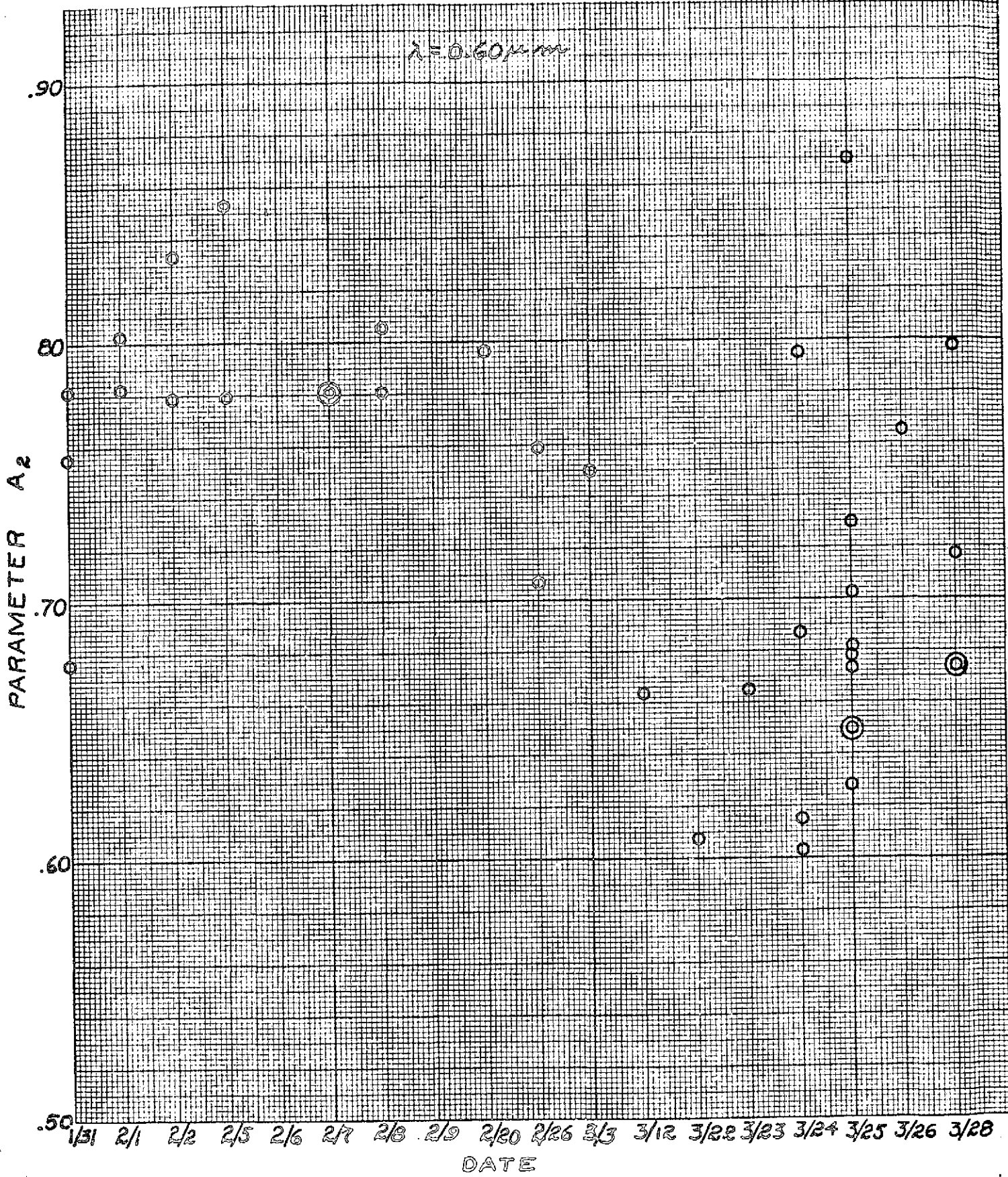


Fig. 7 Magnitude of the coefficient A_2 on different days as observed at $\lambda = 0.60 \mu m$ on Mauna Loa during the period January-March, 1973.

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 polarization 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 polarization component introduced by scattering in the earth's atmosphere were frequently 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 observations 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 present series of polarization measurements was initiated. In fact, the observations 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 properties 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 $\lambda = 0.60\mu\text{m}$ taken during the forenoon of July 25, 1973. The sun elevation varied between -3.6° and 69.4° during the period of the measurements. ^(Figure 8) 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

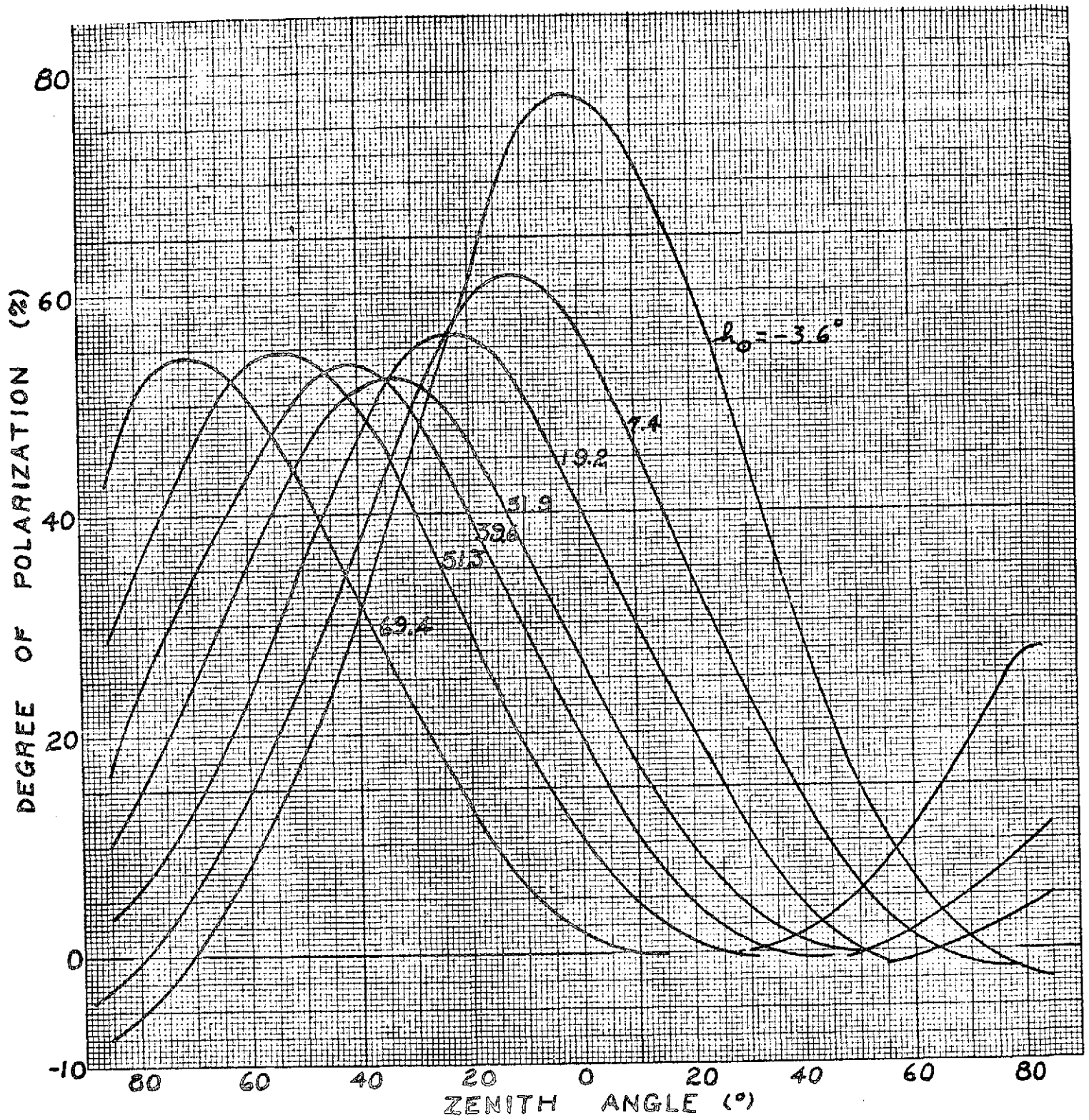


Fig. 8 Degree of polarization as a function of zenith angle in the principal plane as observed at Davis, California, on July 25, 1973, during seven different scans of the sky.

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 polarization for each point in the 64x64 array are calculated and sent to an external 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

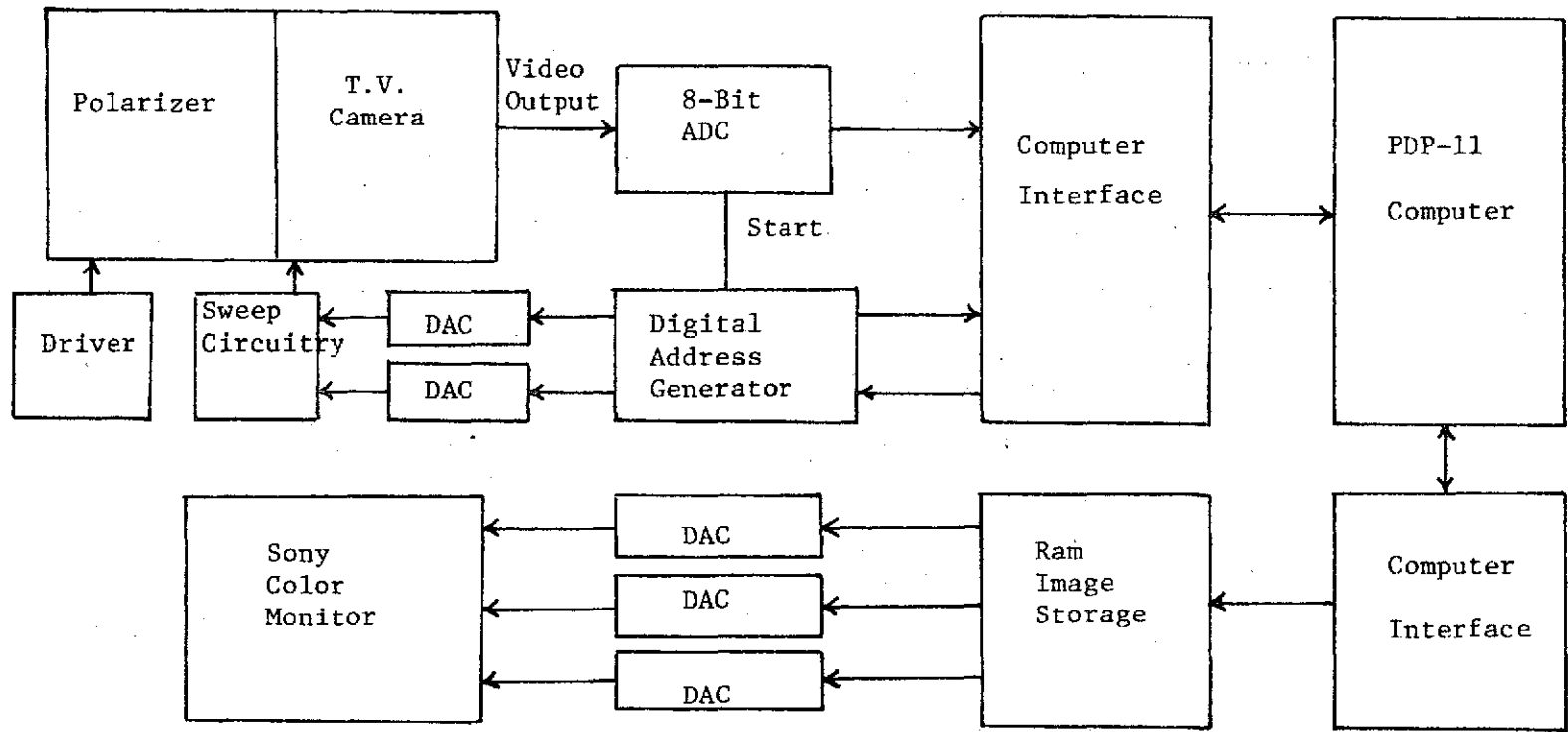


Figure 9. Schematic Diagram of Video Polarizer

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 re-oriented, 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.	<u>2115</u>
		Total salaries	\$13528
		<u>Employee benefits (13% of salaries)</u>	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		<u>300</u>
	Total E&F	\$3100
<u>Supplies and Expense</u>		
Repair of magnetic tape drive		\$1000
Computer time (3 hrs. @ \$500)		1500
Electronic components		<u>250</u>
	Total S&E	\$2750
<u>Travel</u> (domestic)		500
<u>University overhead</u>		
(34.2% of modified direct costs)		<u>\$6340</u>
	Total budget	\$27977

N74-28859

POWER LAW TIME DEPENDENCE OF RIVER FLOOD DECAY
AND ITS RELATIONSHIP TO LONG TERM DISCHARGE FREQUENCY DISTRIBUTION

By

G. Schubert and R. E. Lingenfelter
Department of Planetary and Space Sciences, Los Angeles Campus

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 discharge 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 oversimplification 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 relationship between the total meander pattern and the complete record of the discharge. Hopefully this more general correlation will be sufficiently reliable to quantitatively 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 $\pm 5\%$ 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 $\frac{1}{T} \frac{\Delta t}{\Delta Q}$ where Δt is the portion of time the

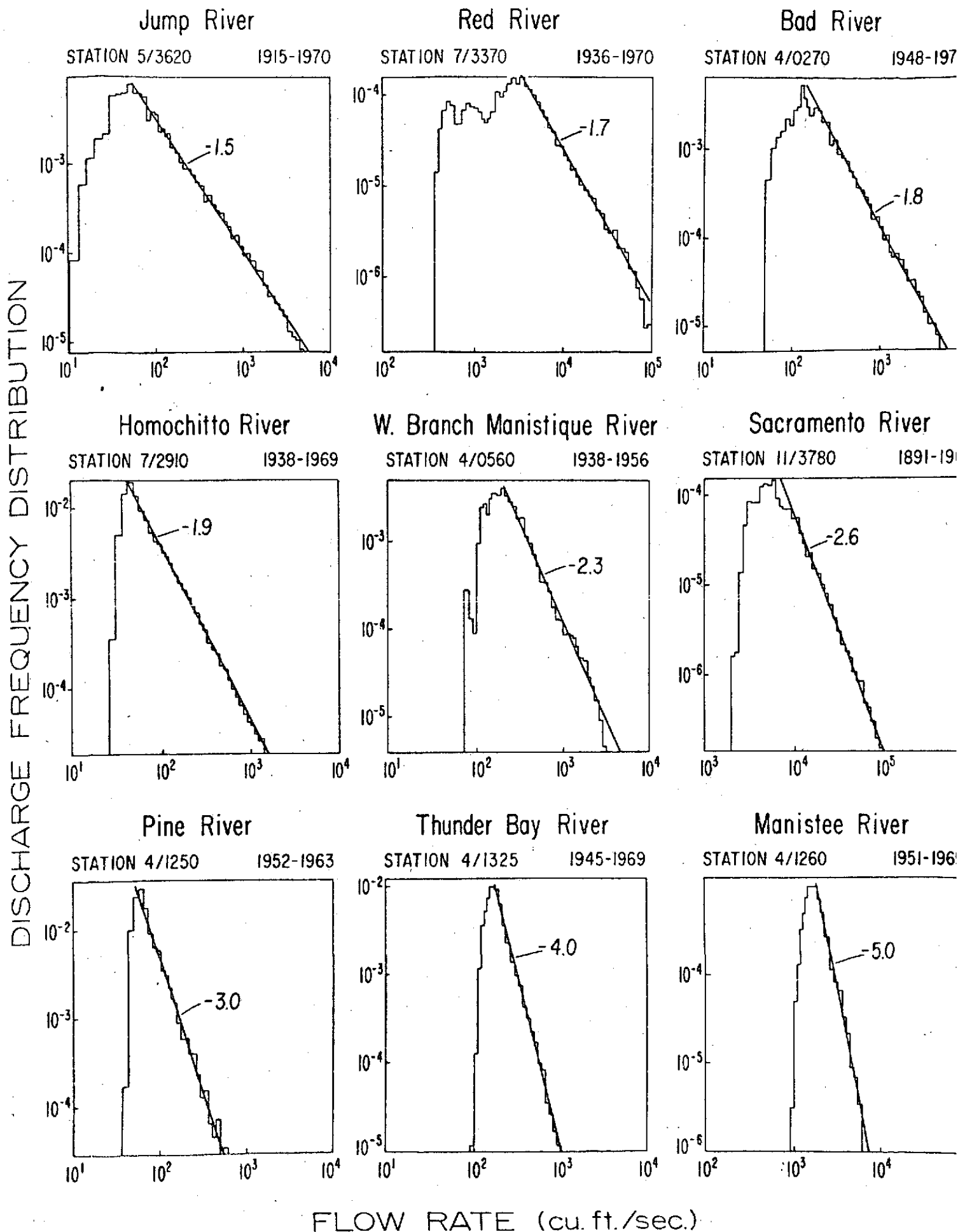


Figure 1. Relationship between flow rate and discharge frequency distributions for nine rivers 5-156

discharge lies within ΔQ at Q . If s is the slope of the log-log frequency distribution, then

$$\frac{dt}{dQ} \propto Q^s \quad (1)$$

Integrating (1) we find

$$Q \propto t^{\frac{1}{s+1}} \quad (2)$$

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

$$t_0 = \left\{ t_2 \left(\frac{Q_1}{Q_2} \right)^{s+1} - t_1 \right\} / \left\{ \left(\frac{Q_1}{Q_2} \right)^{s+1} - 1 \right\} \quad (3)$$

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 frequency distribution represents the recession portion of the flood hydrograph, 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 following 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 discharge. 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

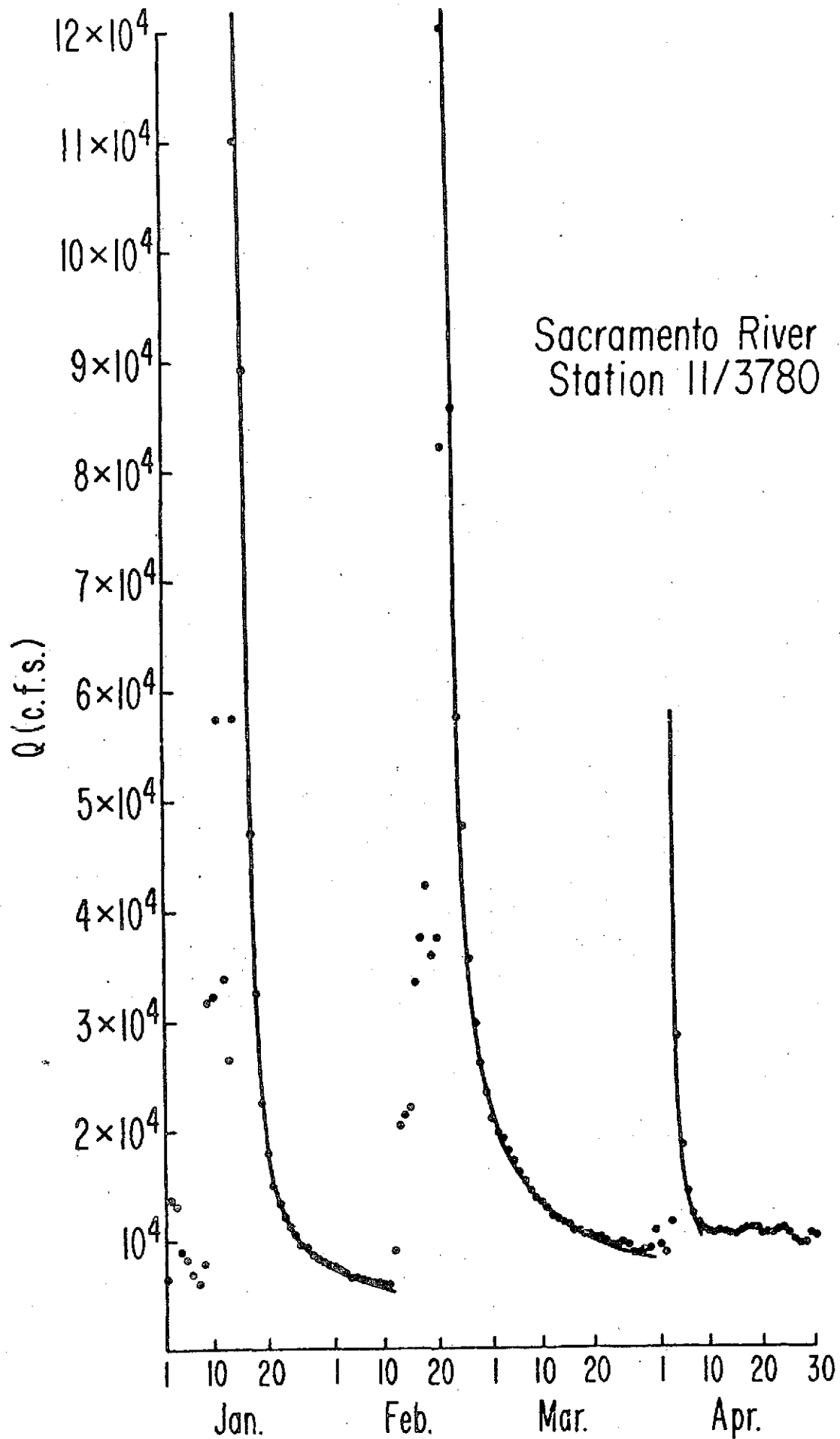


Figure 2. Hydrograph showing degree of agreement between predicted powerlaw flood decays and actual measured flood recession on the Sacramento River 5-158

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

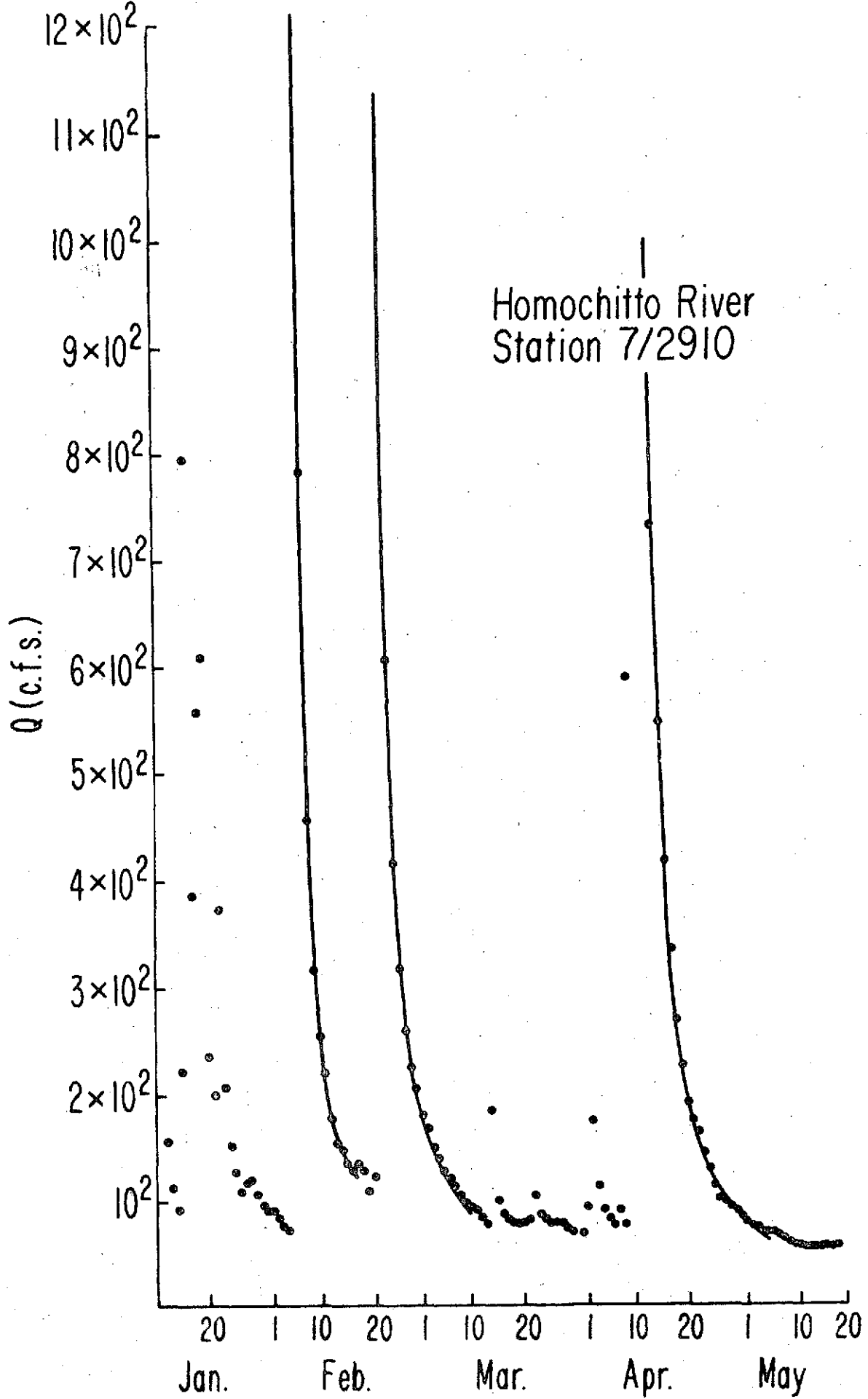


Figure 3. Hydrograph showing degree of agreement between predicted powerlaw flood decays and measured flood recessions on the Homochitto River

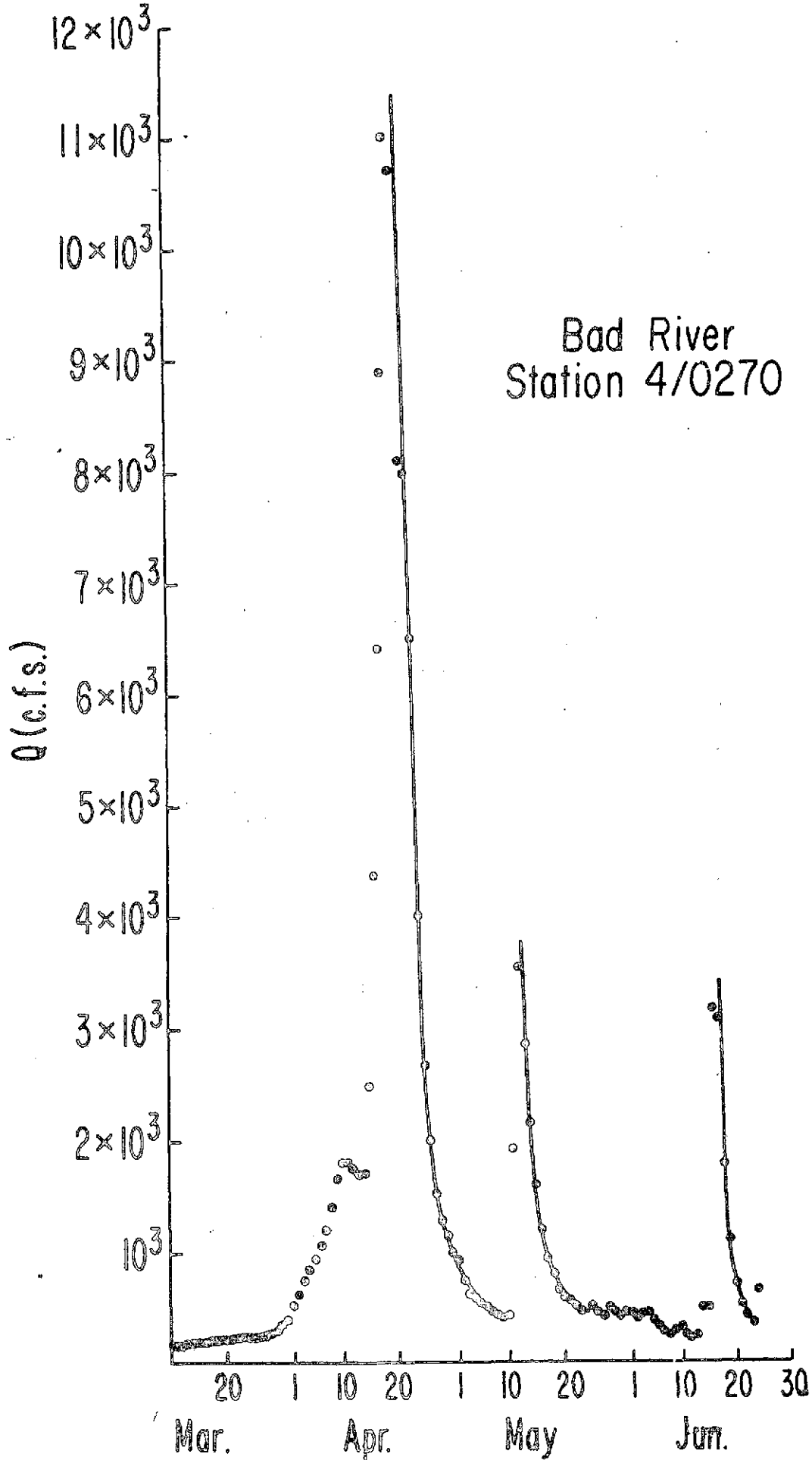


Figure 4. Hydrograph showing degree of agreement between predicted power law flood decays and measured flood recessions on the Bad River. 5-161

TABLE 1. POWER LAW FITS TO RIVER FLOOD DECAYS

RIVER	INCLUSIVE DATES OF FLOOD DECAYS	RMS ERROR OF FIT	MEAN RM 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%
5-162 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%

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	5.9%, 7.2%, 4.2%	5.1%
	2/7-2/14/55, 3/28-4/5/42, 2/27-3/9/53	5/6%, 3.3%, 1.8%	
	2/23-3/9/55, 4/18-4/27/57, 4/10-4/20/51	5.5%, 6.7%, 3.8%	
	4/24-5/4/51	7.4%	
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	4.7%, 9.9%, 6.7%	5.4%
	7/6-7/15/53, 6/4-6/13/51, 7/6-7/15/51	4.4%, 5.7%, 6.7%	
	5/11-5/23/50, 5/14-5/23/52, 4/23-5/5/52	3.2%, 4.0%, 4.3%	
	5/7-5/18/49	4.2%	
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	5.7%, 8.0%, 8.9%	7.1%
	3/1-3/9/39, 2/7-2/15/41, 10/3-10/10/36	7.7%, 8.9%, 8.1%	
	4/4-4/14/45, 2/26-3/8/38, 4/28-5/8/52	3.4%, 7.2%, 4.8%	
	11/7-11/17/41	8.2%	
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	10.5%, 5.4%, 7.9%	7.3%
	6/11-6/21/40, 11/6-11/17/34, 11/24-12/15/34	5.8%, 3.3%, 10.5%	
	4/25-5/10/20, 11/13-11/24/19, 12/24-1/11/19	8.6%, 4.8%, 8.1%	
	11/18-11/27/26	8.3%	

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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CHAPTER 6

SUMMARY

R. N. Colwell

I. SOME BASIC CONSIDERATIONS

As requested by NASA there has been a dramatic reorientation of our study during the present funding period. If, as one reads the following 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 the nature of this new orientation. He also will better appreciate 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 rather extensive summary is given of work done and conclusions arrived at by our multi-campus group during the period covered by this report. The extensiveness of the summary is considered appropriate here because of the very substantial reorientation of our study, at NASA's request, during the present reporting period. Even so, a fuller treatment of any given aspect that is described in this summary will be found in the pertinent preceding chapter.

II. 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 to 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. By 1968 the California Water Project annual delivery capability of 4.23 million acre-feet of water had been fully contracted for.

5. 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.

6. 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.

7. 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.

8. 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.

9. 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.

10. 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.

11. 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.

12. 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 hydroelectric 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. 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 (a) the maximum strength which that storm might achieve, and (b) 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 meteorological 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 predictions, 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 estimations. Dynamic estimations are 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 predictions) 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 relationships relating watershed input directly to output. Since these relationships are determined by statistical line fitting techniques, a given amount of uncertainty 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 hydrologic model are effective basin (watershed) precipitation, basin evapotranspiration, and basin characteristics affecting streamflow.

10. Streamflow predictions based on the RFC model are the result of processing effective precipitation data through an algorithm describing water movement in the soil mantle. This algorithm permits runoff estimates to be made in terms of five basic components: (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 bed-rock 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 photographic appearance and its melt rate is "albedo", i.e. the reflectivity 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" of the type 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 relationships 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 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. 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 the primary 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 during storms and also in determining 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.

18. The foregoing considerations have led to our conduct of remote sensing research along the lines indicated in "D" below.

D. Work done in relation to the Remote Sensing of Water Supply during the period covered by this report includes the following:

1. Snow Survey Study

A snow survey study was carried out in the following three steps:

(a) 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;

(b) 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 categories within which the snow occurs and which greatly influence the appearance of snow as well as its accumulation and depletion characteristics.

(c) 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.

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.

In this study it was found that the presence or absence of snow was: (a) easily detectable in meadows and bare areas, (b) sometimes, but not always, detectable in sparse coniferous forest, and (c) nearly impossible to detect in dense coniferous forest.

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.

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.

Photo interpretation of vegetation/terrain conditions in the entire Feather River watershed was done on ERTS-1 color composites (bands 4-5-7) utilizing three dates of imagery. The dates were July 26, 1972, August 13, 1972 and October 24, 1972.

From the results thus obtained, a regional vegetation/terrain map was produced by projecting and enlarging the ERTS-1 color composite transparencies to a scale of 1:250,000.

An evaluation of the level of accuracy associated with the generalized ERTS-1 map was done by comparing that map with a map made from high flight photography. The average percent correct, assuming the high flight map to be "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

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.

A point-by-point evaluation was made of the detailed ERTS-1 map by comparing it with the high flight map.

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

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 gave 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

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.

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.

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.

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.

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.

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 for this large area at the beginning of the study. Assuming that this study is successful we plan to prepare a set of detailed instructions which might be followed by remote sensing specialists in making similar timber inventories in other parts of the world with the aid of ERTS-type imagery.

6. Work Done Relative to the Handling and Processing of Remote Sensing Data

The progress which we have made in this general area during the present reporting period can be divided into the following broad categories:

- (a) minor hardware modifications and improvements in the digital image processing facility which is central to our work;
- (b) development of a systematic image enhancement procedure applicable to a variety of problems as well as to remote sensing;
- (c) preliminary work on the combining of multispectral data for the study of Earth Resources;
- (d) 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
- (e) articulation and investigation of some of the basic issues which underlie the interactive processing of remote sensing data by digital computers.

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 multispectral data:

- (a) improvement in the quality of the data through the reduction of noise.
- (b) efficient representation of the data either for transmission (encoding) or for further processing.
- (c) presentation of the information provided by sensors in a more interpretable form.

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(d) significant increase in the speed of processing for enhancement or classification.

We have conducted and are continuing to conduct work on the following application areas for the improved ERTS-type data:

(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 Remote 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.

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:

(a) geometric correction.

(b) radiometric correction.

(c) preprocessing and interactive processing of remote sensing data to increase efficiency and interpretability.

(d) subpixel processing.

(e) incorporating all available data, including ground truth in the form of radiometric values, atmospheric modeling, sun angle correction, and sensor characteristics, into a unified analysis of the radiometric value recorded by a satellite.

E. Work done in relation to socio-economic and political considerations:

1. During the present reporting period, research by this project's Social Sciences Group has been conducted 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 of 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 increasing 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 and in nearby arid lands 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 users of water are growing steadily, and not only do they pay two to three times as much for water, but they also are gaining political representation at local, state and national levels 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 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, 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 many of these benefits fall into such categories as "nonmarketable, 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 achieve 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 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. For this reason any benefit analysts should attempt to cope with the fact that recreational developments which constitute a benefit for one group may axiomatically constitute a "disbenefit" for another group.

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 of controversy in the supply aspects of the California Water Plan.

15. The primary objectives 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 construction should be further considered until the many scientific investigations and studies of its impact upon the Bay-Delta System are first completed and thoroughly evaluated.

17. While it is generally agreed that the present beneficial uses of 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 responsibility 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 water supply, not only in California but in other parts of the globe as well.

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

Our work to date clearly shows that information on land use and vegetation types is essential as input for a water demand model.

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

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:

(a) 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.

(b) The making of an 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.

Special emphasis was given to determining the total acreage of agricultural cropland in this area, where water for irrigation is of utmost importance.

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, 1972 ERTS 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, 1973 ERTS imagery.

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.

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.

B. The Study of Perched Water and Soil Salinity-Soil Moisture Problems

The importation of water to sustain and expand croplands in Kern County has brought about new problems associated with water drainage.

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.

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 salinity.

GRSU found that:

(a) 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;

(b) 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;

(c) 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.

(d) ERTS-1 imagery is very useful because repetitive coverage is required for accurately assigning drainage characteristics to different areas.

c. Work Performed by the Geography Department,
Riverside Campus.

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 4 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.

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.

Fortunately, a truly controlled environment in terms of total water importation does exist within southern California, viz. the Imperial Valley.

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 appearance of vegetative growth.

A second obvious surrogate of the condition of the fields was the white barren look of dry fallow ground on this ERTS composite image.

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.

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.

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.

IV. 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, 3 and 4 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 as indicated by the diagram which comprises Figure 1-2.