(NASA-CR-142228) AN INTEGRATED STUDY OF EARTH RESOURCES IN THE STATE OF CALIFORNIA USING REMOTE SENSING TECHNIQUES Semiannual Progress Report, 1 May - 31 Dec. 1974 (California Univ.) 530 p HC $12.50 CSCL 08F G3/43 N75-18693 Unclas 13183

SPACE SCIENCES LABORATORY

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

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

Semi-Annual Progress Report
31 December 1974
Space Sciences Laboratory Series 16, Issue 2

UNIVERSITY OF CALIFORNIA, BERKELEY

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

Principal Investigator:

Robert N. Colwell

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CHAPTER 1

INTRODUCTION

Principal Investigator: Robert N. Colwell

Chapter 1

INTRODUCTION

Robert N. Colwell

During the period covered by this progress report research efforts under our integrated multi-campus study have continued to be concentrated along the lines set forth, at NASA's request, in our statement of 30 September, 1973. Consequently, the major part of our work during this reporting period has dealt with California's water resources. The block diagram of Figure 1-1 and the milestones of Figure 1-2 provide a good overview of both the concept embodied in this study and the activities being engaged in by the various participants. As indicated by both of those figures, our integrated study of California's water resources continues to concern itself primarily with the usefulness of remote sensing in relation to two categories of problems: (1) those pertaining to water supply (dealt with primarily by personnel of the Davis and Berkeley campuses as reported upon in Chapters 2a and 2b, respectively,); and (2) those pertaining to water demand (dealt with primarily by personnel of the Santa Barbara and Riverside campuses as reported upon in Chapters 3 and 4, respectively).

Opportunities which we are exploiting to the fullest in our attempt to achieve true integration of this multicampus project stem from the following fact that repeatedly manifests itself: many of the techniques and methodologies developed by those of our group who are concerned with water supply problems can, with only slight modification, be used by those of us who are concerned with water demand problems, and vice versa. Thus, for example, much of the information contained in chapters 5 and 6 relative to cost-effectiveness methodologies and the techniques for making truly meaningful cost-benefit analyses deal primarily with problems pertaining to water supply. As indicated in those chapters, however, little modification would be needed to apply these same methodologies and techniques to problems of water demand. Similarly, the work being reported upon in Special Study No. 1 of Chapter 9 (viz. the work of Coulson and Walraven of the Davis Campus on atmospheric effects in image transfer) is of very great potential significance in relation to image analysis problems generally, whether they deal with water supply, water demand, or virtually any other kind of problem confronting those who wish to use remote sensing to maximum advantage in relation to the management of earth resources.

With further reference to Chapter 9, two other special reports (numbered 2 and 3) are included. These summarize certain findings under this integrated project that the author considered would be relevant to deliberations being held by the U.S. Senate and House committees,

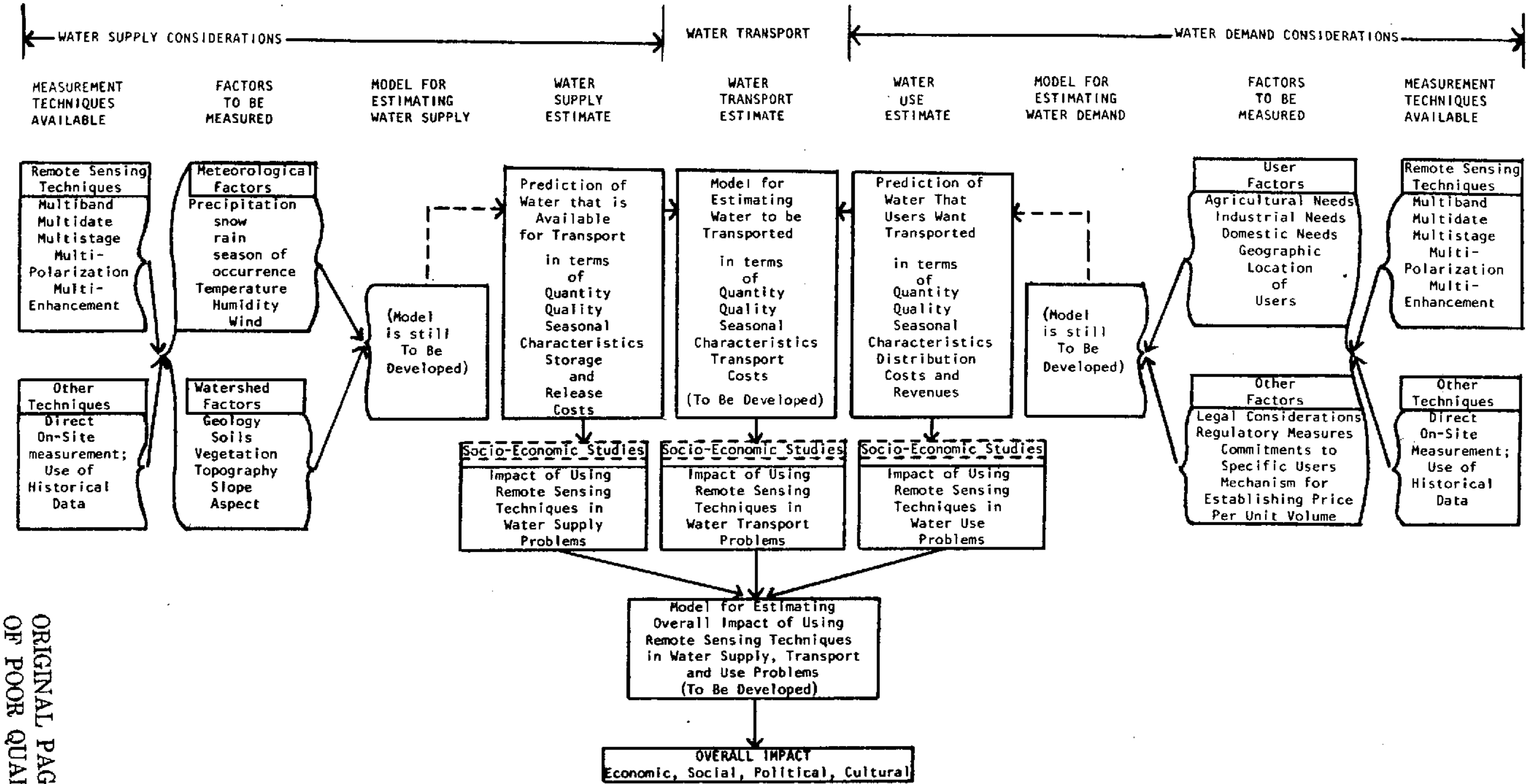

FIGURE 1.1 Block diagram indicating the factors which relate to water supply, water transport, water use and water impact. For a discussion of the proposed remote sensing studies in relation to this diagram, see text.

Work Subtask	Investigators		Period of Performance: Current Funding Year M J J A S O N D J F M A	Period of Performance: Next Funding Year M J J A S O N D J F M A
1. Continue Water Supply Model Definition and Performance Documentation	Algazi-Burgy	(1)		
	RSRP	(2)		
2. Sensitivity Analysis for Critical Parameters in Water Supply Models	RSRP	(1)		
	Algazi-Burgy	(2)		
3. Develop and Test Remote Sensing Techniques for water supply	RSRP	(1)		
	Algazi	(2)		
4. Determine Costs of Information-Gathering Using Conventional and Remote Sensing-Aided Methods	RSRP	(1)		
	Hoos-Churchman	(2)		
	Algazi-Burgy	(2)		
5. Compare Remote Sensing Techniques for water supply with Conventional Ones. Draw Conclusions Regarding Cost-Effectiveness	Hoos-Churchman	(1)		
	RSRP	(2)		
6. Analyze Cost-Benefit Impact on Society Resulting from Changes in Water Supply Information Due to Application of Remote Sensing Techniques	Hoos-Churchman	(1)		
	RSRP	(2)		
7. Determine critical parameters in water demand models	Estes	(1)		
	Bowden	(2)		
	Algazi-Burgy	(2)		
8. Analyze economic impact resulting from changes in water demand information	Bowden	(1)		
	Estes	(1)		
	Hoos-Churchman	(2)		
9. Compute economic effects of changes in estimation of critical water demand parameters	Bowden	(1)		
	Estes	(1)		
	Hoos-Churchman	(2)		
10. Evaluate and test remote sensing techniques in relation to water demand	Bowden	(1)		
	Estes	(1)		
	RSRP	(2)		
11. Determine costs of water demand information-gathering using conventional methods	Bowden	(1)		
	Estes	(2)		
12. Compare water demand remote sensing techniques with conventional methods	Bowden	(1)		
	Estes	(2)		
	RSRP	(2)		
	Hoos-Churchman	(2)		
13. Estimate potential impact of using remote sensing techniques in water demand problems	Bowden	(1)		
	Estes	(1)		
	RSRP	(2)		
	Hoos-Churchman	(2)		
	Algazi-Burgy	(2)		

FIGURE 1.2 Chronological Plan for the Assessment of Water Supply and Water Demand by Means of Remote Sensing. (1) Indicates primary responsibility; (2) indicates secondary responsibility.

respectively, relative to the future of NASA's Earth Resources Survey program. The strength of both of those reports was significantly increased by our being able to draw upon the findings of all of the NASA-funded participants in this multicampus integrated study.

There has been one notable exception to the previously stated emphasis of our project on water resources. The exception, made at NASA's request, has resulted from questions raised by U.S. Forest Service officials regarding the usefulness of ERTS-type data as an aid to forest inventory. In this regard, Mr. Frank Zarb of the federal Office of Management and Budget, Executive Office of the President, in his testimony before the Senate Committee on Science and Astronautics said:

> "The Forest Service has stated that there is as yet no demonstrable need in forest inventory, the major area of benefit in forestry, for frequent acquisition of the relatively low resolution produced by ERTS".

Research efforts* by our group to test the validity of this assertion are reported separately, in Chapters 7 and 8 of this progress report. Suffice it to say here that, as a result of these research efforts, we find ourselves in substantial disagreement with the assertion quoted above. Consequently, during the present reporting period, we have engaged in a series of discussions with senior Forest Service officials in an effort to reconcile our findings with theirs.

Parenthetically it should be noted that both the Chief of the U.S. Forest Service, Dr. John McGuire and the Assistant Chief for Research, Dr. Dickerman were among those present at the FAO World Forestry Congress in Rome, Italy on May 20, 1974 when our project's principal investigator gave a "Pro-ERTS" presentation entitled "Remote Sensing and Proximal Sensing as Aids in the Making of Forest Resource Inventories". Leading forestry officials from the 50 other leading countries, in terms of forest resources, also were present. Reactions to this "inagural address", as expressed by the Chief of the U.S. Forest Service and his counterpart in each of several other countries, were generally very favorable, indeed.

Chapter 10 contains a brief summary of our activities and findings during the present reporting period and indicates the direction which our group, guided by various NASA monitors, proposes to take in the future, consistent with the block diagram of Figure 1-1 and the milestone chart of Figure 1-2.

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* Technique development and testing for the ERTS-aided timber inventory procedures evaluated for cost-effectiveness were performed under Remote Sensing Research Program ERTS-1 studies funded by NASA contract no. NAS 5-21827, Task III, Investigation #317C. The comparative cost-effectiveness analyses described in this report were performed under this NASA grant's funding.

During the period covered by this report we have received guidance from an unusually large number of NASA personnel including 4 from the NASA Ames Research Center. To a very significant degree the contents of this Progress Report reflect advice received periodically from Mr. Leonard Jaffe of NASA's Office of Applications. It was Mr. Jaffe who provided the directives that led to our present emphasis on California's Water Resources and who presided at briefings which we gave in Berkeley on June 20, 1974 and in Washington D. C. on December 9, 1974.

Dr. Al Stratton, the new NASA monitor of our project has found it possible to attend briefings which our group has given during the period covered by this report, whether in California or at NASA Headquarters in Washington D. C. and has ably participated in those briefings. During this same period he also has visited most of our research spaces on the Riverside, Santa Barbara, Berkeley and Davis campuses, thereby acquiring an unusually good grasp of our research capabilities and limitations and an appreciation of the remote sensing equipment, facilities and professional expertise available to us.

Also, during the period covered by this report, on three timely occasions, (October 3, November 8 and December 7, 1974), Dr. Peter Castruccio in his capacity as a special consultant for NASA relative to our project has made himself available in the Washington D. C. area for detailed discussions with our project's principal investigator. These discussions have done much to broaden the perspective of our group, to identify the "drivers" in relation to water supply and demand problems in various geographic areas, and to increase the applicability of our findings to water resource management in other parts of the world.

Through timely consultations with both Dr. Frank Hanzing and Dr. Joe Vitale of NASA's Office of University Affairs, (co-sponsors of our project) we again have received valuable and constructive criticism and with it the opportunity to acquaint two important groups with the results of our efforts to date under this integrated study. The first of these groups was the American Association of Engineering Educators at its annual meeting in June, 1974 at Rensaeller Polytechnic University in New York; the second was the group assembled in Boulder Colorado in July, 1974 under the chairmanship of Dr. Jack Ives of the Institute for Alpine and Arctic Research to discuss problems associated with "Man and the Biosphere". In both instances a presentation of our work was given by the principal investigator and was followed by constructive criticism from conference attendees.

With further reference to Dr. Castruccio's involvement in our project, special mention is made here of his effective role in working with personnel of our Social Sciences group. Largely because of his participation, care has been taken by members of our Social Sciences Group to link their work more directly than heretofore into other phases of the joint research effort, as performed by our remote sensing specialists. In responding to the need for this linkage our social scientists now are able to state:

> "Essentially, we all are engaged in investigating the ways in which satellite - derived and other technologically advanced imagery can be utilized in the management of natural resources. The function of the Social Sciences Group is to ascertain ways in which remote sensing data can enter into the decision making process, their costs and effectiveness, and their potential impact and implications."

Our Social Sciences Group also asserts: "With the California Water Project as our primary, but not exclusive, focus, we try to develop insights into the very complicated web of factors impinging on the management of resources in order to learn how new sources of information can be accomodated, by whom, and for what purpose. It is patently clear that these decisions do not take place in a technological, economic, political and social vacuum; decisions regarding resources take place in a real-life, rapidly changing environment. Our task is, therefore, to map the social landscape, the better to learn where, how, and to what effect new sources of information can prove their mettle."

In recent years it has become increasingly apparent to our project's remote sensing scientists that a lack of "technology acceptance" by resource managers and others very often constituted a major deterrent to the achieving of something of practical value from our research. It therefore became apparent that the most significant of our own findings should be integrated with those of our remote sensing colleagues elsewhere, preferably through the publication of some kind of definitive remote sensing "manual". We all recognized that if such a document, well illustrated, were to be prepared under auspices of some professional group of high repute, (such as the American Society of Photogrammetry), and made quite generally available in highly comprehensible form, much would be done to achieve the necessary technology acceptance.

Such an effort also would do much to stem the criticism that we sometimes have heard to the effect that many of our NASA-funded research findings remained buried in progress reports, never to be seen by resource managers and other potential users of modern remote sensing technology.

Pursuant to this thought, we will conclude this introductory chapter by inviting attention to the unusually substantial contribution which those involved in our integrated study have been making to the "Manual of Remote Sensing" which currently is nearing completion under auspices of the

American Society of Photogrammetry. Collectively speaking, our contribution to this first definitive and authorative treatment of remote sensing ranges from co-editorship of the entire Manual, through authorship of its introductory chapter and co-authorship of several other chapters, to the menial tasks of providing large amounts of illustrative material and of proof-reading manuscripts. Once that Manual has been published, it should be apparent to any interested reader, as it now is to us, that our findings to date under this integrated study provide some of the most compelling evidence, both qualitative and quantitative, for the adoption by resource managers of modern remote sensing techniques.

CHAPTER 2

WATER SUPPLY STUDIES IN NORTHERN CALIFORNIA

Introduction

<u>Co-Investigator</u>: Randall W. Thomas, Berkeley Campus

Algazi-Burgy Group Water Supply Studies (a)

<u>Co-Investigators</u>: V. Ralph Algazi, Davis and Berkeley Campuses and Robert Burgy, Davis Campus

Remote Sensing-Aided Procedures for Water Yield Estimation (b)

<u>Co-Investigator</u>: Randall W. Thomas, Berkeley Campus

CHAPTER 2

WATER SUPPLY STUDIES IN NORTHERN CALIFORNIA

The Remote Sensing Research Program (Berkeley), the Algazi Group (Davis, Berkeley) and the Hoos-Churchman Social Sciences Group (Berkeley) are presently involved in the NASA Grant water supply and remote sensing application studies in Northern California. Continuing analysis of hydrologic model structure, inputs, and performance is being conducted by the former two groups. Performance is being documented with respect to "conventional" and to "conventional plus remote sensing" data inputs. Both the Remote Sensing Research Program (RSRP) and the Hoos-Churchman Group are quantifying costs and benefits associated with current and potential remote sensing-aided hydrological model applications.

Analysis of the California Water Project as a system continues from the standpoint of physical and economic phenomena. It is apparent from the current analysis of future product importance in the California Water Project, that water quality in both transport and demand areas will become increasingly significant. All three water supply investigating groups funded under the present grant and cited above are moving to investigate in a coordinated fashion according to their respective expertise, various physical, economic, and social aspects of water quality as they are related to remote sensing's impact.

The RSRP, Algazi, and Hoos-Churchman groups are conducting remote sensing water supply application studies in a truly integrated manner. Figure 2.1 gives the time schedule by subtask for this effort. It should be noted with reference to this figure that studies documenting remote sensing economic impact are now significantly under way. Cost-effectiveness methodologies are cited in Chapter 2b and are documented in Chapters 6, 7, and 8. Preparation for cost-benefit analysis, requiring much data on technique development as well as a wide social spectrum of cost documentation, is cited in Chapters 5, 6, and 8.

The progress report of the Social Science Group is given in Chapter 5, while that of the Algazi and RSRP groups is reported here in Chapter 2. For organizational and clarity purposes, Chapter 2 is broken into two parts. The first, Chapter 2a, is devoted to the Algazi Group report, and the second, Chapter 2b, consists of RSRP work relating to remote sensing-aided water variable estimation. Chapter 6 reports on a cost-effectiveness analysis for a remote sensing-aided snow water content estimation system which is based on work reported in Chapter 2b.

FIGURE 2.1 - CHRONOLOGICAL PLAN FOR THE PERFORMANCE OF WATER SUPPLY STUDIES

Work Subtask	Investigators	Period of Performance: Current Funding Year (M J J A S O N D J F M A) / Next Funding Year* (M J J A S O N D J F M A)
1. Continued Water Model Definition and Performance Documentation	Algazi-Burgy RSRP	
2. Sensitivity Analysis for Critical Parameters in Water Supply Models	Algazi-Burgy RSRP	
3. Develop and Test Remote Sensing Techniques	RSRP Algazi	
4. Determine Costs of Information-Gathering Using Conventional and Remote Sensing-Aided Methods	Hoos-Churchman RSRP Algazi-Burgy	
5. Compare Remote Sensing Techniques with Conventional Ones. Draw Conclusions Regarding Cost-Effectiveness	Hoos-Churchman RSRP	
6. Analyze Cost-Benefit Impact on Society Resulting from Changes in Water Supply Information Due to Application of Remote Sensing Techniques	Hoos-Churchman RSRP	

* Beginning on 1 May, 1975.

CHAPTER 2(a)

ALGAZI-BURGY GROUP WATER SUPPLY STUDIES

Co-Investigators: V. Ralph Algazi, Davis and Berkeley Campuses
R. Burgy, Davis Campus

Contributors: A. Samulon, C. Johnson

CHAPTER 2(a)

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CHAPTER 2(a)

ALGAZI-BURGY GROUP WATER SUPPLY STUDIES

2.0a INTRODUCTION

Since the focus of our integrated study currently is on the application of remote sensing to water resources, a considerable part of the effort by research personnel on the Davis campus in the past year has been devoted to the elucidation of the California Water Project. Specifically, we have been treating that project as an example of a complex system, many components of which might better be understood and managed through the intelligent use of modern remote sensing technology. In this work we have tried to proceed from a general understanding to a study of specific problems.

In addition to our studying this system's engineering and modeling aspects, we have continued our technical work, as digital signal processing specialists, in several areas of application of remote sensing. We also have been able to engage in certain fundamental, but germane studies, for which we have been funded in a significant part by the National Science Foundation.

Thus the work which our Davis group has performed in the past year, and principally since our May, 1974 progress report, falls into the following categories:

A. Updating of the analysis and understanding of the California Water Project as a system.

B. Analysis and study of watershed models amenable to remote sensing inputs.

C. Application of signal processing techniques to user oriented problems.

D. Basic studies on signal processing algorithms pertinent to remote sensing applications.

2.1a OVERVIEW OF THE CALIFORNIA WATER PROJECT - AN UPDATE

An overview of the California Water Project was presented in our portion of May, 1974 report. Our continuing work since that date has been directed toward the further elucidation of some aspects of the Project and an assessment of the evolving perspective and concerns of personnel of the California Water Project. The following factors relative to the California Water Project are expected to assume steadily increasing importance and hence are commanding our attention:

A. <u>Water conservation factors</u>: These do not constitute an operational constraint at this time, but will become progressively more important and will eventually affect operations quite significantly.

B. <u>Water quality factors</u>: These are looming to be of more importance in the immediate future and in the long run. Maintaining some standards of flow rate and water quality in the Delta may soon represent a major constraint on the possible operation of reservoirs.

C. <u>Energy supply and demand factors</u>:

a. The Department of Water Resources needs huge amounts of power and has given consideration to nuclear power plants for power generation.

b. Hydroelectric power has become more important and valuable and may lead to changes in the operation of the dams.

A significant economic benefit has been achieved by the California Water Project in power generation during the Winter 1973-74, by reexamination of the compromise achieved during the winter months between the requirements of flood control operations and hydroelectric power generation. In the short run, this potential increase in generated hydroelectric power appears as the only economic benefit to be expected from a modification of reservoir operations in the Feather River Watershed.

In broader terms, the cost involved in the generation of energy is looming as a factor of increasing importance in the operation of the California Water Project. To understand this evolving situation, the diagrams of Figure 2.1a and 2.2a are informative. In Figure 2.1a the water deliveries in 1973 indicate that only a small fraction of the water entitlement of Southern California has been delivered. Since water which originates at only an 800 foot elevation, at Lake Oroville, has to be pumped to more than a 3000 foot elevation over the Tehachapi Mountains, pumping energy required will increase rapidly as more water is delivered to Southern California. Figure 2.2a shows the evolving power consumption in the short run and in the long run.

As a result of the focusing of public attention on energy uses and energy resources, the California Department of Water Resources (DWR) has carried out a background study on Hydroelectric Energy Potential in California, reported in the DWR Bulletin 194, March 1974. This study and discussion with personnel of the Department of Water Resources indicate a continuing reassessment of objectives and management of water resources in the State of California. We shall, in the coming year, keep informed of this evolving situation and report on changes with potential impact on remote sensing applicability.

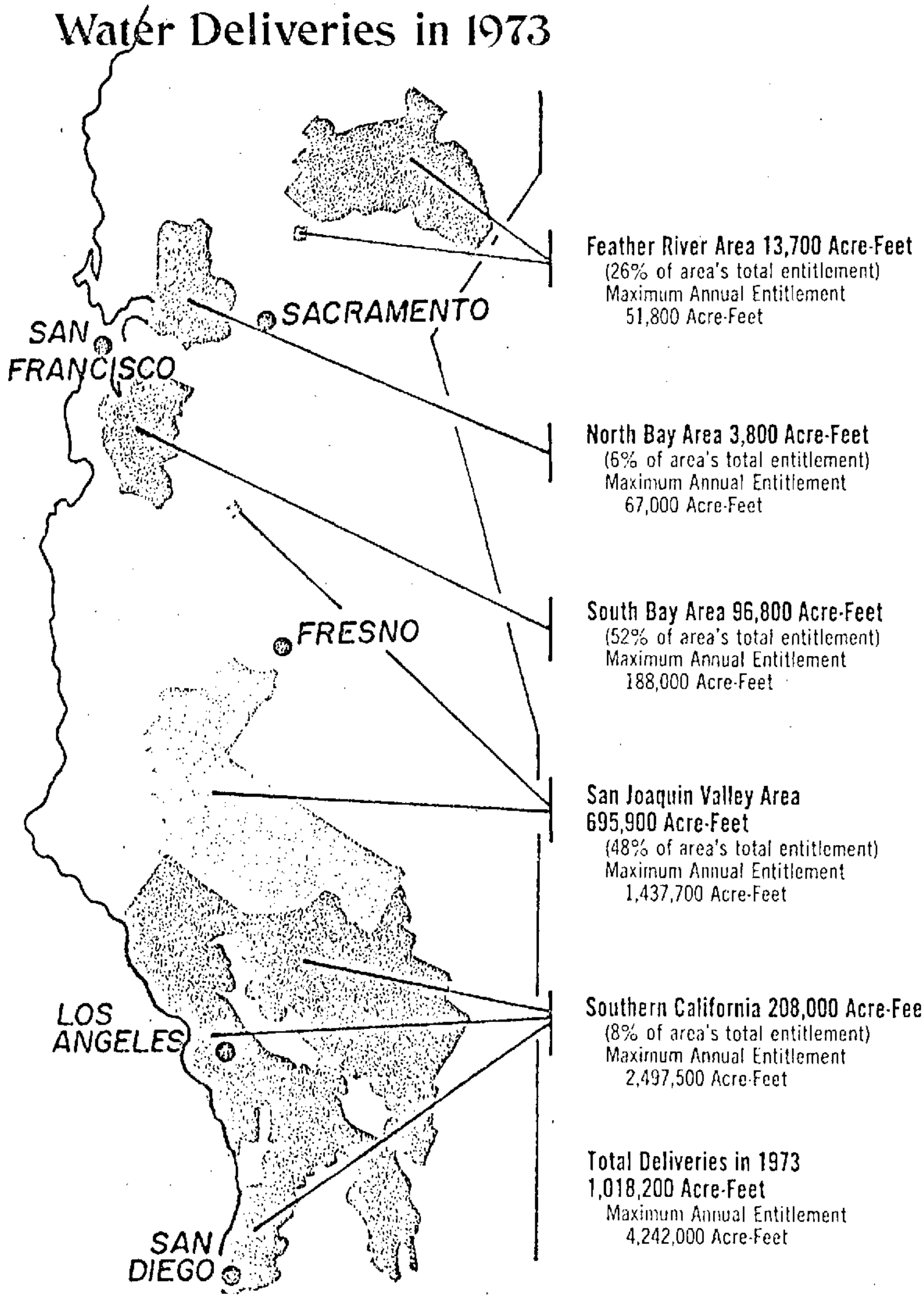

Figure 2.1a. Water Deliveries in 1973

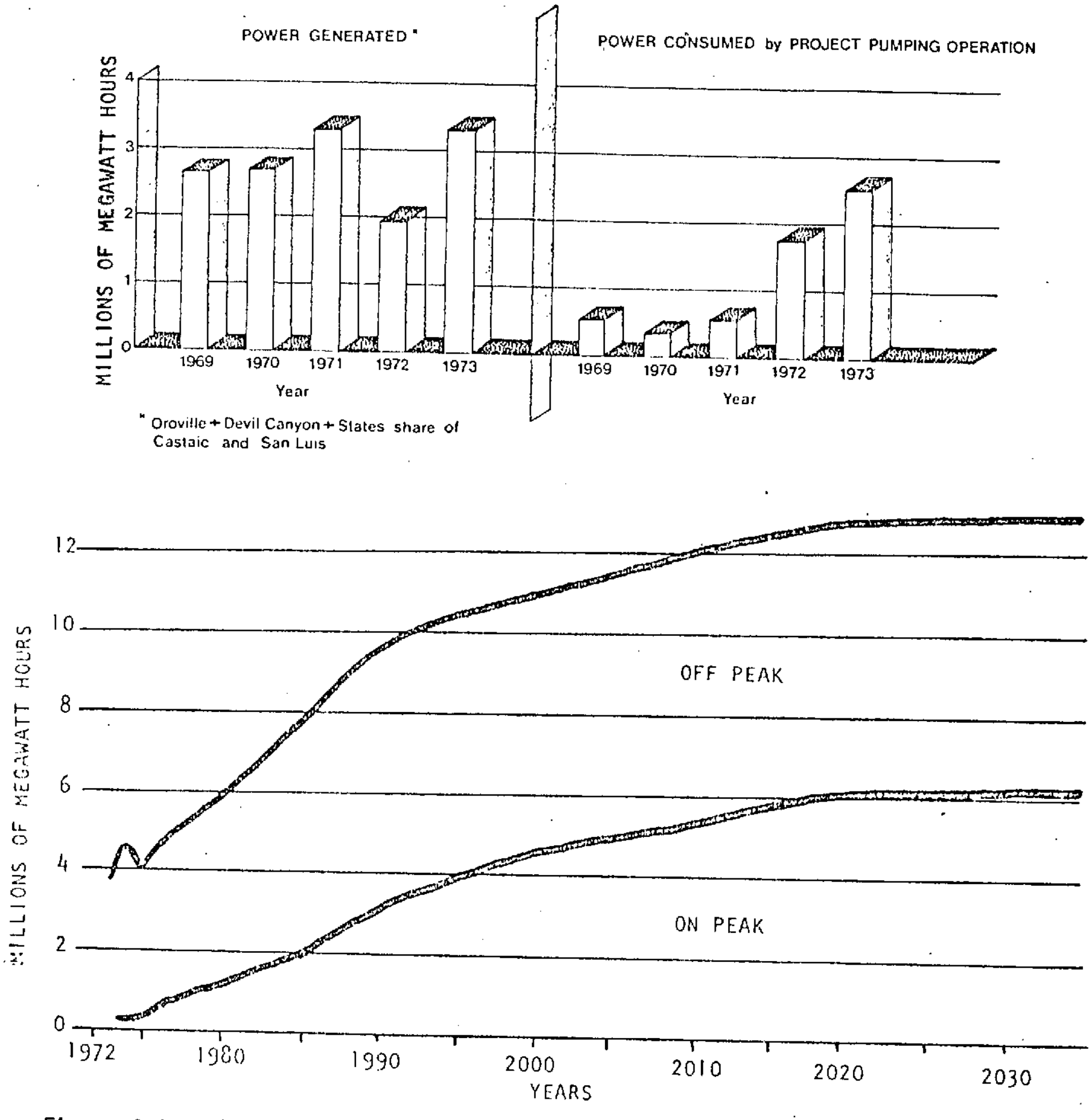

Figure 2.2a. Projected Power Generated and Pumping Energy Requirements Associated with the California Water Project.

2.2a ANALYSIS AND STUDY OF WATERSHED MODELS AMENABLE TO REMOTE SENSING INPUTS

We have undertaken in the past year a study of watershed models which are used operationally or which are given most serious consideration in technical literature.

Chronologically our work has proceeded as follows:

A. We started our work by a study of the technical literature and reports of work done on applications of remote sensing to hydrology. From this study, which is a continuing effort, it appeared that the work most germane to our interest was that of Ambaruch and Simmons (4,5) on the use of remote sensing in the Kentucky Watershed Model.

B. The work of Ambaruch and Simmons suggested that a reasonable starting place in quantitative assessment of the potential of remote sensing inputs of a watershed model would be an evaluation of the sensitivity of the model to inputs and parameters. Although hydrologists have, from experience, a good feel for the importance of various parameters, it appeared that a quantitative sensitivity analysis would be of more than academic interest.

C. We then proceeded to analyze the RFC hydrologic model* to establish such a sensitivity to inputs and it became apparent that such work cannot be carried out analytically. The reason for this is that hydrologic models such as the RFC model or other models based on the Stanford Watershed Model are only partly analytical. Some of the parameters are actually determined by computer optimization during a calibration phase. This type of optimization, known in the engineering community as system identification, consists of the computer determination of unknown parameters of a model so that the output of the model approximates physical outputs in an optimum fashion, according to some objective function or approximation measure.

D. Given this state of affairs, it became clear that the quantitative study of hydrologic models would require their actual implementation on one of our computers and thus would necessitate the availability of the programs, input data sets, output data, germane

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*As detailed in our earlier reports the two models most commonly used in hydrologic forecasting as applied to the Feather River Watershed are a short range RFC (River Forecast Center) model and a longer range CCSS (California Cooperative Snow Survey) model. Both are discussed in the following pages.

historical records, etc.

E. By direct contact with J. Brown and C. Howard of the Department of Water Resources, Snow Surveys, we have obtained some preliminary information and documentation on the CCSS model, which we believe we can implement with a limited amount of time and effort.

F. Randy Thomas of the Remote Sensing Project in Berkeley has been in communication with the personnel of the Department of Water Resources responsible for the operation of the RFC Model, to clarify the procedures and conditions under which that Model and operational data necessary for testing it will be made available to personnel of the University of California. A formal agreement has been reached in the past few weeks which will allow us to proceed with this phase of our work.

G. In parallel with the above work, we have done some work (not supported by the grant) on the application of remote sensing to hydrology for the Hydrologic Engineering Center, Corps of Engineers (HEC) in Davis. This work, carried out in cooperation with R. Burgy, has made us familiar with some other hydrologic models used by hydrologists and civil engineers. It has also made us familiar with the work of Blanchard (6) on the use of remote sensing in the hydrologic model of the Soil Conservation Service, Department of Agriculture. Finally, we have become informed of several engineering applications of hydrologic modeling.

It seems appropriate in concluding this section to describe here the activities planned by our small group in the study of hydrologic models for the coming months: We shall first assess carefully the manpower, time and cost needed to implement the RFC and CCSS models on our campus computers. In this phase we shall rely on the information and cooperation of personnel of the DWR. At the same time we shall formulate a set of specific questions about these hydrologic models that we shall examine. These questions are related to the critical periods of forecasting in the operational use of hydrologic models as well as the sensitivity analysis of the models and the potential impact of remote sensing inputs. In this phase we shall solicit the advice of hydrologists and hydrologic engineers on campus, at the DWR in Sacramento, and at HEC in Davis. Based on this work, we shall implement the hydrologic models and examine the effect of remote sensing imputs and parameters acquired by us or by others on the operation of these models in their most critical phases.

In parallel with this work we shall proceed with our work of the HEC models and propose to NASA, Office of University Affairs, a specific research project in the use of remote sensing in hydrologic engineering, carried out for HEC and on the matching fund formula outlined by Dr. Vitale. We expect that such a proposal will be ready in January or February 1975.

2.3a APPLICATION OF DIGITAL PROCESSING TECHNIQUES IN REMOTE SENSING

A. Delineation and mapping of snow cover and estimation of areal extent.

We have continued work on the enhancement preprocessing and quantification of snow cover. The technique involves a combination of multispectral enhancement, ratioing to reduce effect of shadows in mountainous areas, masking of parts of the image and of the use of a likelihood ratio classification scheme. We are at the stage where we can generate snow cover areal extent estimates which are internally robust in the sense that the sensitivity of the estimate to a change of decision threshold is quite small (4% variation in areal extent for a 20% change in threshold). We are planning to complete this work by comparing it to the best available ground truth data. We shall also apply this algorithm to the Kings River Watershed and parallel and support the photo-interpretation work done by the DWR, Snow Survey, with support of NASA-GSFC. As part of this work we have acquired some NOAA-NESS-VHRR data in the visible and the thermal IR and will combine this temperature information with areal extent for use in models. (7)

B. Mapping and Enhancement of Salt-Affected Soils.

This work carried out by A. Samulon, one of our PH.D. students, has been completed technically and is described by Samulon as follows:

> "This work includes the design and implementation of a non-stationary 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. Non stationarity 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."

We have now undertaken the application of these algorithms to the specific problem of mapping salt affected soils. This is an important problem related to irrigation, which has been drawing the attention of the DWR and county officials in California. Since ground truth is available in parts of California, we shall assess this technique by comparing it to available maps and examine to which class of problems the method applies.

C. Work on Water Quality.

Another of our Ph.D. students, C. Johnson, is continuing work on the application of digital image processing techniques to the mapping and quantification of water quality parameters. A new area of applied work which we have just undertaken is the mapping of isotherms in water, using VHRR thermal IR data. This work uses some of the algorithms for the digital filtering of data that we have developed in the past few months. This application is being carried out in cooperation with personnel of NOAA NWS in Redwood City. We shall report more fully on this work in the Annual Report.

2.4a DIGITAL IMAGE PROCESSING TECHNIQUES DEVELOPMENT

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

A. Spectral-Spatial Combination of Multispectral Data.

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.

1. Improvements of the quality of the data by reduction of the noise due to errors and coarse quantization.

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

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

4. Significant increase in the speed of processing for enhancement or classification. This capability depends upon the choice of linear combination with fast algorithms.

Significant results have been achieved on points 1 and 2 above. A set of filtering algorithms has been developed and is being tested in various applications. Under the sponsorship of the National Science Foundation, a new approach to image encoding, applicable to multispectral data, has been developed. Preliminary results have been presented to the 1974 Picture Coding Symposium, Goslar, West Germany and some of these results are summarized in the appendix. In the coming months we are planning to ready work on 2 and 3 above for publication. Results obtained by B. J. Fino and V. R. Algazi on 4 have been submitted for publication and some additional work, under the sponsorship of NSF, has been proposed.

B. Geometric Correction.

We have implemented some sample geometric correction algorithms. We are planning to assess the range of applications for which this level of correction is adequate. We are also working on some subpixel processing algorithms which have bearing on the problem of radiometric degradation which result from sophisticated geometric correction of the data.

C. 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 still another of our Ph.D. students, Minsoo Suk, with partial support of the grant. A paper on basic design considerations has been submitted for publication to the IEEE Society on Circuits and Signals. Both fundamental and applied work in this area will be continued. In particular, the work by May (8) presented at the 3rd ERTS Symposium, will be examined in the light of the fundamental limitations discussed in our work.

2.5a FUTURE ACTIVITIES OF THE GROUP

Most of the future activities of the group have been described within the context of the work to date. In this section we outline the significant results expected from our work in the coming six months and in the coming year.

A. Applications. We expect to bring to a conclusion the work currently underway in the application of developed algorithms to the detection and mapping of salt-affected soils and to the quantification and use in hydrologic models of snow cover data and thermal data acquired by satellite. In these two applications we shall be working directly with personnel of the Department of Water Resources in Sacramento.

B. Systems Analysis and Planning. Our involvement in the description and analysis of the California Water Project as a system will continue. In particular, we consider it an important part of our work to keep abreast of the evolving and important role that water resources have in the economic and social well being of California.

Thus, the long range research and operational needs of hydrologic engineering in the management of water resources will be matched to current and planned capabilities in remote sensing. This phase of advice and consultation with personnel of the DWR and other State and Federal agencies is related to our support of the quasi-operational activities in applications of remote sensing to hydrologic engineering sponsored by NASA-GSFC.

C. Analysis and Study of Current Hydrologic Models with Regard to Remote Sensing Inputs.

As outlined earlier, we shall implement one or several of the hydrologic models currently in operation. By so doing, we expect to be able to reach some very significant conclusions during this coming calendar year as to the merit of remote sensing data in operational hydrologic models. To perform this task, we shall rely on the assistance of a part-time programmer in Davis, in the consultation with colleagues in the Department of Water Science and Engineering in Davis and hydrologists of the Department of Water Resources.

In the last two months we have examined and discussed with professional hydrologists the question of whether a junior person, such as a graduate student with training in hydrology would contribute significantly to our work. After implementation of hydrologic models in our computers, we shall proceed and hire the best professional hydrologist available to assist in the task of the interpretation of the results. We believe that in the longer run, a hydrologist of stature should carry prime responsibility for advanced work on hydrologic models and to that end, we shall pursue our contacts with professional colleagues within the University and reorganize our research activities accordingly.

D. Application of Image Processing Algorithms.

From the start we have taken as part of our role within the remote sensing project, the developement and application of image processing algorithms. This was done in part as a service function for the benefit of users interested in the application of remote sensing techniques to their problems. We now have available an extensive and flexible set of programs and a hardware facility which allows us to handle, with considerable ease, a very large number of application problems.

We shall continue our interactions on this technical basis, with the Department of Water Resources in Sacramento, with the Hydrologic Engineering Center in Davis, and with the Geologic Survey and the National Weather Service in the San Francisco Peninsula.

E. Image Processing Techniques Development.

We shall continue our work in technical areas in which we can make a contribution. This work, of a fundamental nature, is relevant to a number of remote sensing applications. We expect to benefit from the continued support of the National Science Foundation in several aspects of this technical work.

2.6a INPUT QUALITY ENCODING OF MULTISPECTRAL DATA

A summary of work done during the present reporting period relative to this topic by Davis participants in the Integrated Study appears as Special Study No. 4 in Chapter 9 of this progress report.

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CHAPTER 2(b)

REMOTE SENSING-AIDED PROCEDURES FOR WATER YIELD ESTIMATION

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Special acknowledgement is given to William C. Draeger, Leon Johnson, and Susan Williams who participated in research reported in this chapter.

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CHAPTER 2(b)

REMOTE SENSING-AIDED PROCEDURES FOR WATER YIELD ESTIMATION

2.000b INTRODUCTION

The justification for the development of remote sensing-aided water yield estimation procedures lies in the fact that more accurate and timely estimates of that quantity are needed as projected water demands exceed projected available supplies. Close management of the water resource is therefore necessary to maximize usable available water production within the interrelated constraints of other watershed resource objectives such as timber production. Remote sensing data can provide a cost-effective means for obtaining a significant portion of the data needed for more intensive water management. This can be especially the case if water yield estimation procedures are combined with data from other resource inventories and environmental monitoring programs.

The focus of the water supply studies that are being performed by personnel of the Remote Sensing Research Program (RSRP) is such as to develop remote sensing-aided procedures to provide cost-effective, timely, and relatively accurate estimates of components of the hydrologic cycle. Specifically, procedures are being developed for estimating the amount of precipitation, the areal extent and water content of snow, and the amount of evapotranspiration of each major component of a large watershed such as that comprised by the Feather River. Additionally work has started on methods to quantify impervious surface locations and types important in the timing of water yield. Associated methods to quantify watershed pervious surface area and therefore subsurface flow (temporary water loss) mechanisms are being examined for remote sensing applicability.

The projected output from these methods will be used as inputs to current state-of-the-art water yield models operated by the California Federal-State River Forecast Center (RFC) and by the California Cooperative Snow Surveys (CCSS) program. These models were defined and described in detail in Chapter 2 of the May, 1974 Grant Report. Precision and accuracy improvements in water yield estimation made possible by remote sensing-aided water parameter estimates will be quantified.

Assessment of the performance of water yield models currently being used in California is a coordinated effort between the Davis and Berkeley NASA Grant groups. The effort consists firstly of a further analysis of model driver variables, such as total effective precipitation, snow water content and evapotranspiration. The second aspect of this analysis involves the hydrologic model performance analysis. This effort consists of three parts: (a) performance (accuracy, precision, timeliness) of current water supply models in relation to current drivers and data types, (b) performance of current models in relation to drivers whose data values are defined through remote sensing-aided estimation systems developed by RSRP and Davis groups, and (c) performance of models (yet to be developed) that have been modified to make most effective use of remote sensing data.

These performance studies are being conducted in cooperation with the California agencies involved. Due to the complex nature of data flow and computer-human interaction in developing water yield forecasts the NASA Grant participatns will, at the request of the RFC, encourage hydrologic model analysis work review, response, and advice from the state organizations involved.

The remote sensing-aided system will also be used by RSRP in simple water balance equations to provide estimates of water supply. These water supply estimates will be used as checks on the accuracy of our watershed water loss estimates. The ultimate check on both state hydrologic model and RSRP water balance equations will be actual gaged streamflow.

2.100b APPROACH TO REMOTE SENSING-AIDED WATER YIELD ESTIMATION

2.110b General Estimation Procedure

The basic approach to remote sensing-aided water yield estimation involves a multistage, multiphase sample of three increasingly resolved information data planes. The products are estimates of several water loss parameters which may be combined with an estimate of basin water input to provide watershed water yield estimates. Alternatively, the water loss variable estimates may be substituted into more complex hydrologic models such as those of RFC and CCSS to aid in accurate determinations of water yield. Water loss variables currently being considered by RSRP include snow water content, evapotranspiration, and subsurface flow. The first and third variables are primarily temporary water loss quantities, most of their stored water eventually returning to stream flow or lost through evapotranspiration.

The proposed approach to the estimation of the magnitude of water yield parallels that of other remote sensing-aided resource inventories developed by RSRP. Examples would be the timber resource inventory approaches analyzed for cost-effectiveness in Chapters 7 and 8 of this report.

The first step in the procedure involves a stratification of the water source area into basin or subbasin areas of hydrologic significance. For instance, the Feather River Watershed, focus of the NASA Grant Study and source watershed for the California Water Project, may be divided into its component branch basins and/or stratified based on water quantity related elevational zones.

After stratification, the general water loss variable estimation procedure is given in Figure 2.1.1b. That sample design for estimating water loss quantity is given in the right side of that figure while the left side is devoted to formulation of models and data sets to estimate water loss at each stage and phase of the sample design. A definition of sample design terminology is given in Figure 2.1.2b.

A first level of information resolution is developed by merging ERTS, NOAA (meteorological satellite), and digitized topographic data planes. Vegetation, terrain, and meteorological information are defined for a convenient base resolution element, in this case the ERTS pixel. Based on the information associated with each base resolution element an estimate of the water loss variable of interest is made for that location. The appropriate water loss estimation equation, defined as an Order 1 model in Figure 2.1.1b must be able to perform adequately on the information available from this first data level. Adequate performance is defined in the context of the sampling procedure as a generation of water loss variable estimates strongly correlated to actual ground-measured or ground-based estimates of water loss for the variable of interest.

After water loss estimates are made for a given water loss variable for each level 1 resolution element, a grouping of resolution elements into primary sample units (PSU's) is performed. The standardized size and shape of the PSU's is selected so as to minimize total first sample stage variance among PSU's for all watershed water loss variables to be simultaneously estimated. Alternatively, the PSU geometry may be optimized to minimize first stage estimate variance for another resource parameter, such as timber volume, for which information utilized in the water inventory was originally collected.

Based on the water loss variability among PSU's, a sample of these units is selected in each water related stratum for further sampling. Selection may be with probability proportional to estimated amount of water loss within given PSU's for a given loss variable or combination of variables. Thus sampling is on the average directed to areas of higher water loss. PSU selection with equal probability can be considered an alternative where subsampled information is used to estimate water quantities for other water loss variables.

The chosen PSU's are then overflown with medium and large scale photography as in the case of other resource inventory procedures. Each medium scale photograph within a selected PSU provides the framework for a definition of a secondary sampling unit (SSU). The SSU's form a series of large scale photographic plots within each PSU centered at the medium scale photo center. The photographic SSU data along with nearby snow course and ground station calibrated meteorological satellite data provide the second level of information resolution.

Figure 2.1.1b Hydrologic Modelling: Quantification of Time Specific Water Runoff Loss to Snow, Evapotranspiration, and Subsurface Flow

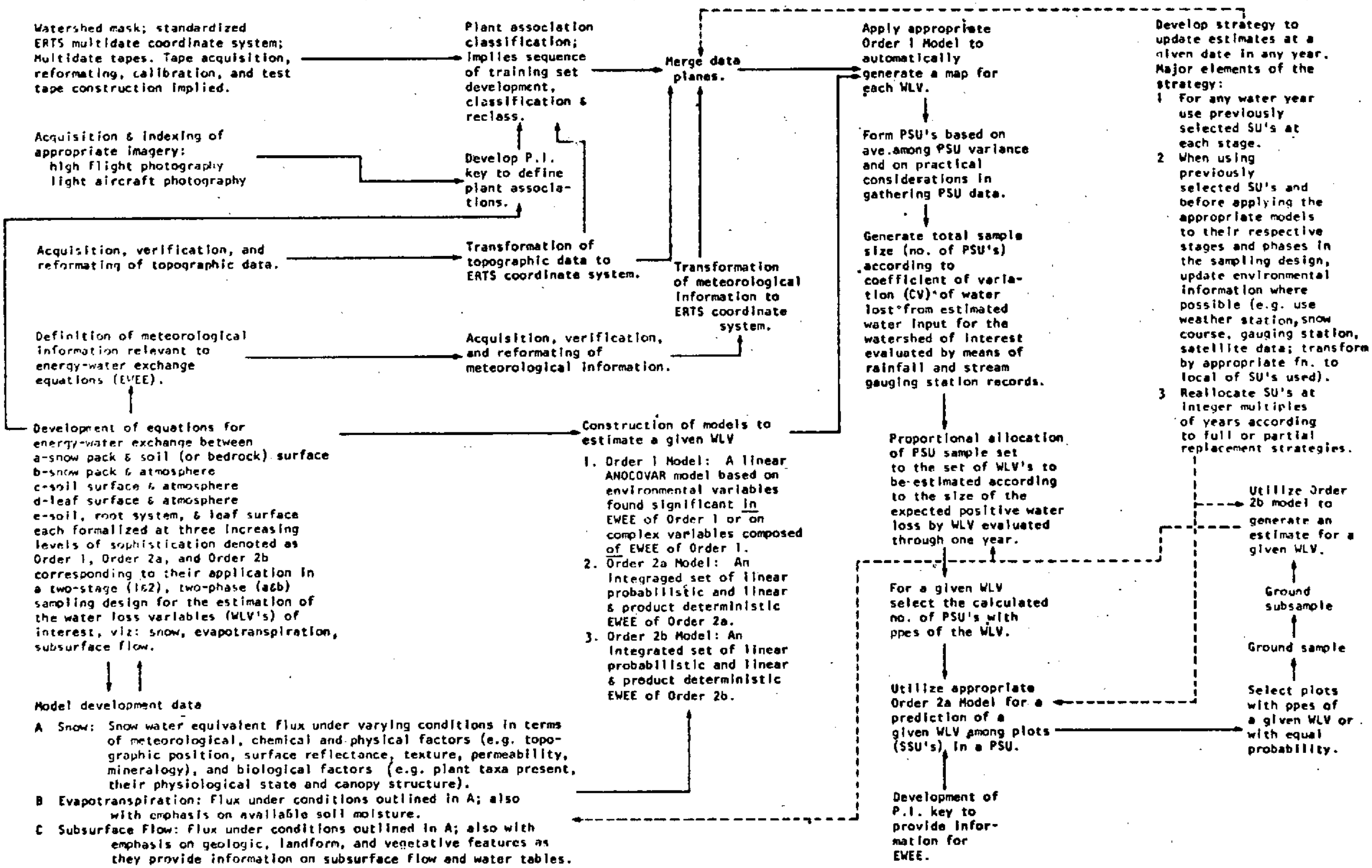
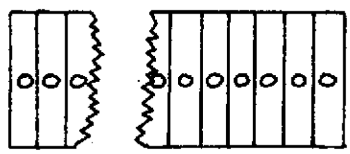
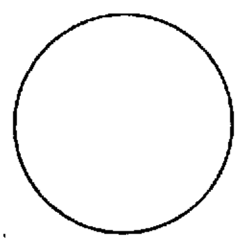
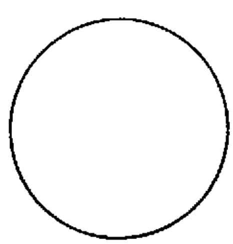


FIGURE 2.1.2b - WATER LOSS SAMPLE DESIGN TERMINOLOGY

Information Level	Sample Unit	Sample Design Level	Comments
1	PSU 	Stage 1 Multistage portion of sample design	All PSU's in watershed have water loss estimates made based on a summation of water loss estimates for ERTS resolution elements occupying each PSU. A sample of the PSU's is selected for further sampling
2	Photo SSU 	Stage II Phase 1 Multiphase or double sample portion of sample design	All SSU's within a selected PSU have water loss estimates made based on surface characteristics interpreted from the photography
3	Ground SSU 	Phase 2	Ground measurements resulting in ground-based water loss estimates are made for a sample of the photo SSU's

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OF POOR QUALITY

At the SSU stage of the sampling design, much more specific information concerning local vegetation canopy composition and geometry, soil characteristics, and local climatic conditions is available as opposed to that obtainable from information at level 1. Thus water loss models employing more data types and more refined data are used to generate water loss estimates for each PSU. These equations are denoted as Order 2a models in Figure 2.1.1b. Estimates at this stage will be more expensive on a unit basis than for first stage (PSU) water loss variable estimates.

Lastly a sample of the photo SSU's is selected for further detailed measurement on the ground. This sample is based on the "within PSU" second stage sample unit constraints. Either probability proportional to size of the water loss estimate or equal probability selection can be employed for this phase of the sampling design.

For each of the SSU's selected, detailed ground measurements are made of vegetation canopy geometry, color, species composition, etc. as well as of soil and litter-organic debris physical and chemical characteristics. The detailed data from this third level of information will then drive very sophisticated Order 2b water loss estimation models. Since estimates of water loss will be for the entire ground area of the SSU photo plot, this third stage unit (TSU) will actually comprise a double sample of the SSU's. The cost of acquiring data for the ground sample, that is for information level three, is the most expensive of all levels.

Figure 2.1.1b describes this double sample in terms of a photo SSU first phase and a ground SSU second phase. Note that the photo SSU is simultaneously the second sample stage and the first sample phase in the basic two stage, two phase water loss estimation sample design. The double sample allows the development of a specific least-square relationship between the more precise and accurate water loss ground SSU-based estimates and the photo SSU estimates. Such relationships can be employed to calibrate photo SSU estimates where no ground data were obtained. In addition, ground to photo least-square relationships can be developed to calibrate vegetation and soil surface quantifications made on aerial photography. Such calibrated photo data give rise to more accurate water loss estimates at the second stage of the sample design (information level 2).

In sample design overview and with reference again to Figure 2.1.2b, it is clear that information levels 1, 2, and 3 specify the data plane at which a sampling operation takes place. Obtaining and processing information at increasingly higher information level numbers is exponentially more costly. Thus a smaller and smaller watershed area is sampled as the information level number increases.

The full watershed estimate of water loss for a given water loss variable can then be developed by first using the ground based water loss estimate to calibrate the SSU estimate based on photo data. The calibrated SSU estimates can then be expanded to the PSU stage by employing the SSU selection weights developed earlier. Finally, PSU water loss estimates can be expanded over the pertinent stratum and then to the entire watershed by applying the PSU selection weights originally calculated. In this way, a cost-effective combination of an increasingly smaller sample of more precise and more expensive information levels can be utilized to give basin-wide watershed estimates.

2.120b Water Loss Estimation Models Specific to Given Information Levels

The sampling procedure just described differs from previous RSRP remote sensing-aided inventory systems in several ways. The first, apparent from Figure 2.1.1b, is that for water loss prediction at each stage or phase of the sample design, moderate to complex mathematical models based on known energy-water exchange relationships are employed. These models are based on the type, resolution, and amount of data available from the information level relevant to the sample stage or phase in question.

These mathematical water loss models are formalized at three increasing levels of sophistication according to the increase in type, amount, and detail of information proceeding from information level 1 to level 3. They are denoted as Order 1, 2a, and 2b models corresponding to their application in the two stage (1&2), two phase (a&b) sample design.

The Order 1 models, designed to operate on information available from level 1, are presently formulated as linear statistical models. These equations are often referred to as analysis of covariance (ANOCOVAR) models, as they provide for both qualitative and quantitative independent predictor variables and their interactions. Statistical tests are available to test for the significance of estimated parameters corresponding to these variables. Thus predictor variables may be included or excluded for a basin or sub-basin area depending on their statistical significance or non-significance to precise water loss prediction respectively.

Water loss estimation equations for level 2 information, denoted as Order 2a models in Figure 2.1.1b, are composed of a combination of linear-product deterministic as well as linear statistical relationships. The deterministic equations, generally not stochastic (probabilistic) in nature, are designed to physically model actual energy-water exchange processes. The resulting increased sophistication of the Order 2a models over the Order 1 is intended to take advantage of the specific vegetation canopy and surface information available from the SSU photo plots. The result is a tendency for more environment-specific, accurate, and precise water loss estimates than obtained for corresponding PSU's from level 1 information.

Order 2b models differ from Order 2a models primarily in the complexity of the deterministic equations and in the sophistication of the predictor variables utilized. The Order 2b relationships are designed to give the most complete and accurate estimate of water loss in the multistage, multiphase sample design as they may utilize detailed ground measurements for information level 3. Tests of predictor variable significance in Order 2a and 2b models are more difficult than for just the linear statistical case found in the Order 1 model. These significance tests must be based inpart on the information loss resulting from predictor variable or complex expression exclusion from the physical relationships of the Order 2a and 2b models.

The predictor variables and structure of the water loss estimation models of Order 1, 2a, and 2b are based on the development of relationships for energy-water exchange identified in the literature and in RSRP research. These energy-water exchange relationships are defined between the following environmental surfaces: (a) snow pack and soil surface (or bedrock surface), (b) snow pack and atmosphere, (c) soil surface and atmosphere, (d) leaf surface and atmosphere, and (e) soil, root system, and leaf surface. Each of these relationships is formalized at three increasing levels of sophistication corresponding to information available to Order 1, 2a, and 2b models, respectively. Each relationship is specific to the energy-exchange process for the water loss variable of interest: snow water content, evapotranspiration, and subsurface flow.

Predictor variables based on these energy-water exchange relationships utilized in the water loss estimation relationships (Order 1, 2a, 2b) may be simple or complex. An example of a simple independent variable is average daily temperature. Complex predictor variables consist of mathematical relationships, physical or probabilistic, which themselves predict the value of an independent variable. Moreover, the juxtaposition of independent variables and their interactions in the Order 1, 2a, and 2b models is dependent on the defined energy-water exchange relationships. That is, the physical location of variables or variable expressions in the water loss prediction models may be determined from analysis of the energy-water exchange relationships.

2.130b Data Requirements

The energy-water exchange equations necessitate the need for a broader data type base than utilized in other resource inventories. This statement is true both for developing data needed in the water loss prediction equation and for that information required to drive the remote sensing-aided water loss estimation system operationally.

The scope of these data requirements is summarized in Table 2.1.3b. Initial information types and procedures for data collection are given for ground SSU plots and photo SSU plots in Appendices III and IV respectively.

TABLE 2.1.3b - WATER LOSS ESTIMATION DATA TYPES

Information Source	Derivable Data	Highest Fetch Rates	Remote Sensing-Aided Evapotranspiration System Information Level of Application*
ERTS (hardcopy and digital data)	1. Vegetation types 2. Terrain types 3. Snow types	Every 18 days	1
NOAA (hardcopy and digital data)	1. Canopy-top temperature 2. Snow surface temperature 3. Cloud-top temperature correlated to precipitation 4. Generalized snow presence data	Twice Daily, 9-10 am and pm LST	1,2,3
Large-medium scale photography	1. Vegetation canopy composition and spatial configuration 2. Ground surface zone characteristics	1 to several times yearly	2
Supplemental Imagery	1. Optional additional canopy and temperature quantification for large area energy flow modeling	multiyear to several times yearly	2,3
Ground Plot Data	1. Canopy geometry 2. Ground surface zone characteristics	multiyear	3
Topographic Data (USGS quadrangles or stereo planigraph output)	1. Elevations	once	1,2,3
Ground Meteorological Station data			
a. National climatic data station network (Includes federal, state, and local stations)	1. Maximum, minimum average temperature 2. Precipitation data (solid and liquid) 3. Wind direction and wind travel/day 4. Cloud cover percentages 5. Evaporation pan data 6. Total incoming solar radiation	hourly to once daily	1,2,3

TABLE 2.1.3b (continued)

Information Source	Derivable Data	Highest Fetch Rates	Remote Sensing-Aided Evapotranspiration System Information Level of Application*
b. Wildland fire danger rating station network (U.S. Forest Service, U.S. Bureau of Land Management, State Wildland Fire Control Organizations)	1) to 5) above plus 6. Relative humidity 7. Fuel moisture	2 hours to daily	1,2,3
Snow courses and automatic snow sensors	1. Snow depth 2. Snow density 3. Snow water content	Courses: monthly during season Sensors: minutes	2,3
Stream gaging stations	1. Stream flow volume 2. Water yield data	Hourly to Daily	1,2,3
Literature	1. Albedo 2. Energy-water exchange data		1,2,3

* Legend: 1 = information level 1: ERTS level of information resolution

2 = information level 2: large scale photograph level of resolution

3 = information level 3: ground level of information resolution

The data types recommended for use within the remote sensing-aided water loss estimation system must be available to varying degree throughout many regions of the world in order to maximize the utility of the proposed technique. In addition they must be cost-effectively obtained, ideally in the context of other data application programs, at fetch-rates utilizable in water loss estimation models.

2.140b Necessary Spatial Transforms and Real-Time Water Loss Estimates From the Sampling Framework

The proposed water loss estimation approach differs from other remote sensing-aided inventories in two additional ways. First, spatial transforms must be developed to distribute coarsely defined information, such as meteorological satellite pixel data, and/or sparse point information to small resolution elements at a given information level, for example ERTS pixels. The second difference is that of reporting time period. While estimates of total timber volume, for instance, may be required at three, five, and higher year intervals, estimates of water yield may be required for quarterly, monthly, weekly, daily, and even hourly periods. This high frequency inventory situation requires a cost-effective turnover of sample units and application of the set of special transforms cited above. The result is a real-time update of variables important in water loss estimation at selected sample unit locations.

Spatial transforms and real-time estimation are discussed in detail in sections 2.522b and 2.523b, respectively, for the case of evapotranspiration estimation. Briefly, spatial transformations involve microclimatic functions to transform data from, for example, a NOAA meteorological pixel, into information specific to each of the approximately 100 corresponding ERTS pixels. In the case of meteorological satellite information, a calibration is made of transformed meteorological data by double sampling the resulting transformed pixel information with corresponding ground data station values. The type of microclimatic spatial transformation function cited above is also used to transform ground meteorological data to SSU locations. Such transformed ground station values can be used as a check on transformed, ground calibrated meteorological satellite data specific to given SSU's.

The second type of spatial transform is that used to take the canopy-top meteorological data generated by the first spatial transform type (horizontal) and generate a vertical profile of the meteorological parameter in question. This vertical profile of magnitude (for example, temperature or relative humidity) will be based on SSU canopy and surface geometry. These canopy meteorological variable profiles will be used to provide the detailed information necessary to drive Order 2a and 2b water loss estimation models.

Real-time estimation involves the repeated use of photo ground SSU data over a period of several months to several years. A subset of the originally selected SSU and associated PSU units is deactivated in a given year and a new set chosen to replace it. This process is a form of partial replacement sampling. Through use of the horizontal and vertical transformations just discussed, real-time meteorological sample unit-specific values are estimated using previously defined canopy and surface geometry-composition characteristics. Real-time estimates of water loss may then be made using the existing multistage, multiphase sampling framework.

2.150b Components of the Current RSRP Water Supply Study

In addition to the development of the multistage, multiphase sampling design for water loss estimation discussed in section 2.100b, specific technique development for remote sensing applications supporting this design is progressing. Included here is the development of cost-effective remote sensing-aided methodologies for watershed snow areal extent estimation, snow water content estimation, evapotranspiration estimation, and impervious surface estimation. Each of these techniques is utilized in the context of the remote sensing-aided water loss estimation system outlined in Figure 2.1.1b. Each of the resulting water variable estimates will be employed in current California Department of Water Resources water supply models to document water yield performance improvements resulting from remote sensing data.

Associated with these techniques is the development of microclimatic transformation functions just discussed. As stated there, this transformation function analysis involves the integration of meteorological data, particularly meteorological satellite information, with ERTS and more conventional remote sensing and ground data planes. Such integration promises significant gains in the usefulness of remote sensing information to renewable resource inventory and monitoring.

The following sections of Chapter 2b deal successively with (1) manual approaches to snow areal extent estimation, (2) semi-automatic snow areal extent estimation, (3) manual and potentially semi-automatic impervious surface area estimation, (4) semi-automatic evapotranspiration estimation, (5) preliminary meteorological satellite data work, (6) current water supply model definition and performance evaluation, and (7) recommendations for future work. Appendices I and II document and evaluate evapotranspiration models relevant to remote sensing applications. Appendix III gives data collection instructions for ground SSU's defined in the water loss estimation sampling design, while Appendix IV documents data collection instructions for photo SSU's in the same sample design.

Preliminary procedures for snow water content estimation based in part on ERTS data are given in the context of a cost-effectiveness analysis in Chapter 6. That chapter is especially important from the standpoint of an economic measure of value for remote sensing applications to water supply quantification.

2.200b AREAL EXTENT OF SNOW ESTIMATION USING ERTS-1 SATELLITE IMAGERY*

2.210b Introduction

One of the most easily detected of all resources from Earth orbiting satellites is snow. Investigators have proposed that relationships could be developed between snow-cover depletion and water runoff (Leaf, 1969) and in more specific terms, between snow-cover depletion and snow water content. It is also deemed possible and cost-effective to relate areal extent of snow in specific vegetation, elevation and aspect relationships to the actual snow water equivalent for a given area using snow survey data collection systems similar to those in use in many areas (Thomas, section 2.100b; Sharp and Thomas, Ch. 6). Since it is highly probable that relationships such as the ones described above could be developed using areal extent of snow to provide the major portion of the information to be used in water runoff equations, techniques had to be developed which would provide fast, economical, and accurate estimation of this parameter. The following research deals with the development of techniques for estimation of snow areal extent.

Using conventional aerial photography as the data base for obtaining snow areal extent information would obviously prove extremely costly if this necessitated covering entire watersheds on a sequential basis. Satellite imagery, more specifically ERTS-1 satellite imagery, could provide the data base, relatively inexpensively and on a repetitive basis. In order to quantify areal extent of snow, techniques were developed under this NASA grant which analyzed the imagery for areal extent of snow based on reflectance and such parameters as elevation, vegetation and aspect. The first technique described provides a preliminary analysis of such research using a relatively simple procedure which none-the-less provides some very solid quantitative results. The second technique described is still in the research stage and as of yet has not been utilized to produce areal extent of snow estimates.

2.211b Procedure

The estimation procedures described in the following pages are based upon analyses of imagery defined by artificial units (grids) and environmental units (coincident units dealing with vegetation, aspect, and elevation, respectively). These techniques differ substantially from the snow mapping approach reported in the literature (Wiesnet, 1974; Barnes and Bowley, 1969), where the snowpack boundary is delineated directly. The procedures developed at the Remote Sensing Research Program, during water supply studies sponsored by this NASA grant, allow the image analyst to make decisions in discrete units of the imagery as to the areal extent of snow based upon such factors as density and type of vegetative cover, elevation, aspect, actual reflectance of the snowpack, and by inference (i.e. by the presence of directly observable snowpack). These techniques also provide for the direct

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* The work reported in this section is considered to be complementary to, and not duplicative of, work currently being performed by NASA-Goddard personnel under the title "GSFC Snow Mapping ASVT."

application of appropriate statistical methods for the estimation of the true areal extent of snow, as well as providing a means of determining the precision of that estimate.

ERTS-1 imagery in the form of simulated color infrared enhancements of bands 4, 5, and 7 was used for the interpretation procedures. These enhancements were made from individual 9 1/2 inch ERTS-1 black-and-white positive transparencies and combined using a technique developed at the Remote Sensing Research Program (Katibah, 1973). Consequently, enhanced imagery of just that portion of the ERTS-1 frame desired could be produced with excellent quality. Use of this technique also provided original enhancements directly on negative color film so that high quality reflection prints could be produced for interpretation purposes.

2.212b Snow Areal Extent Inventory Type I

During the spring of 1973, the ERTS-1 satellite provided essentially cloud-free coverage of the Feather River Watershed on April 4, May 10, and May 28. On these dates (or at the most, one day thereafter) random transects were flown across the watershed using a 35 mm camera to acquire large scale photography that could be used as an aid in determining the actual snow condition on the ground (i.e. "ground truth").

To estimate the areal extent of snow, the ERTS-1 images were gridded with image sample units (ISU's), each equaling 980 acres (392 ha) Figures 2.2.1b, 2.2.2b, 2.2.3b, and 2.2.4b). These cells were then transferred to the large scale photography where applicable. The image sample units on the large scale photography were coded as follows:

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

The gridded ERTS-1 images were then interpreted, sample unit-by-sample unit, and coded using the following method to account for vegetative cover and density and to some degree, aspect, elevation and slope as they impact snow cover.

Scale matched simulated color infrared enhancements of ERTS-1 imagery were produced for April 4, 1973; May 10, 1973; May 28, 1973 and also for August 31, 1972 in reflection print form. The April and May dates represent the snowpack and were gridded, while the August 1972

Figure 2.2.1b April 4, 1973 ERTS-1 simulated color infrared enhancement. Image sample units (grids) = 980 acres each.

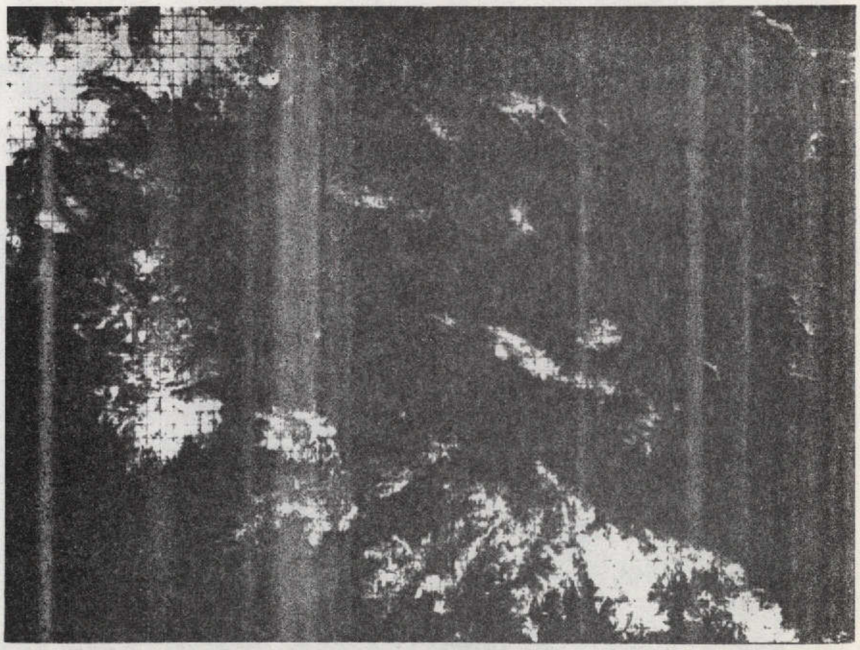

Figure 2.2.2b May 10, 1973 ERTS-1 simulated color infrared enhancement. Image sample units (grids) = 980 acres each.

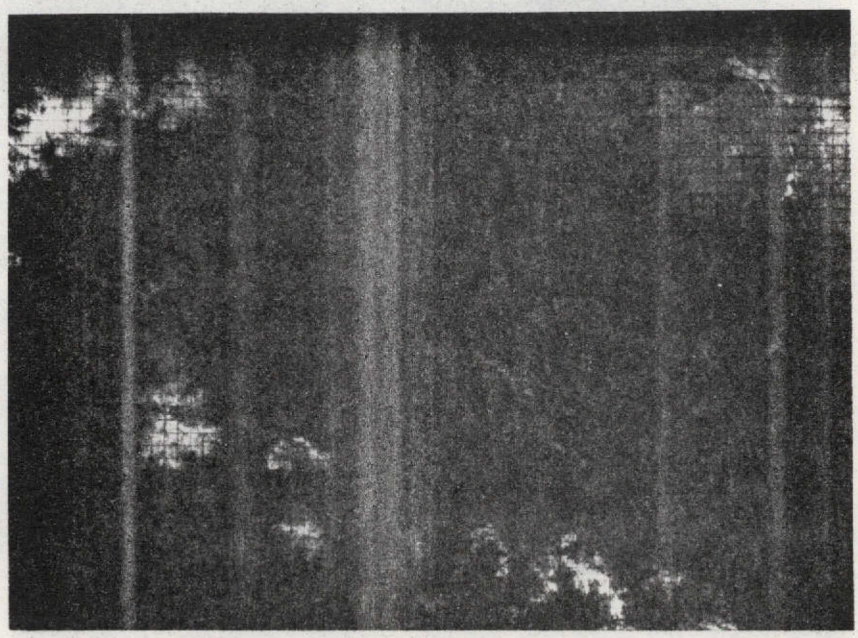

Figure 2.2.3b May 28, 1973 ERTS-1 simulated color infrared enhancements. Image sample units (grids) = 980 acres each.

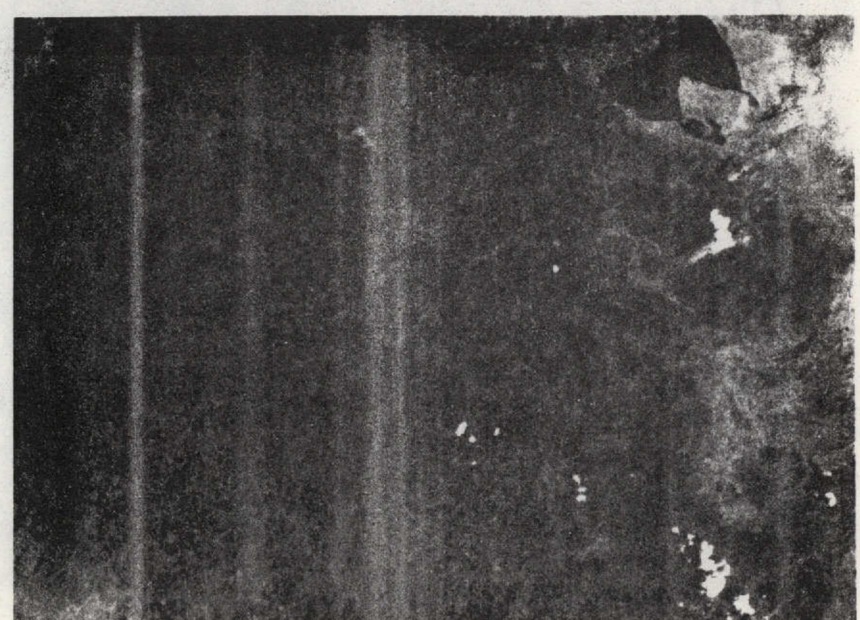

Figure 2.2.4b August 31, 1972 ERTS-1 simulated color infrared enhancement. Cloud-free summer image.

date, representing a cloud free summer image, was not gridded. The purpose of the August date was to provide a clear aerial view of actual ground relationships of vegetation/terrain features. The August date was superimposed with each of the snowpack dates using a mirror stereoscope. By blinking first one eye and then the other the image analyst could observe what conditions actually occurred on the ground in the image sample unit he was interpreting for snowpack. Obviously this technique capitalizes on the human image analyst's ability to synthesize large amounts of pertinent data and quickly arrive at a decision.

The image analyst, using this technique, spent three hours training himself to interpret the ERTS-1 imagery. The April 4th date comprising 2218 image sample units was subsequently interpreted in nine hours, the May 10th date (2050 image sample units) in six hours, and the May 28th date (2013 image sample units) in three hours. The decrease in interpretation time can undoubtedly be related to the increasing experience of the analyst and the decreasing snowpack.

The ERTS-1 interpretation results were compared to the coded large scale photography where applicable. Tables 2.2.1b, 2.2.5b and 2.2.9b summarize the interpretation test results. The sample unit-by-sample unit interpretation of the ERTS-1 image was then used to find the estimate for the areal extent of snow in the watershed. Totals for each of the individual snow cover classes were found and multiplied by 980 acres, the area of each image sample unit on the ground. This gave the acreage for each class; these values were then multiplied by the appropriate snow cover class midpoints to give the total acreage of snow in each class. Finally, these totals were added to give the estimated areal extent of snow. See Tables 2.2.2b, 2.2.6b and 2.2.10b.

The areal extent of snow thus calculated was based solely upon the ERTS-1 interpretation results. To correct this estimate, the image sample units where snow areal extent "ground truth" was obtained (from large scale aerial photographs) were compared with the same image sample units on the ERTS-1 imagery. The relationship between the snow areal extent values on these corresponding ERTS-1 and "ground truth" sample units is the basis for the application of the ratio estimator statistical technique (Cochran, 1959). This technique not only provides a correction for the original interpretation estimate, but also allows for an estimate of the precision of this technique through the application of confidence intervals. The confidence intervals around the areal extent of snow estimates were calculated for four different levels of confidence 99%, 95%, 90% and 80% for comparative purposes. The confidence intervals are expressed as actual acreages and in the form of allowable error.

Y_R = The actual areal extent of snow

$\hat{Y}_R$ = Estimate of the true areal extent of snow = $X\hat{R}$

where $$X = \sum_{j=1}^{N} X_j$$

X_j = ERTS-1 interpretation estimate of the numberof acres of snow by snow cover class

= (snow cover class midpoint)(980 acres/image sample unit)

j = index for all ERTS-1 image sample units

N = maximum ERTS-1 image sample unit index number

$$\hat{R} = \frac{\bar{y}}{\bar{x}} = \frac{\sum_{i=1}^{n} y_i}{n} \div \frac{\sum_{i=1}^{n} x_i}{n} = \text{population ratio estimator}$$

n = total number of ERTS-1 image sample units sampled with large scale aerial photography

i = sample index

y_i = large scale photo estimates of the acres of snow for sampled ERTS-1 image sample unit i

= (snowcover class midpoint)(980 acres/image sample unit)

x_i = ERTS-1 interpreter estimate of the number of acres of snow for sampled image sample unit i

= (snowcover class midpoint)(980 acres/image sample unit)

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

Confidence intervals around Y_R:

Example for 95% level of confidence:

As expressed in acreage

$$\text{Probability } \hat{Y}_R - t_{n-1},\ .025\sqrt{V(\hat{Y}_R)} \leq Y_R \leq \hat{Y}_R + t_{n-1},\ .025\sqrt{V(\hat{Y}_R)} = .95$$

As expressed as allowable error

$$\text{Allowable error (AE)} = \frac{t_{n-1},\ .025\sqrt{V(\hat{Y}_R)}}{\hat{Y}_R}$$

It is desirable to check and see if the values in the snow cover class from the ERTS-1 image data come from the same statistical probability distribution as the values in the snow cover classes from the large scale photography data. If they come from the same distribution it may be expected that our estimation procedure will provide good results. If there were also a way to lump snow cover classes to improve the indications that the two sets of values came from the same distribution, this would give some idea on how to improve the estimation procedure in the future. To perform such probability distribution likeness tests, a Chi-square statistic, $\chi^2 \sim \sum_{i=1}^{k} \frac{(Oi-Ei)^2}{Ei}$, was used. The values in the snow cover classes from the large scale photo data were designated as the expected values (Ei), since they were assumed to be "ground truth". The values in the snow cover classes from the ERTS-1 image data were designated as the observed values (Oi). For each date a Chi-square test was run, using the data as recorded versus the data with snow cover classes 4 and 5 combined, to see if an improvement in class widths could be realized.

2.213b Results of the Snow Areal Extent Inventory Type I

The results of the type I inventory are summarized in the following tables. Tables of interpretation results, statistical computations (including areal extent of snow estimates, variance of areal extent of snow estimate, population ratio estimator, etc.), confidence intervals and allowable errors, and Chi-square test results are found in the following pages. Tables 2.2.1b, 2.2.2b, 2.2.3b, and 2.2.4b deal with April 4, 1973 interpretation data, tables 2.2.5b, 2.2.6b, 2.2.7b, and 2.2.8b deal with May 10, 1973 data, and tables 2.2.9b, 2.2.10b, 2.2.11b, and 2.2.12b deal with May 28, 1973 data.

2.214b Conclusion of Snow Areal Extent Inventory, Type I

Improvement in the snow areal extent inventory, type I as it is currently done is possible by increasing the sample size and by optimizing the image sample unit size.

The Student's-t statistic reaches its smallest value when the degrees of freedom (sample size minus one) are approximately 120. In subsequent inventories using this approach, each date for which large scale aerial photography is flown should have approximately this number of image sample units definable.

One of the items being currently investigated is the optimum size of the image sample unit. Several approaches are possible as well as a combination of all of them. For instance, image sample unit size may be plotted against interpretation time, variance, or variance times cost to determine the optimum image sample unit shape and size under those constraints.

TABLE 2.2.1b - APRIL 4, 1973 ERTS-1 INTERPRETATION RESULTS (ALSO LISTING OF X_i's AND y_i's)

		Large Scale Photo Data				
		Snow Cover Classes				
		1	2	3	4	5
ERTS-1 image data	Snow cover classes 1	0 0 6	98 0 1			
	2		98 98 10		705.6 98 1	
	3		98 343 2	343 343 6	705.6 343 2	
	4			343 705.6 1	705.6 705.6 12	
	5				705.6 970.2 6	970.2 970.2 33

	y_i
X_i	f

X_i = sample ERTS-1 estimate of the number of acres of snow per cell by snow cover class

= (snow cover class midpoint)(980 acres)

y_i = sample large scale photo estimate of the number of acres of snow per cell by snow cover class

y_i = (snow cover class midpoint)(980 acres)

f = interpretation frequencies

TABLE 2.2.2b - RESULTS OF STATISTICAL COMPUTATIONS FOR APRIL 4, 1973

ERTS-1 estimate of the areal extent of snow = χ = 1,263,642 acres

Estimate of the true areal extent of snow = $\hat{Y}_R$ = 1,238,874.62 acres

Variance of the areal extent of snow estimate = $V(\hat{Y}_R)$ = 996,697,274.78

Population Ratio estimator = $\hat{R}$ = .9804

Total number of acres inventories = 2,173,640

Total number of image sample units inventories = N = 2218

Total number of image sample units sampled = n = 80

TABLE 2.2.3b - TABLE OF CONFIDENCE INTERVALS AND ALLOWABLE ERRORS FOR APRIL 4, 1973

Level of Confidence	Confidence Intervals in acres	Allowable Error
99%	$1,180,295.85 \leq Y_R \leq 1,346,988.15$	6.13%
95%	$1,200,785.11 \leq Y_R \leq 1,326,498.89$	5.07%
90%	$1,211,077.10 \leq Y_R \leq 1,316,206.90$	4.24%
80%	$1,222,821.33 \leq Y_R \leq 1,304,462.67$	3.30%

TABLE 2.2.4b - CHI-SQUARE TEST FOR APRIL 4, 1973 DATA

Test at 5% significance level

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

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

Test statistic under the null hypothesis:

$$\sum_{i=1}^{k} \left[\frac{(Oi-Ei)^2}{Ei}\right] \sim \chi^2_{k-1}$$; where k-1 = the degrees of freedom

Class	Oi	Ei	$\frac{(Oi-Ei)^2}{Ei}$
1	7	6	.1667
2	11	13	.3077
3	10	7	1.2857
4	13	21	3.0470
5	39	33	1.0909
		$\sum_{i=1}^{5}$ =	5.8986

= calculated value

χ^2_{5-1}, .05 = χ^2_4, .05 = 9.49 = table value

.˙. Since 5.8986 < χ^2_4, < .05 (9.49) the null hypothesis is accepted with a probability value of less than 25%

.˙. Since the calculated value (5.8986) is less than the table value (9.49), the null hypothesis is accepted.

TABLE 2.2.4b (continued)

Class	Oi	Ei	$\frac{(Oi-Ei)^2}{Ei}$
1	7	6	.16666
2	11	13	.30769
3	10	7	1.28571
4&5	52	54	.00707
		$\sum_{i=1}^{4}$ =	1.76713

= calculated value

$\chi^2_{4-1}, .05 = \chi^2_3, .05 = 7.81$ = table value

∴ Since the calculated value (1.76713) is less than the table value (7.81), the null hypothesis is accepted.

TABLE 2.2.5b - MAY 10, 1973 ERTS-1 INTERPRETATION RESULTS (ALSO LISTING OF x_i's AND y_i's)

ERTS-1 Image Data: Snow Cover Classes	Large Scale Photo Data: Snow Cover Classes 1	2	3	4	5
1	0 0 $\boxed{4}$	98 0 $\boxed{4}$			
2		98 98 $\boxed{13}$	343 98 $\boxed{2}$		
3		98 343 $\boxed{1}$	343 343 $\boxed{9}$	705.6 343 $\boxed{1}$	
4			343 705.6 $\boxed{2}$	705.6 705.6 $\boxed{3}$	
5				705.6 970.2 $\boxed{5}$	970.2 970.2 $\boxed{8}$

TABLE 2.2.6b - RESULTS OF STATISTICAL COMPUTATIONS FOR MAY 10, 1973

ERTS-1 estimate of the areal extent of snow = χ = 508,463 acres

Estimate of the true areal extent of snow = $\hat{Y}_R$ = 483,497.47 acres

Variance of the areal extent of snow estimate = $V(\hat{Y}_R)$ = 1,288,366,549.32

Population ratio estimator = $\hat{R}$ = .9509

Total number of acres inventories = 2,009,000

Total number of image sample units inventories = N = 2050

Total number of image sample units sampled = n = 52

TABLE 2.2.7b - CONFIDENCE INTERVALS AND ALLOWABLE ERRORS FOR MAY 10, 1973

Level of Confidence	Confidence Intervals in acres	Allowable Error
99%	$412,412.25 \leq Y_R \leq 604,513.75$	19.87%
95%	$436,389.04 \leq Y_R \leq 580,536.96$	14.91%
90%	$448,305.65 \leq Y_R \leq 568,620.35$	12.44%
80%	$461,837.47 \leq Y_R \leq 555,088.53$	9.64%

TABLE 2.2.8b - CHI-SQUARE TEST FOR MAY 10, 1973 DATA

Test at 5% significance level

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

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

Test statistic under the null hypothesis:

$$\sum_{i=1}^{k}\left[\frac{(Oi-Ei)^2}{Ei}\right] - \chi^2_{k-1}; \text{ where k-1 = the degrees of freedom}$$

Class	Oi	Ei	$\frac{(Oi-Ei)^2}{Ei}$
1	8	4	4.0
2	15	18	.05
3	11	13	.3077
4	5	9	1.7777
5	13	8	3.125
		$\sum_{i=1}^{5}$ =	9.2604

= calculated value

$\chi^2_{5-1}, .05 = \chi^2_{4}, .05 = 9.49$ = table value

∴ Since the calculated value (9.2604) is less than the table value (9.49) the null hypothesis is accepted.

TABLE 2.2.8b (continued)

Class	Oi	Ei	$\frac{(Oi-Ei)^2}{Ei}$
1	8	4	4.0
2	15	18	.05
3	11	13	.3077
4&5	18	17	.0588

$$\sum_{i=1}^{4} = 4.416 = \text{calculated value}$$

$$\chi^2_{4-1}, .05 = \chi^2_{3}, .05 = 7.81 = \text{table value}$$

$\therefore$ Since the calculated value (4.416) is less than the table value (7.81), the null hypothesis is accepted.

TABLE 2.2.9b - MAY 28, 1973 ERTS-1 INTERPRETATION RESULTS (ALSO LISTING OF x_i's AND y_i's)

		Large Scale Photo Data				
		Snow Cover Classes				
		1	2	3	4	5
ERTS-1 Image Data	Snow Cover Classes 1	0 0 3	98 0 4			
	2	0 98 1	98 98 16	343 98 1		
	3		98 343 2	343 343 9	705.6 343 3	
	4			343 705.6 2	705.6 705.6 4	
	5				705.6 970.2 4	

TABLE 2.2.10b - RESULTS OF STATISTICAL COMPUTATION FOR May 28, 1973

ERTS-1 estimate of the areal extent of snow = χ = 149,539 acres

Estimate of the true areal extent of snow = $\hat{Y}_R$ = 142,944.33 acres

Variance of the areal extent of snow estimate = $V(\hat{Y}_R)$ = 1,790,996,036.02

Population ratio estimator = $\hat{R}$ = .9559

Total number of acres inventoried = 1,972,740

Total number of image sample units inventoried = N = 2013

Total number of image sample units sampled = n = 49

TABLE 2.2.11b - CONFIDENCE INTERVALS AND ALLOWABLE ERRORS FOR May 28, 1973

Level of Confidence	Confidence Intervals in acres	Allowable Error
99%	$35,994.01 \leq Y_R \leq 263,083.99$	79.43%
95%	$64,433.16 \leq Y_R \leq 234,644.84$	59.54%
90%	$78,525.77 \leq Y_R \leq 220,522.23$	49.68%
80%	$94,522.79 \leq Y_R \leq 204,555.21$	38.49%

TABLE 2.2.12b - CHI-SQUARE TEST FOR MAY 28, 1973 DATA

Test at 5% significance level

Null Hypothesis: Ho: The observed values (Oi) come from the same distribution as the expected values (Ei).

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

Test statistic under the null hypothesis:

$$\sum_{i=1}^{k} \frac{(Oi-Ei)^2}{Ei} \sim \chi^2_{k-1}$$; where k-1 = the degrees of freedom

Class	Oi	Ei	$\frac{(Oi-Ei)^2}{Ei}$
1	7	4	2.25
2	18	22	.7272
3	14	12	.3333
4	6	11	2.2727
5	4	0	0

$\sum_{i=1}^{5}$ = 5.5832 = calculated value

χ^2_{5-1}, .05 = χ^2_4, .05 = 9.49 = table value

∴ Since the calculated value (5.5832) is less than the table value (9.49), the null hypothesis is accepted.

TABLE 2.2.12b (continued)

Class	Oi	Ei	$\frac{(Oi-Ei)^2}{Ei}$
1	7	4	2.25
2	18	22	.7272
3	14	12	.3333
4&5	10	11	.0909
		$\sum_{i=1}^{4}$ =	3.4014

$\sum_{i=1}^{4} = 3.4014$ = calculated value

$\chi^2_{4-1}, .05 = \chi^2_3, .05 = 7.81$ = table value

∴ Since the calculated value (3.4014) is less than the table value (7.81), the null hypothesis is accepted.

The one improvement that by itself can substantially decrease the width of the confidence intervals (and consequently the allowable errors) is that of decreasing the sample variance. As already shown, the April 4 data had the smallest variance, the May 10 data had the next smallest and the May 28 data had the largest. The reason for this progressive increase in sample variance most likely can be attributed to the decrease in the snow pack over the three dates. The image analyst's ability to classify seems to be related to the proportion of snow cover; however the majority of the variance may not be due to the analyst, but rather to a natural state of greater snow areal extent variability among sample units over an area defined as a watershed.

The Chi-square test indicated that on all dates the experimental set-up was adequate. Substantial improvements in matching the corresponding value distributions of the large scale photography data and the ERTS-1 image data were realized by lumping snow cover classes 4 and 5. This indicates that the analyst had difficulty in separating high snow areal extent class 4 areas from class 5 areas. If the snow cover classes were to be redistributed (0-20%, 20-40%, 40-60%, 60-80%,80-100% for example) the analyst might realize an improvement in his ability to classify snow cover conditions. Provided the interpreter's ability to classify snow cover conditions did improve, then it would be expected that the sample variance for each set of interpretation results would go down, and consequently, the width of the confidence interval would decrease (as well as the allowable error, AE) given constant sample sizes and confidence levels.

2.220b <u>Snow Areal Extent Inventory Type II</u>

The method of estimating snow areal extent previously described, provided a fast, low cost, and accurate method of conducting this type of inventory. The snow areal extent inventory type II represents a refinement in which accuracy gains should offset the longer interpretation time and higher initial cost anticipated.

The type II inventory stratifies the watershed into homogeneous environmental units defined by vegetative cover, aspect, and elevation. These three factors were chosen because of their unique relationship to snow dynamics. Other parameters such as isohyet lines, slope, nearness to a meteorological baseline, etc., could also have been used but were not at this time. It is believed, but remains to be verified, that each homogeneous environmental unit defined by vegetative cover, aspect, and elevation will provide information on snow areal extent and snow-water content behavior that is unique to that particular environmental unit.

The Spanish Creek Watershed, a subunit of the larger Feather River Watershed, was chosen as the test area for this technique. Fourteen vegetation/terrain cover units were defined in an adaptation from the work of Paul Krumpe (1973). Table 2.2.13b lists these types. The watershed was divided into seven different compass aspects. The classification of the aspects that occurred in the Spanish Creek Watershed was relatively generalized. These aspects were (1) North facing slopes, (2) East facing slopes, (3) South facing slopes, (4) West facing slopes, (5) Southwest facing slopes, (6) Northeast facing slopes, and (7) level areas (both ground and water). The elevation units were delineated from 7 1/2 minute U.S.G.S. quadrangle maps and were divided into five categories: (1) 3000-4000 feet above sea level (a.s.l.), (2) 4000-5000 feet a.s.l., (3) 5000-6000 feet a.s.l., (4) 6000-7000 feet a.s.l., and (5) 7000-8000 feet a.s.l. with 500 foot elevational gains being noted in each delineation.

The vegetation/terrain units, the aspect units, and the elevational units were transformed into clear acetate maps of common scale and then were overlayed. Each unique combination of vegetation/terrain, aspect, and elevation became an environmental unit. Examples of environmental units within the watershed are the high density Mountain Mixed Conifer, northern aspect, and a 4000-5000 foot environmental type, and the impervious wildland bare ground (rock), eastern aspect, and 5000-6000 foot type (see figures 2.2.5b and 2.2.6b).

Each set of unique environmental units is plotted on acetate overlays on which the watershed boundary has been delineated. The watershed boundary provides the control for placement of these units during plotting and also for the final interpretation process. The end-product is a series of acetate maps (overlays), each clearly partitioning a unique segment of the environment with relation to snow.

As in the type I inventory, "ground truth" will again be acquired through the use of large scale aerial photography. Since we are working with 1973 data presently, some image sample units used for the testing and training procedures will have to be taken from outside of the Spanish Creek Watershed. However, it is believed that snow/environmental unit relationships will not change due to the similarity between the Spanish Creek Watershed and the Feather River Watershed. A statistical approach such as the ratio estimator may again be used and/or a new technique such as a regression estimator could be tried depending on the final sample design.

Such questions as whether the image sample units will be based on the environmental units or on some optional image sample unit size (research on which is discussed in the previous section on the Type I inventory) will have to be determined. The outcome of such a decision will have a major influence as to the statistical design used for the final estimation procedures.

2.230b Conclusions and Recommendations

Although the nature of the data acquired by the ERTS-1 satellite lends itself directly to automatic computer analysis for areal extent

TABLE 2.2.13b - VEGETATION/TERRAIN UNITS DEFINED FOR THE SPANISH CREEK WATERSHED. ADPATED FROM PAUL KRUMPE (1973).

1. Red fir, high density
2. Red fir, low density
3. Mountain Mixed Conifer, high density
4. Mountain Mixed Conifer, low density
5. Eastside Mixed Conifer, high density
6. Eastside Mixed Conifer, low density
7. Drysite (Xeric) hardwoods, high density
8. Brush, high density
9. Brush, low density
10. Bare ground, impervious, wildland
11. Bare ground, impervious, urban
12. Water
13. Meadow
14. Grassland

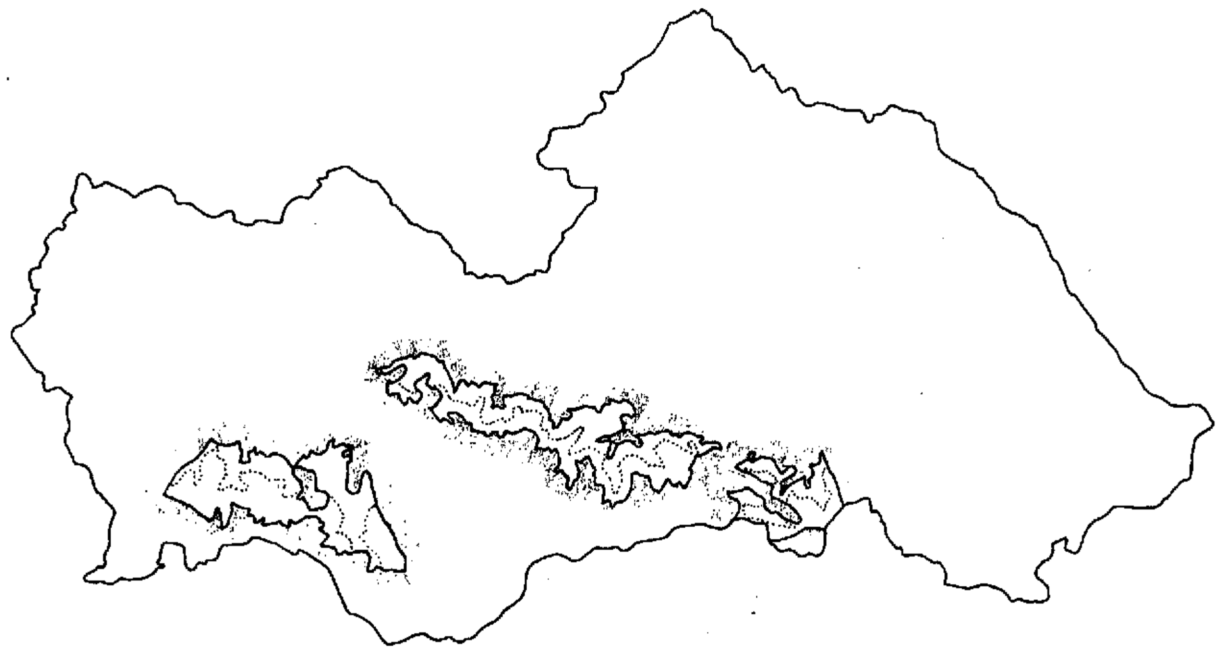

Figure 2.2.5b Outline of the Spanish Creek Watershed showing the high density mountain mixed conifer, northern aspect, 4000-5000 foot environmental unit. Dotted lines indicate the 4500 foot contour.

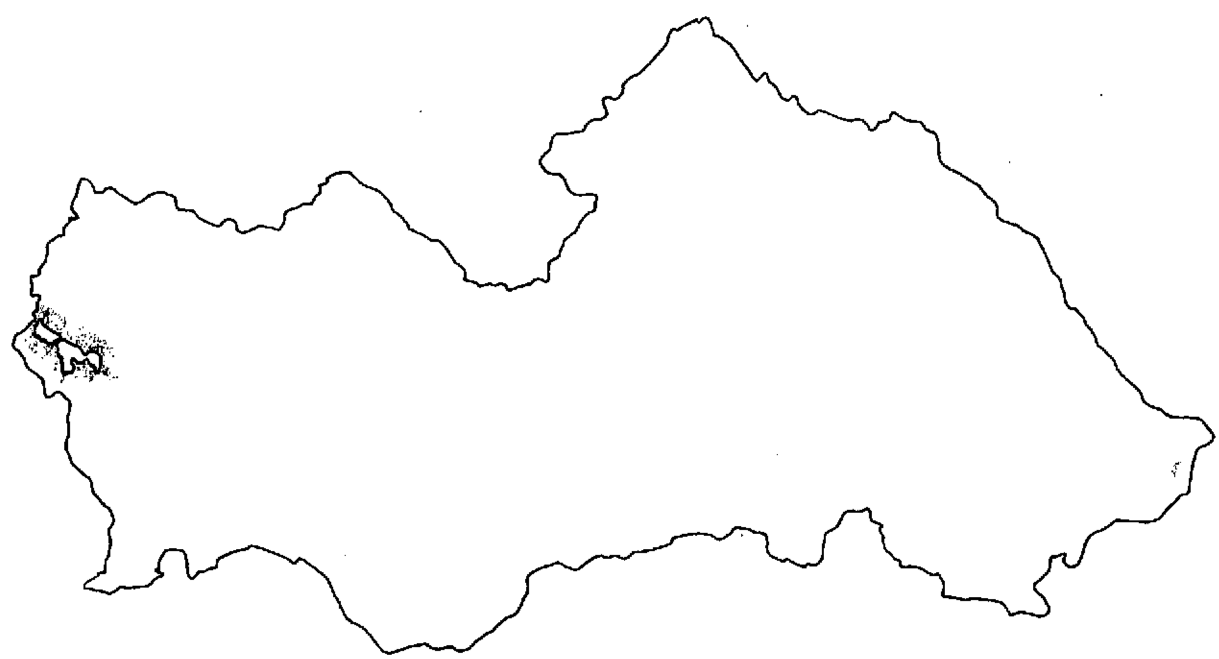

Figure 2.2.6b Outline of the Spanish Creek Watershed showing the impervious wildland bare ground eastern aspect, 5000-6000 foot environmental unit. Actual elevations within this particular environmental unit range from 5500 to 6000 feet.

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of snow estimation, research into manual techniques can be justified by comparing the two methods of operation to one another on a cost-effective basis. Research under this NASA Grant which is currently being carried out on both phases of snow areal extent estimation procedures and analyses will be conducted testing both automatic, manual, and a combination of automatic and manual on a cost-effective basis.

Besides being justifiable on this basis, continued research utilizing manual techniques can provide analyses in certain circumstances where computer classification has not been sufficiently refined. Scattered cloud cover over snowpack may present some difficulty to present computer analysis; however the human has little difficulty distinguishing the two as they appear on ERTS-1 images.

Both the type I and the type II inventory methods for areal extent of snow estimation show great promise for providing fast, economic, and accurate inventories of snowpack estent. As each is refined, such as by optimizing image sample unit sizes and snow cover class widths, estimates as to the true areal extent of snow should become more precise and should be made with greater confidence, all other factors being equal.

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2.300b SEMI-AUTOMATIC ANALYSIS OF ERTS-1 DIGITAL DATA FOR SNOW AREAL EXTENT ESTIMATION

2.310b Approach and Data Set

In order to quantify additional improvements in performance, cost-efficiency, and available information to be gained by computer analysis of image sample units (ISU's) relative to manual methods, a semi-automatic analysis of ERTS-1 digital data for snow areal extent estimation is being performed. This analysis will also provide the ERTS digital base for eventual first sample stage PSU estimates of snow water content and evapotranpiration.

The manual procedure to be used for comparison will be that described in section 2.211b. Thus computer classified image sample unit results using a parametric classifier will be double sampled in the same manner as for the human interpreter approach. A comparison will then be made of the relative precision, cost and timeliness of the two methods.

Snow season dates selected for analysis include April 4, May 10, and May 28, 1973. These are the same dates analyzed in the manual technique and were selected so as to allow the most direct comparison between methods possible. In addition, one cloud free summer ERTS-1 overpass has been selected, that of August 13, 1972, which will provide a clear recording of vegetation/terrain relationships. This summer date will be used to generate spectral mean and variance statistics for the specific vegetation/terrain parameters found to be necessary for semi-automatic snow areal extent estimation. The manual technique utilized a summer date for similar purposes.

A subunit of the Feather River Basin, the Spanish Creek Watershed, has been selected as the location for initial evaluation of the computer snow classification technique. This smaller watershed provides a good representation of the vegetation/terrain conditions of the larger basin. It therefore provides an opportunity for more time and cost-efficient intensive analysis of the semi-automatic approach. Manual areal extent estimates by image sample unit have been summarized for the Spanish Creek Watershed for comparative purposes.

2.320b Procedure for Semi-Automatic Snow Areal Extent Estimation

ERTS-1 frame digital data for dates of interest are divided into four quadrants. After those quadrants covering the specified basin are selected, the human-computer processing steps proceed as follows at the Remote Sensing Research Program.

The first step involves data reformatting for each of the quadrants selected on the ERTS-1 raw digital tapes. The reformatting simply transforms the ERTS-1 data into a form acceptable to the data processing system. Before the actual reformatting procedure begins, the tapes are checked for calibration with respect to the spectral information (in the form of reflectance histograms) gathered by each of the six sensors which simultaneously acquire data in each band. Means of spectral response for each sensor histogram are compared. The sensors are readjusted if their means do not fall within one spectral level of all other sensor means for the same band.

After the applicable quadrants of the ERTS-1 raw tapes on all dates have been reformatted and recalibrated, the adjacent quadrants on a given date are combined on one tape, this new tape being designated a test tape. The test tape is then used to form color enhancements of selected areas which are displayed on a video monitor. The area covered, the location of the area, the color balance, and informational content of the area displayed can all be controlled by the operator. A gridding system can be introduced to the video display to facilitate the precise location of control point features and training field locations for snow-environmental units of interest.

In order to accurately analyze the ERTS multidate information, the test tapes for given dates must be calibrated to each other in an x,y coordinate system. In other words, the digital information on each tape must be aligned so that all features on one tape overlay the same features on the next date. In this way information on a point-by-point basis may be compared foranalysis purposes. This is done by selecting a given number of control points on each date that will be visible on all other dates. Then, using a least squares regression fit, the test tapes may be mathematically aligned with respect to each other.

Control points such as bends in river channels, points of lakes, and other conspicuous features are chosen so that they are visible on all dates. The selected points are displayed for each date on the video color monitor, using the grid command to allow accurate x and y location, and photographed using Polacolor Type 108 film. Use of this film type allows the establishment of a permanent record of the control point with respect to its own coordinate system. Thus the ERTS absolute coordinates of the points may be established and checked later.

Snow cover class vegetation/terrain environmental units defined in the manual technique are located on the digital data video presentation and photographed in a manner similar to control points. The snow-environmental units provide training statistics for automatic classification of snow presence on a pixel by pixel basis. This classification will proceed on a multidate ERTS data set consisting of a summer date and the snow season date of interest. It is possible that two summer dates may be used to increase accuracy of environmental unit definition.

After computer classification, the pixels are grouped automatically according to user specifications into image sample units. These sample units may then be subsampled with medium altitude photography as in the case of the manual technique. Resulting ratio or regression estimates of snow areal extent for the basin or sub-basin of interest may then be formulated.

Resulting computer classified image sample unit data may also be combined for several dates, as described in Chapter 6, to estimate snow water content. Image sample units may then be subsampled by ground measurements to provide stratified basin estimates of snow water content.

The computer classified output will in addition be used to form PSU's to allow first stage estimates of water loss as described in section 2.110b. These results can be used in the multistage, multiphase sampling design proposed there.

2.400b IMPERVIOUS SURFACE-PARAMETER ESTIMATION

2.410b Justification and Definitions

An important aspect of watershed management is the estimation of the magnitude and timing of runoff after a basin has experienced a hydrometeor (precipitation input). One parameter that has a significant impact on this estimation is the amount of impervious surface area within the watershed. An impervious surface can be defined as an area which exhibits almost instantaneous runoff upon the receipt of precipitation in the form of water. If the surface is adjacent to an established water channel, the runoff is immediately conducted to the channel system and is, therefore, delivered to the appropriate gauging station more quickly than water falling on pervious areas which act as delay mechanisms. Precipitation falling on pervious (permeable) areas must percolate through the soil and satify given soil moisture requirements before runoff can be released to the channel system. Pervious surfaces, in that they delay delivery of precipitation to the channel system, tend to smooth out and lower maximum flow peaks on the hydrograph of a channel system. Impervious surfaces, in contrast, tend to sharpen and amplify the maximum flow peaks. Thus in trying to assess the ability of storage facilities to accept the runoff from a given amount of precipitation within a given period of time, the amount of impervious surface adjacent to stream channels within a basin is an important parameter to consider and evaluate.

There are two general types of impervious surfaces that must be considered--permanently impervious surfaces and temporarily impervious surfaces. Permanently impervious surfaces experience direct runoff almost immediately upon the beginning of the receipt of precipitation. Such surfaces include water surfaces such as lakes, streams, bogs, bare rock surfaces which do not have any significant surficial soil accumulations, paved areas such as roads, and compacted soil areas.

Temporarily impervious surfaces do not experience direct runoff until a given moisture storage capacity has been exceeded. After this point, any additional input of water flows away as direct runoff. Such surfaces include any saturated soils (those which are incapable of absorbing any further amounts of water within their structure) as found in wet meadow and riparian vegetation areas, or areas where the precipitation rate exceeds the infiltration rate for a particular soil. In the latter case, the excess which flows away as a direct runoff is the difference between the precipitation rate and the infiltration rate.

Area estimates for watershed impervious surfaces and temporarily impervious surfaces are two drivers in the California Federal-State River Forecasting Center (RFC) Sacramento hydrologic model. The RFC model flood peak magnitude and timing predictions may be particularly sensitive to these two parameters during short time intervals of high watershed precipitation intensity. Presently these parameters are generally set through analysis procedures, except stream hydrograph analysis. Thus a cost-effective means of utilizing remote sensing techniques to accurately estimate the watershed area of impervious and temporarily impervious surfaces may provide an especially valuable check on current estimates of these parameters.

2.420b Sample Design

The approach to estimation of permanently impervious and temporarily impervious surface areas (ISA's) utilizing remote sensing data is presently proposed in terms of two procedures. The first procedure (sample design I) uses high altitude, 1:120,000 scale photography to produce these estimates. Effective areas[1] on overlapping photographs of this kind for the watershed of interest are stratified into units of relative impervious surface proportion homogeneity. Within these strata, sample points are examined for presence of impervious surfaces. A subset of these are sampled again (i.e. double-sampled) on more resolved information to calibrate the high flight estimate.

A sampling technique as opposed to a delineation technique for ISA estimation on high altitude photography is proposed due to the following reason. Contiguous areas of impervious surfaces can be relatively small when imaged on high altitude, 1:120,000 scale photography. While the original scale of the photography is sufficient for identification, it is not for annotation. Thus, to map the boundaries of these areas so that their acreage can be determined is a difficult and time consuming job. Consequently the suggested point sampling technique has been proposed to generate a percentage estimate of the impervious surface for the watershed of interest.

The second estimation procedure (sample design II) involves the multistage, multiphase sampling design described in section 2.110b for water loss estimation. In this scheme, estimates of permanently and temporarily impervious surface areas can be made from automatically classified ERTS digital data. These estimates can be grouped by primary sampling units. Subsampling of these sampling units as illustrated in Figure 2.10b, should allow refined estimates of ISA.

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1. By definition, for any aerial photograph that is one of an overlapping series, the "effective area" is that central part of the photograph delineated by the bisectors of overlaps with the adjacent photographs.

2.421b Stratification Strategy

The first step in either procedure is to stratify the watershed into relatively homogeneous geologic-geomorphic units. This can be quickly done by transferring the boundaries of the units from geologic maps of the area to the high altitude photography in the case of sample design I. These boundaries may be digitized for automatic overlay on ERTS digital data for sample design II. It may be desirable to consolidate some of the geologic units if they respond similarly to processes of weathering and erosion. The reason for stratifying on a geological-geomorphological basis is that different lithologic (rock) types give rise to different proportions of impervious surfaces and thus to different variability values for impervious surface area estimates. By sampling strata with relatively similar impervious surface area proportions, the variance and therefore precision of the area estimate can be controlled.

The phenomenon of different impervious surface area proportions among geologic-geomorphic strata is due to the fact that different rock types respond differently to weathering and erosional processes and thus develop different characteristic terrain types. These terrain categories in turn may or may not foster conditions which would tend to develop one of the kinds of impervious surfaces. For example serpentenitic areas tend to develop soils of low permeability due to their mineralogy. These areas support a sparse vegetation cover in a rock matrix thus allowing their identification on imagery. Also massive granitic areas weather along rectalinear joints and fractures such that these terrains often display numerous domal features. Along the joints and fractures which occupy the low areas between the domal highs, drainage rates may be low enough to allow development of saturated soil conditions. Such effectively water impervious saturated areas can be relatively permanent for many months during the spring and summer runoff periods. Glaciated areas (especially within granitic terrains) may have numerous small tarn or cirque lakes, as well as a high proportion of other water-impervious surfaces such as exposed bare rock. Thus the proportion of an area occupied by impervious surfaces is somewhat dependent on its lithologic type and on the landscape that develops within that type. By stratifying on this basis, the variance of the point sample is lowered and so the precision of the area estimate is improved.

The geologic-geomorphic units that are pertinent within the Spanish Creek sub-basin (Bucks Lake-American Valley Area) are:

Granitic terrain
Metamorphic terrain (includes both Paleozoic and Mesazoic metasedimentaries and metavolcanics)
Serpentinetic terrain
Tertiary volcanics
(Eocene gravels)
Quaternary alluvium
Pleistocene glacial depositions
Water surfaces

Water surfaces (lakes) smaller than 150 acres should be excluded from individual strata in order to control estimate variance. The area of these larger water bodies is put into a separate "water-only" watershed stratum defined as a 100 percent impervious surface. For efficient ISA estimation on high flight imagery, the minimum geologic-geomorphic area to be delineated, other than water bodies, should be no smaller than one square mile.

2.422b Sampling Method for High Flight Imagery

After the stratification system has been developed for an area, the point sampling grid can then be developed. The density of the grid in a given stratum is set so as to give a watershed or sub-basin estimate of impervious surfaces adjacent to stream channels with a given precision (Cochran 1963 and Thomas 1974). Resulting grids are then overlaid randomly on the effective area of the photography for each stratum. The area falling beneath each grid point is then identified as to whether it is:

water surface bare rock surface paved road dirt road compacted soil area	permanently impervious surfaces

or

riparian hardwood area wet meadow area dry meadow area	temporarily impervious surfaces or potentially impervious surfaces

or

other - (pervious) surfaces

and whether it is adjacent to a channel system or not.

The permanently impervious surface conditions listed above are easily identified on 1:120,000 scale color infrared photography. As they are all non-vegetated conditions, the surface below a grid point can be identified relatively easily unless it is in shadow. The temporarily impervious surfaces usually have some form of vegetative covering whether it be trees and brush or grasses and forbs. Many riparian hardwood areas occur as lineal features along small channels. These riparian stringers appear as bright red on color infrared photography due to the relatively high near-infrared reflectance of such vegetation. There is possible confusion of riparian hardwood types with dry site hardwood types since the dry site hardwoods also have a high infrared reflectance. However, by taking into account the topographic location of the hardwood vegetation, one can infer within certain probabilities whether the site is a riparian site or a dry site.

The wetness or dryness of a meadow area can be evaluated on the color infrared photography by the amount of near-infrared reflectance returned. The bright red color of moist meadows can be observed to decrease in some of the meadows as the summer season progresses and the meadows dry out. As the meadow's vegetation dries, the near-infrared reflectance decreases.

Since there is a good amount of snow that falls within the area during the winter months, the residual snowpack often prevents impervious surface photo interpretation well into June. Thus for evaluating impervious surface areas, it is necessary to obtain photography flown in the summer months (mid-June through late September). On imagery evaluated to date, September color-infrared photography appears to offer the best contrast between riparian hardwood vegetation and the surrounding conifers. This could possibly be due to a real decrease in the near-infrared reflectance of conifers relative to earlier values in the summer. Such reflectance decreases may result from partial collapse of the normally turgid and highly infrared-reflective spongy leaf mesophyll, caused by lower available soil mositure late in the summer season. However, a definitive statement about the higher contrast of the September imagery cannot be made due to photographic processing variability among different sets of color infrared photography.

After interpretation is completed for grid points in all strata for the watershed areas of interest, a sample of grid points in each stratum is examined on large scale photography or by ground visitation. For these double sampled points the actual presence or absence of an impervious surface area is determined from the examination of the large scale imagery or from ground data. These "ground truthed" points then allow a calibration of the ISA estimate made on high flight data according to area estimation formulas described in Cochran (1963) and Thomas (1974). ISA estimates are summarized by impervious and temporarily impervious surface types adjacent to stream channels.

2.423b Sampling Method Utilizing ERTS Data

Impervious surface area estimation performed in accordance with the multistage, multiphase sampling design for water loss estimation given in Figure 2.1.1b may proceed after geologic-geomorphic stratification is completed. Computer classification training statistics are generated for the impervious and pervious surfaces given in section 2.422b. These statistics should be specific to a clear, late summer ERTS overpass date, or a combination of several clear, snow-free dates. Computer training fields for these surfaces are most efficiently located on video displays of ERTS scenes by manually referring to known locations on highflight imagery.

After automatic classification of ERTS digital data has been accomplished, pixels are grouped into primary sampling units (PSU's) following the discussion of section 2.110b. These PSU's are then subsampled with photo and ground secondary sampling units (SSU's) as discussed there. In fact, these SSU's may be the same ones used for snow water content or evapotranspiration estimation. Estimates of impervious surface area would then be made for each geologic-geomorphic stratum according to the PSU's and associated SSU's falling in each. Strata estimates of ISA would be grouped to give watershed or sub-watershed estimates of both impervious and temporarily impervious surface areas. Weighting coefficients to quantify the distance of impervious surface areas in SSU's from stream channels will have to be developed in order to make the final ISU estimates truly consistent with RFC hydrologic model impervious and temporarily impervious surface input requirements.

2.430b Future Work for Impervious Surface Estimation

Tests and further development of the proposed impervious surface estimation procedures should be conducted coincident with the development of the water loss and hydrologic parameter estimation procedures described elsewhere in this chapter. Further work regarding impervious surface evaluation and estimation will necessitate additional field work next summer to better define certain vegetation type-site location associations.

2.500b DEVELOPMENT OF A METHODOLOGY FOR EVAPOTRANSPIRATION ESTIMATION

2.510b Introduction

2.511b Justification

Water vapor is the principal participant in the many energy exchanges taking place in the atmosphere. These energy exchanges are responsible for the weather phenomena which serve as important links connecting the various phases of the hydrological cycle.

Quantification of the water flux mechanisms, viz. evaporation and evapotranspiration (which includes active plant water loss), is of importance in many scientific fields. They form one of the main components of the water budget, knowledge of which is indispensable for the solution of numerous water management problems. Reliable evaporation data are required for planning, designing and operating reservoirs, ponds, shipping canals, and irrigation and drainage systems. Evapotranspiration is especially important in arid zones where water must be used in the most efficient way possible. In addition, knowledge of the water requirement of crops depends partly on an accurate determination of the loss of water by evapotranspiration from cultivated fields.

Evapotranspiration, utilized here to represent both the evaporation and evapotranspiration processes, is the major water loss mechanism for watersheds throughout the world. Wherever there is vegetation or inorganic surfaces with water capable of being evaporated, water vapor loss from usable water yield will occur. At present only a thin network of transpiration measuring devices throughout the world exists (WMO, 1966). Significant difficulties are involved in extrapolating these data over watersheds with varying environmental conditions and in translating evaporation values to evapotranspiration values. No current operational evapotranspiration estimation system exists.

In view of the overriding importance of evapotranspiration to accurate basin water yield estimation and to other water consumptive use determinations described above, any cost-effective, precise evapotranspiration estimation system would be of significant utility to a water manager. Remote sensing techniques may provide the key to such a system's data requirements. Its timely, spatial, and relatively inexpensive nature when combined with other conventional meteorological data can potentially give rise to accurate, location-specific estimates of evapotranspiration.

Moreover, current water yield estimation procedures such as the California River Forecasting Center model can incorporate evapotranspiration estimates. It is therefore the purpose of this section to lay the foundation for a remote sensing-aided methodology for accurate and efficient watershed evapotranspiration estimation.

2.512b Background and General Definitions

The technology of water resources development, distribution, control, and management for the production of food and fiber has advanced significantly during the past quarter century. Similarly, the technology of measurements and determination of evaporative flux from land surfaces has made great strides since the studies of evaporation and energy balance by Bowen in the 1920's, and the aerodynamic studies of Thornthwaite and Holtzman in the 1930's.

Evaporation may be defined as the transfer of water vapor from a non-vegetative surface on the earth into the atmosphere. Evapotranspiration is the combined evaporation from all surfaces and the transpiration of plants. Except for the omission of a negligible amount of water used in the metabolic activities, evapotranspiration is the same as the "consumptive use" of the plants. The fact that the rate of evapotranspiration from a partially wet surface is greatly affected by the nature of the ground leads to the concept of potential evapotranspiration. Penman (1956) defines potential evapotranspiration as "the amount of water transpired in unit time by a short green crop, completely shading the ground, of uniform height and never short in water." Recently, Pruitt (1960) designated the term "potential maximum evapotranspiration" to describe the situation when advected (horizontal movement of energy through the atmosphere surrounding the plant) energy is present. This removes any confusion on Penman's definition. Thus, one should not expect an empirical formula for potential evapotranspiration derived in a humid climate to be adequate for estimating the potential maximum evapotranspiration in an arid climate. The other term that must be defined is actual evapotranspiration. Actual evapotranspiration is the actual amount of water vapor transferred to the atmosphere. In addition to existing meteorological conditions, actual evapotranspiration also depends on the availability of water to meet the atmospheric demand and, in the case of vegetation, its ability to extract moisture from the soil.

Data on evapotranspiration are useful for estimating irrigation requirements, rainfall disposition, safe yield of ground water basins, water yields from mountain watersheds, and stream flow depletion in river basins.

In water resource investigations and water right controversies, engineers are frequently called upon to make, within a limited time, estimates of probable past, present and future consumptive use, irrigation requirements, and stream depletions in river basins. Currently determining actual or potential water losses from vegetation is difficult because of the complexity of the factors affecting evapotranspiration and the many problems involved in their measurement. Relatively accurate, timely, and cost-effective evapotranspiration estimates by a remote sensing-aided system could therefore provide needed and important data to engineers, land managers, and planners.

One objective of the current NASA Grant water supply study in the Feather River Watershed is to develop a general evapotranspiration estimation procedure utilizing remote sensing data. This method will be part of the larger water loss estimation procedure, described in section 2.100b, designed to produce more precise estimates of water yield. As such, data collection and processing will proceed in a cost efficiently integrated manner with other water loss variable estimation (e.g. snow water content determination).

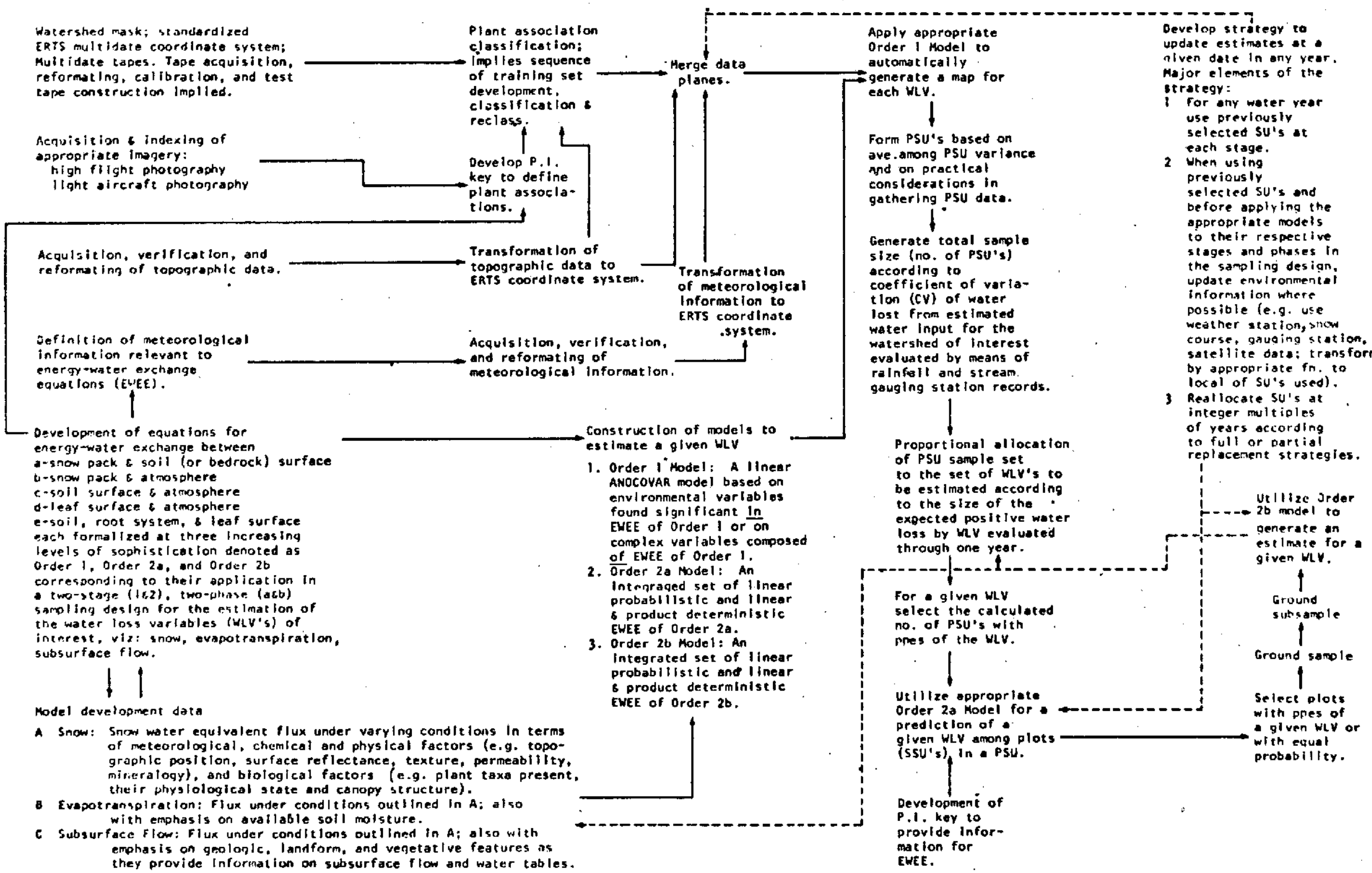
Similar to the case of snow areal extent methodology development, it will be efficient for initial tests of the technique to be performed on the Spanish Creek Watershed. Later application of the estimation procedure to the entire Feather River Watershed is to be considered later.

2.520b General Approach

2.521b Basic Sample Design and Corresponding Levels of Evapotranspiration Model Sophistication

A multistage, multiphase sample design will be utilized to estimate watershed evapotranspiration water losses. The general discussion of this approach was given in section 2.100b. Figure 2.5.1b repeats the outline of the discussion given there.

Figure 2.5.1b Hydrologic Modelling: Quantification of Time Specific Water Runoff Loss to Snow, Evapotranspiration, and Subsurface Flow



Basically there are three increasingly resolved levels of information each of which is sampled. The first level is composed of satellite and topographic data. Vegetation, terrain, and meteorological types of information are defined for a convenient base resolution element, in this case the ERTS pixel. Based on the information associated with each base resolution element an estimate of evapotranspiration is made for that location. The appropriate evapotranspiration equation, defined as an Order 1 model in Figure 2.5.1b, must be able to perform adequately on this "least resolved" information available from the first data level. Adequate performance is defined as a generation of evapotranspiration estimates strongly correlated to actual ground measured or ground-based estimates of evapotranspiration.

After an estimate of evapotranspiration has been made for each basin resolution element, the resolution elements (here ERTS pixels) are grouped into primary sampling units (PSU's). The size and shape of these PSU's will be selected to minimize watershed evapotranspiration estimate variance within cost and practical subsampling constraints. A further aggregation of sampling units into various strata will then be performed. These strata may define sub-basin reporting units within the entire watershed and/or may define subunits of relatively homogeneous expected evapotranspiration rates designed to further reduce the estimate variance.

Based upon the variability among PSU's, a sample of these units will be selected within each stratum for further sampling. Selection may be with probability proportional to estimated size of evapotranspiration within given PSU's. The result in this case would be to direct the subsampling to areas of higher water loss. Alternatively, PSU selection could be with equal probability in the case where subsampled information would be used to estimate other water loss variables (e.g. snow water content) as well.

This subsampling will involve a series of large scale photographic plots, or secondary sampling units (SSU's), within each selected PSU. The photographic SSU data along with nearby snow course and ground station calibrated meteorological satellite data will provide the second level of information resolution.

At the SSU stage of the sampling design, much more specific information concerning local vegetation canopy, soil, and local climatic conditions will be available as opposed to that obtainable from information at level one. Thus evapotranspiration models employing more data types and more refined data will be used to generate evapotranspiration estimates for each PSU. These equations are denoted as Order 2a models in Figure 2.5.1b. Estimates at this stage will, however, be more expensive on a unit area basis than for first stage (PSU) evapotranspiration estimates.

A subsample of the SSU's within a given PSU will then be performed. This sample will be based on the within-PSU second stage sample unit variance and selected precision constraints. Either probability proportional to "size of the evapotranspiration estimate" or equal probability selection will be utilized for this phase of the sampling design.

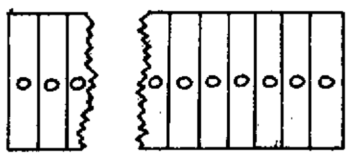
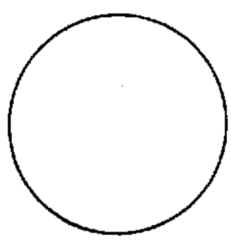
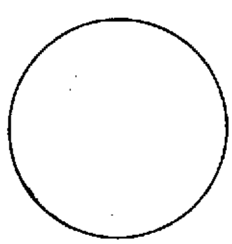
For each of the SSU's selected, detailed ground measurements will be made of vegetation canopy geometry, color, etc. as well as of soil and litter-organic debris conditions. The detailed data from this third level of information will then drive very sophisticated Order 2b evapotranspiration prediction models. Since estimates of evapotranspiration will be for the entire ground area of the SSU photo plot, this third stage unit (TSU) will actually comprise a double sample of the SSU's. Stated another way, the ground sample will comprise the second phase of a double sample in which the photo plots are considered the first phase. Data collection for information in level 3 will be the most expensive of all levels.

Figure 2.5.2b summarizes the sampling concepts and terminology in the preceding discussion. Note that the photo SSU is simultaneously the second sample stage and the first sample phase in this basic two stage, two phase sample design. Information levels 1, 2, and 3 specify the data plane at which a sampling operation takes place. Obtaining and processing information at increasingly higher information level numbers is exponentially more costly. Thus a smaller and smaller watershed area is sampled as the information level number increases.

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

Before moving further in this discussion, an additional advantage of the double sample between ground and photo SSU's should be noted. This advantage consists of the ability to calibrate vegetation and soil surface quantifications made on aerial photography with similar measurements made on the ground. Thus statistical relationships can be developed between ground and photo environment measurements. Importantly, these relationships may also be employed with SSU's where no ground data are available. Hence more accurate information is available from photo interpretation and thus more reliable evapotranspiration estimates are possible based on level 2 information. The same double sampling technique, sometimes used in combination with multistage sampling, can be employed with ground plots to efficiently describe very detailed canopy and soil characteristics. The information types and procedures for data collection utilized in the current year's NASA Grant water supply work

FIGURE 2.5.2b - EVAPOTRANSPIRATION SAMPLE DESIGN TERMINOLOGY

Information Level	Sample Unit	Sample Design Level	Comments
1	PSU	Stage 1	All PSU's in watershed have evapotranspiration estimates made based on a summation of evapotranspiration estimates for ERTS resolution elements occupying each PSU. A sample of the PSU's is selected for further sampling
		Multistage portion of sample design	
2	Photo SSU	Stage II	All SSU's within a selected PSU have evapotranspiration estimates made based on surface characteristics interpreted from the photography
		Phase I	
		Multiphase or double sample portion of sample design	
3	Ground SSU	Phase 2	Ground measurements resulting in ground-based evapotranspiration estimates are made for a sample of the photo SSU's
			

on the Feather River Watershed are given in Appendices III and IV for ground and SSU photo plots, respectively.

2.522b Other Models Important in the Evapotranspiration Estimation Process

In addition to (a) the information calibration models, (b) the model combining PSU and SSU estimates into watershed-wide evapotranspiration estimates, and (c) the models used to generate evapotranspiration estimates at the three levels of information, two other necessary modeling and estimation approaches should be described. The first of these is an equation set that is necessary to differentially segregate information obtained at resolution sizes spatially larger than the base resolution element sizes. An important example would be transforming data from a NOAA meteorological pixel, approximately 100 ERTS pixels square, into information specific to each of the corresponding ERTS pixels. This transformation process would involve two equation types. One would be a microclimatic function driven by topographic data, associated air flow characteristics, and ERTS results for vegetation/terrain types for individual pixels. This function would spatially define canopy-top meteorological values for each ERTS resolution element. The second equation would be a reltionship, based on a double sampling technique, calibrating estimated meteorological data for ERTS pixels with corresponding data from ground meteorological stations occupying those resolution elements. Use of the calibration equation for ERTS pixels not having ground data would then be possible.

The second basic model not yet discussed involves a set of algorithms to distribute the canopy-top meteorological input derived as just described, vertically through the plant canopy. Thus a set of temperature and humidity profiles would be generated for the SSU photo and ground plot forest canopies. These micrometeorological profiles would allow the most efficient operation of the Order 2a and 2b evapotranspiration models. Each profile generating equation would be based on a number of plant geometry, soil, and topographic variables obtained from photo and field measurements.

2.523b Real-Time Evapotranspiration Estimates from the Sampling Framework

Depending on the use of water yield information, estimates of basin evapotranspiration may be needed on a daily, weekly, or monthly basis. In many cases, it would be extremely costly and perhaps physically impossible to reselect and reallocate sample units for each estimate reporting time. Hence a method allowing the use of previously selected sample units to generate evapotranspiration estimates must be employed.

The proposed procedure is as follows. The same photo SSU's, corresponding ground data, and associated photo-ground relationships are utilized repeatedly for a given period. The only changes in these data would be assumed to actual sample-obtained corrections for seasonal change in vegetation canopy or surface characteristics. Canopy-top meteorological data would be obtained by real-time spatial transformations of ground meteorological station, snow course-sensor, and meteorological satellite information. Meteorological profiling functions would then distribute the value of these parameters through the plant canopy. Real-time evapotranspiration estimates for evapotranspiration models operating at information levels 2 and 3 would then be made. Similar meteorological updating of previously obtained ERTS and topographic information would provide current evapotranspiration estimates from level 1 information. Evapotranspiration estimates for the entire watershed would then be obtained by the expansion process previously described. Primary and secondary sampling unit weights used in the "probability proportional to estimated size" multistage design would then be a function of the recalculated relative estimated evapotranspiration for each sampling unit.

Selected PSU's and SSU's would be replaced on a partial replacement basis at integer multiples of years. This would provide a cost-effective procedure to reallocate sample units and at the same time account for more situations and thus variability in watershed evapotranspiration.

2.524b Factors Affecting Evapotranspiration

Many factors operate singly or in combination to influence evapotranspiration. Their effects are not necessarily constant, but the factors may differ with locality, and water consumption may fluctuate from year to year. Some effects involve the human factor; others are related to the natural influences of the environment and to the growth characteristics of the plants.

The more important of the natural influences are climate, water supply, soils, and topography. The climatic factors that particularly affect consumptive use are temperature, solar radiation, precipitation, humidity, wind movement, length of growing season, latitude and sunlight. Most of these parameters then have the potential of being sensed remotely, and these data can be deduced from satellites equipped with suitable sensors.

Another factor which affects evapotranspiration is spatial variation. Factors determining spatial variation may be classified into energy supply and available moisture supply. Energy supply is governed by radiant energy, advected energy, stored heat, and wind turbulence. Available mositure supply is governed by areal rainfall distribution, runoff characteristics, and plant and soil characteristics.

The impact of the above factors on evapotranspiration is discussed in sections 2.530b and 2.540b and in detail in Appendices I and II. It is appropriate here, however, to summarize the general factors affecting evapotranspiration. Thus the factors to be included in the development of a complete formula for evapotranspiration should include consideration of the following:

1. Climatic variables
    a. radiation
    b. air temperature
    c. humidity
    d. wind movement
    e. precipitation
        (1) snow
        (2) rain
        (3) dew
        (4) fog drip
    f. evaporation
        (1) land areas
        (2) water surfaces
    g. transpiration

2. Physical variables
    a. latitude and longitude
    b. elevation
    c. geological characteristics

3. Soil variables
    a. soil type
    b. permeability
    c. transmissibility
    d. homogeneity
    e. composition
        (1) depth
        (2) friability
        (3) humus
        (4) litter

4. Hydrologic variables
    a. surface water
        (1) direct flow
        (2) storage supplies
        (3) water quality
        (4) entrained sediments
        (5) suspended sediments
        (6) temperature
    b. ground water
        (1) height of water table
        (2) quantity
        (3) quality
        (4) sediments
        (5) temperature
        (6) availability
        (7) transmissibility
        (8) recharge aspects

5. Ground cover variables
    a. natural vegetation
        (1) areal extension
        (2) developmental stage
        (3) canopy taxon composition
        (4) canopy geometry

b. crop types
   (1) areal density of plants
   (2) vertical density of plants
   (3) growing season
   (4) cultivation practices
   (5) irrigation practices
   (6) drainage
   (7) availability of water supply
      (a) amounts and timing

6. Management variables
   a. watershed management
   b. agricultural management

2.525b Available Data

Sources of data include the entire spectrum of environmental data gathering programs and information banks currently operating. Satellite information sources include ERTS and NOAA, the latter being an operational meteorological satellite administered by the National Environmental Satellite System of the National Oceanic and Atmospheric Administration (NOAA). The primary photographic data base consists of large to medium scale photography obtained by the U.C. Remote Sensing Research Program (RSRP). Supplementary image data includes that available from public and private imagery libraries, particularly medium to small scale hardcopy data available through EROS, and Federal, State, and local land management and planning organizations. Ground data are obtained through RSRP group plot sampling, U.S. Geological Survey topographic quadrangles, state and federal meteorological stations, state snow course and snow sensor systems, and the literature.

General information derivable from the above sources presently seems to be adequate to operate specified evapotranspiration estimation models at all three information resolution levels. Data types required for specific models are discussed in section 2.540b. Table 2.5.1b summarizes information sources, derivable data, fetch rates, and remote sensing-aided system information level applications. Appendices III and IV give detailed initial data collection procedures for ground SSU and photo SSU plots, respectively. Expanded characterizations of data input types, quantity, and error rates will be given when documentation on implementation results for specific evapotranspiration models is available.

Data types eventually recommended for use within the remote sensing-aided evapotranspiration estimation system must be available to varying degrees throughout many regions of the world in order to maximize the utility of the proposed technique. In addition they must be cost-effectively obtained, ideally in the context of other data application programs, at fetch-rates utilizable in evapotranspiration models.

TABLE 2.5.1b - WATER LOSS ESTIMATION DATA TYPES

Information Source	Derivable Data	Highest Fetch Rates	Remote Sensing-Aided Evapotranspiration System Information Level of Application*
ERTS (hardcopy and digital data)	1. Vegetation types 2. Terrain types 3. Snow types	Every 18 days	1
NOAA (hardcopy and digital data)	1. Canopy-top temperature 2. Snow surface temperature 3. Cloud-top temperature correlated to precipitation 4. Generalized snow presence data	Twice Daily, 9-10 am and pm LST	1,2,3
Large-medium scale photography	1. Vegetation canopy composition and spatial configuration 2. Ground surface zone characteristics	1 to several times yearly	2
Supplemental Imagery	1. Optional additional canopy and temperature quantification for large area energy flow modeling	multiyear to several times yearly	2,3
Ground Plot Data	1. Canopy geometry 2. Ground surface zone characteristics	multiyear	3
Topographic Data (USGS quadrangles or stereo planigraph output)	1. Elevations	once	1,2,3
Ground Meteorological Station data			
a. National climatic data station network (Includes federal, state, and local stations)	1. Maximum, minimum average temperature 2. Precipitation data (solid and liquid) 3. Wind direction and wind travel/day 4. Cloud cover percentages 5. Evaporation pan data 6. Total incoming solar radiation	hourly to once daily	1,2,3

TABLE 2.5.1b (continued)

Information Source	Derivable Data	Highest Fetch Rates	Remote Sensing-Aided Evapotranspiration System Information Leve of Application*
b. Wildland fire danger rating station network (U.S. Forest Service, U.S. Bureau of Land Management, State Wildland Fire Control Organizations)	1) to 5) above plus 6. Relative humidity 7. Fuel moisture	2 hours to daily	1,2,3
Snow courses and automatic snow sensors	1. Snow depth 2. Snow density 3. Snow water content	Courses: monthly during season Sensors: minutes	2,3
Stream gaging stations	1. Stream flow volume 2. Water yield data	Hourly to Daily	1,2,3
Literature	1. Albedo 2. Energy-water exchange data		1,2,3

* Legend: 1 = information level 1: ERTS level of information resolution

2 = information level 2: large scale photograph level of resolution

3 = information level 3: ground level of information resolution

2.530b Description and Brief Evaluation of Current Models for Evapotranspiration Estimation

Planning for the optimum utilization of available water supplies involves consumptive use of water as its basic precept for the future development of any area, whether it be for irrigation, flood control, power production, municipal use, recreational use, or for multiple purposes.

A large number of methods have been used to estimate evapotranspiration. In applying these methods it is usually necessary to make assumptions with respect to at least one of the variables. It is important that these assumptions are not overlooked, particularly when methods are being transferred from one watershed or field of investigation to another. The accuracy with which each term in the equation can be evaluated is another important consideration; this varies from one method to another.

A very brief review of the main methods will be discussed in this section; a more complete discussion of the methods can be found in Appendices I and II. This description will provide the baseline against which to judge the applicability of each model type to a remote sensing-aided evapotranspiration system in general and also the applicability of each to the three levels of information resolution within that system, specifically.

2.531b Water Balance

This method is used for both terrestrial and water surface evaporation measurement. It is based on a hydrological equation, which is usually considered on a large scale or on a catchment basin basis. In this method water gain (precipitation, stream input) balances water loss (stream flow, evapotranspiration, water in solid form, subsurface storage) and by knowing the ways that water is lost evapotranspiration can then be measured or estimated.

The primary use of this model in the remote sensing-aided system will be to provide an equation of estimated water input versus loss on a watershed basis. The difference will represent estimated water yield for the watershed or sub-watershed of interest. Predicted precipitation, snow water content loss, evapotranspiration water loss, and subsurface flow water loss based on the remote sensing-aided approach described earlier will be substituted into the water balance equation to give water yield.

2.532b Energy Balance

The energy used in evaporation, LE, is the product of the latent heat of vaporization, L, and the mass loss of water, E. This energy must be supplied from the energy sources (solar and advected). Since the ideal surface is only two-dimensional, conservation of energy requires that as much energy reaches the surface as leaves the surface. The other sources and sinks of energy are the net radiant energy gained or lost; that gained or lost by air above the surface; heat gained or lost by soil and vegetation, and heat used in metabolism (mainly photosynthesis minus respiration). Melting or freezing of snow also acts as a heat sink or source, which usually is not considered in the energy-balance equation. The energy-balance method is based upon the conservation and flow of energy between the above mentioned components. Therefore the energy used for evapotranspiration and consequently the amount of evapotranspiration can be estimated.

Since the heat flux to the air is as difficult to measure as evapotranspiration itself, the Bowen ratio, defined as the ratio of heat flux to the air to LE, is used for estimation of evapotranspiration. This method is called the energy-balance method using Bowen ratio, β.

2.533b Aerodynamic Methods

These techniques assume similarity of the flux of momentum, heat, and water vapor. This assumption is not always justified and is almost always troublesome.

It is assumed that these fluxes are proportional to the vertical gradients of horizontal wind speed, temperature, and specific humidity. It is also assumed that the transfer coefficients of diffusiveities for momentum, water vapor and wind are equal; therefore, evapotranspiration may be evaluated from the associated water vapor flux equation if simultaneous measurements of the gradients of temperature, wind movement and water vapor are made at the same site.

The assumption of similarity in eddy transfer coefficients for momentum, water vapor, and heat holds reasonably well only during near neutral or non-buoyant conditions of stability. Conditions of neutral stability are common at sunrise and sunset and occur seldom, if ever, during periods of high evaporative flux. However, a stability correction factor might be considered for better results.

Aerodynamic equations may be combined with other approaches such as the empirical and energy balance formulations to form a more comprehensive model for evapotranspiration prediction.

2.534b Combination Methods

This title is usually given to a group of rational methods which are derived from a combination of energy-balance and aerodynamic methods. Some of the best known combination methods are those of Penman (1948), Ferguson (1952), Slatyer and McIlroy (1961), Priestly and Taylor (1972), and McNaughton and Black (1971, 1972). The Penman and Ferguson methods give estimates of free water evaporation while others can be used to estimate actual evapotranspiration.

The original Penman equation has been applied fairly successfully in a range of climates. The Penman method combines aerodynamic and energy-balance approaches and the components of his equation are net radiation, an aerodynamic term, and some standard meteorological parameters. The form of the aerodynamic term has been changed since the equation was first proposed. For free water evaporation Penman (1956) used an empirical equation to estimate the aerodynamic term from wind movement. The above-mentioned version of the Penman equation gives the evaporation estimates for a freewater surface, and consequently an adjustment factor is required to estimate potential evapotranspiration.

Limitations of the Penman equation (such as defining potential evapotranspiration rates, inadequacy of application to natural vegetation surface, requirement of wind data, and so on) may be found in Appendix II.

The modified Penman, McIlroy et al. equations represent more realistic models of transpiring plants in the atmosphere than does the original Penman type. But the introduction of crop surface and soil-water parameters serves chiefly to complicate the estimation procedure, and unless these parameters are evaluated for conditions at the site for which evaporation estimates are required, then estimation is still essentially empirical.

In the Slatyer and McIlroy equation, apart from the convenience of using wet-bulb depression instead of saturation deficit, the essential difference is that several factors, including vapor atmospheric conductance, neglected by Penman are taken into account. Evaluation of the wind function with regard to McIlroy's equation is the major difficulty of applying this technique, whereas other measurements required are simple and can be obtained from climatological stations.

McNaughton and Black (1971) applied a modified form of the Van Bavel (1966) combination model to an experimental Douglas fir forest in British Columbia, Canada. They also used the Monteith (1965) model, which introduces the effect of plant stomatal diffusive resistance to vapor flow by considering the vegetative canopy as a single extensive isothermal leaf. Following a similar procedure to Penman (1948), and utilizing Montieth and Von Bavel equations, McNaughton and Black developed a formula for forest evapotranspiration. The McNaughton and Black model attracted criticism because of considering only one layer of the canopy, and consequently ignoring leaf boundary layer diffusion resistances and aerodynamic diffusion resistances between different levels of the canopy.

Priestly and Tyalor (1972) have reviewed several experiments over surfaces where surface resistance was expected to be negligibly small and evaporation from the free water surface was expected to be equal to the actual evaporation rate. They developed an equation identical to the final equation of McNaughton and Black (1971). Their experimental data was then used to determine the value of their equation's single empirical coefficient that gave the best fit possible to observed evapotranspiration.

A realistic estimate of the influence of intercepted water was obtained by comparison of the McNaughton and Black model with the Priestly and Taylor formulation. As a result, a more complete model which includes the importance (quantity) of interception losses by the forest was made by McNauthton and Black.

Of the general group of combination methods it may be said that they are readily adaptable to the generalized estimation of evaporation from an area. It should be borne in mind, however, that loss of accuracy to some extent is inevitable, particularly where there are spatial variations in meteorological conditions, available soil moisture and types of vegetation.

2.535b Empirical Methods

Any formulas based on empirically determined coefficients are called empirical methods. Estimation of evapotranspiration based on empirical equations may be realistic only for localities and time periods for which the coefficients used in these equations were developed. Potentially serious errors may occur in extrapolation of results to other regions and shorter periods of time. On the other hand, several general methods for estimating evaporation or evapotranspiration have been developed which require only minor modification to be applicable to local situations where an appropriate weather record exists. These are the models most often applied to agricultural surveys. Some of the empirical methods will be mentioned in the following discussion, but more detail may be found in Appendices I and II.

Thornthwaite uses mean temperature and a monthly heat index for estimating potential evapotranspiration. This method has several short-comings, including a lag of actual with calculated evapotranspiration.

Blaney and Criddle, by correlating plan evaporation with monthly mean temperature, relative humidity, and percentage of the total yearly daylight hours for each individual month, derived an empirical consumptive use index. They assumed that water supply to the growing plants never becomes limiting. This method is easy to use, necessary data are readily obtainable, and results have been sufficiently accurate for many practical applications.

Hargreaves (1956) developed an empirical equation based on relative humidity, a monthly day length coefficient, and the mean monthly temperature. The Hargreaves formula provides a simple and reasonably reliable method of calculating evaporation under a fairly wide range of conditions. Hargreaves estimated evapotranspiration by multiplying the computed or measured pan evaporation by a monthly coefficient. The model therefore has implicitly integrated many of the effects of the different climatic factors.

Christiansen et al. (1966) developed an empirical formula for estimation of evapotranspiration by multiplying a set of factors. These factors are a set of dimensionless constants determined from theoretical values of the solar radiation reaching the earth's outer atmosphere, and a dimensionless empirical coefficient determined from the product of any number of subcoefficients each expressing the effect of given climatic or other factors. Christiansen's formula produces good results when data are available for temperature, wind, humidity, percent of possible sunshine, and elevation. But by using the relationship (empirical) between some of the above-mentioned parameters, the formula can provide acceptable results, given only data for temperature and elevation.

The Jensen and Haise (1963) model uses total short-wave solar radiation as its climatic factor and a dimensionless crop coefficient to estimate potential evapotranspiration. A somewhat similar equation has been proposed by Turc (1961) for computing potential evapotranspiration from solar radiation and temperature.

The semi-empirical methods based on solar radiation are essentially energy-balance methods, being formulated on the fact that the principal source of energy for evapotranspiration is incoming solar radiation. These methods are more reliable for both short and long-time periods than those using meteorological parameters that are not a measure of available energy, basic components of energy-balance, and/or mass transfer.

2.540b Recommendations for Evapotranspiration Model Applicabilities to Information Resolution Levels within the Remote Sensing-Aided Evapotranspiration Estimation System

Based on the discussion in section 2.530b and in Appendices I and II the following recommendations can be made for current evapotranspiration model applicability to the information resolution levels within the remote sensing-aided evapotranspiration estimation system. The models recommended for level one will be used to provide evapotranspiration estimates for individual base resolution elements which are the size of the ERTS pixels. Those recommended for levels two and three will generate estimates for individual SSU photo and ground plots respectively.

2.541b Model Recommendations for Level 1

Empirical formulas will be applied in this level, particularly using methods based on the:

Jensen and Haise equation
Hargreaves equation
Blaney-Criddle equation.

The input for these models comes primarily from ERTS, meteorological satellites, ground meteorological stations, and digitized topographic data. The variables to be derived from these data for the above models are surface temperature (daily average, minimum, maximum), all radiation components, relative humidity and cloud cover. These data will be obtained and processed as described in sections 2.100b, 2.520b, and 2.530b as well as in Appendices I and II.

The general reasons for choosing the above models for the first information resolution level are (1) the availability of needed input data on a watershed-wide basis from the satellites and (2) the maximization of physical realism when compared to other empirical models. Specific reasons for selection of the above three models are as follows.

a. Desirable attributes of the Jensen and Haise equation include:

(1) use of solar radiation, a variable highly correlated to evapotranspiration, as a primary variable,

(2) based on the first law of thermodynamics (energy conservation), which has been repeatedly shown to be a reliable and conservative method of determining evapotranspiration for both short-term and long-term periods,

(3) based partially on energy balance and therefore is semi-physically realistic (that is semi-empirical), a situation that may maximize reliability over time,

(4) most input variable data may be derived from satellite information according to transformations outlined earlier,

(5) a comparison of results with and without using remote sensing techniques may be possible, thus allowing evaluation of the performance of the remote sensing-aided systems, and

(6) allows a calculation of potential evapotranspiration which may be input to more sophisticated models or which may be used in information levels two and three to check the performance of models utilized there.

b. Desirable attributes of the Hargreaves equation include:

(1) one of the most practical and useful procedures for estimating plant consumptive water use according to Christiansen (1966),

(2) has been shown to give good results when checked against other methods (see Appendices I and II),

(3) since it is originally based on pan evaporation data, it integrates climatic and other factors important to the evapotranspiration process,

(4) most needed data inputs can be supplied by satellite information, and

(5) required meteorological data include temperature and humidity, or temperature only, since humidity may possibly be derivable from temperature; frequent ground station values for temperature and in some cases humidity are available to calibrate meteorological satellite surface temperature and humidity values derived from satellite temperature data.

c. Desirable attributes of the Blaney-Criddle equation are:

(1) uses same data as the Hargreaves equation; therefore could be used as check against Hargreaves' equation,

(2) used extensively within and outside of the U.S.,

(3) has been applied to a range of climate with reasonably successful results, and

(4) remote sensing data inputs (for level one, satellite data inputs along with calibrating ground information) can supply most of the information required.

2.542b Model Recommendations for Level II

The basis for the evapotranspiration models to be applied to the second level of information resolution is that of energy conservation, which is a proven law of thermodynamics. For this level, the energy-balance method will be combined with other methods for consideration of vegetation canopy effects and advected energy processes. The objective of the model applied at level two will be to capitalize on vegetation canopy, geometry-composition, and other surface data available from aerial photography to provide improved evapotranspiration estimates. The following models are being examined for application:

Priestly and Taylor
McNaughton and Black
Modified McIlroy and Slatyer Model
Models to be developed using radiation as the primary variable

Justification for the use of these methods at this level is as follows:

(1) they are based on the first law of thermodynamics,

(2) these models are based on physical relationships and consider some parameters which the empirical methods do not, such as
(a) resistance of all the stomata of canopy leaves, and
(b) aerodynamic resistance,

(3) the McNaughton and Black model has been applied to a forest watershed vegetation type with acceptable results,

(4) the Priestly and Taylor model is based on a survey of a large number of experiments over various surfaces and climatic conditions; the results have agreed with the McNaughton and Black model; in addition, the Priestly and Taylor model utilizes solar radiation, a highly evapotranspiration correlated variable, as its primary input, and

(5) the McIlroy and Slatyer method is one of the well known combination methods; it has been shown to be a rational model giving acceptable results by experts in the field.

The variables to be estimated for input to the above models are much more canopy and ground surface specific than those required for level one. In general, input variables to be applied in level two must be determined more precisely and more frequently as well. Data requirements include temperature, humidity, and wind value profiles in the soil surface-vegetation zone. Wind friction velocity, rainfall, ground cover, and topographic data must also be obtained.

These canopy data requirements will be fulfilled in large part through large scale photographic measurements collected from photo second stage sampling units and calibrated by corresponding ground data. Canopy-top meteorological data will be obtained as in level one, viz. through meteorological satellite data calibrated by ground station information and by microclimatic functions extrapolating satellite and ground data values to SSU's of interest. Vertical meteorological variable profiles within the canopy will be generated from canopy-top data according to canopy geometry functions.

2.543b Model Recommendations for Level III

The third information resolution level in the ERTS-aided evapotranspiration estimation system will allow application of the most sophisticated models. The approach will be to select and develop those evapotranspiration estimation equations which are most rational and physical in terms of the actual processes involved. A combination of empirical, energy balance, and aerodynamic methods will be applied at this level.

In addition, a new model will be developed and tested against other techniques. It will be based on a combination of methods using radiation energy and temperature as primary variables (e.g. Jensen and Haise equation) and on methods considering vegetation canopy effects and aerodynamic resistance (e.g. Priestly and Taylor equation, McNaughton and Black equation, and McIlroy and Slatyer equation). This new model will be constructed so as to take best advantage of the data gained through remote sensing and ground sampling.

Both the new model formulation and the combination of rational methods using energy and radiation will be designed to give the most precise and accurate evapotranspiration estimates possible based on level three information. Canopy-top meteorological input to subcanopy profiling functions will be obtained as for models operating on level one data. Required variables to be estimated are similar to those required of level two models. However, some additional data for subcanopy and vertical meteorological profiles must be obtained.

2.550b Summary and Future Work Related to Evapotranspiration Estimation

The sampling framework has been proposed for a remote sensing-aided evapotranspiration estimation system designed to give timely, relatively accurate, cost effective evapotranspiration estimates on a watershed or sub-watershed basis. The system employs a basic two stage, two phase sample of three information resolution levels to estimate this important water yield-water use related quantity.

A necessary documentation of assumptions, structure, and limitations of current evapotranspiration models has been performed. Based on this analysis recommendations have been made concerning the applicability of these models to evapotranspiration estimation at various information levels corresponding to given stages and phases of the sampling design.

Factors affecting evapotranspiration have been identified. Current data sources and available data types necessary to support evapotranspiration estimation are listed.

Based on the foregoing design, documentation, and feasibility analysis, work is not proceeding to implement the remote sensing-aided system. Effort will be focused on refining the sample design, developing in detail supporting data flow mechanisms, and adapting evapotranspiration models to their respective information levels.

Input data sets and evapotranspiration estimate output will be coordinated with concurrent sensitivity analyses of State of California water yield models performed jointly by the Davis and Berkeley NASA Grant groups. Initial data set location will be specific to the Spanish Creek Watershed, a representative subarea of the Feather River Watershed. Later expansion to the entire Feather River Watershed, the NASA Grant water supply test site, will occur after the economical testing on the smaller basin is completed.

The final product will be a documentation of any improvements in accuracy, timeliness, and cost considerations for the determination of water yield attributable to the remote sensing-aided evapotranspiration estimation system. Results will be specific to the state-of-the-art hydrologic models under examination.

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2.600b RSRP PRELIMINARY METEOROLOGICAL SATELLITE DATA INVESTIGATIONS

Meteorological data, particularly meteorological satellite data, when combined with ERTS or conventional photographic and ground data sources, can potentially provide significant gains in remote sensing information usefulness to renewable resource inventory and modeling. Modeling abilities for evapotranspiration, snow dynamics, vegetative growth, and insect infestation dynamics, to name just a few, are much enhanced.

Therefore, the Remote Sensing Research Program (RSRP) is presently investigating the problems involved in integrating real-time meteorological satellite information into the water supply analysis. Work is presently proceeding to install a high quality phone line between the National Weather Service (NWS) Field Satellite Service Station in Redwood City, California and the RSRP Lab in the Space Sciences Laboratory building at U.C. Berkeley. Twice daily reception of NOAA-4 Very High Resolution Radiometer (VHRR) data at the NWS station will be transmitted in an analog mode over the phone line to RSRP. Analog recorders will be automatically set to receive the transmitted data. After cataloging the NOAA-4 data for snow or evapotranspiration estimation dates of interest will be translated to digital form for merging with ERTS and other data sets.

A one month test of this system is scheduled for late winter or early spring 1975. Signal quality as received at Berkeley will be compared with signals recorded directly from the NWS transmitting devices at Redwood City. In addition, analog data will be compared with copies of direct satellite reception data in digital form. If signal degradation on the phone line is not significant, the system will be utilized on a selective basis to acquire real-time information for hydrologic parameter estimation. Otherwise, NOAA-4 digital data will be acquired from NWS Redwood City on a selective basis.

One of the major goals of meteorological satellite information acquisition will be to build a significant research data set for the California region. The NOAA satellite provides VHRR data in a visible channel (.6μm - .7μm) twice daily (approximately 9:30 a.m. and 9:30 p.m. LST) with a nominal pixel resolution of 930 meters at the nadir. The scanned swath ranges from horizon to horizon. Such an information bank can serve as a valuable source of remote sensing data for many disciplines in addition to hydrology.

RSRP proposes to systematically address the implementation problems of this new data bank. These include image rectification, ground station calibration of NOAA data for meteorological parameters of interest, and microclimatic transforms to fractionate meteorological pixels into smaller subpixel resolution elements. Pattern and spectral analyses of NOAA cloud formation data also will be conducted in order to develop rainfall intensity correlations.

2.700b WATER SUPPLY MODEL DEFINITION AND PERFORMANCE EVALUATION

Documentation of the California Joint-Federal State River Forecasting Center (RFC) Sacramento hydrologic model and the California Cooperative Snow Survey (CCSS) volumetric and dynamic water yield models and associated driver parameters was given in the May 1, 1974 report for this NASA Grant. Additional analyses of model structure and driver variables may be necessary to fully refine remote sensing-aided water loss estimation procedures and the set of variables considered. In addition, another RFC model, the Antecedent Index (AI) model, may require documentation as it is of historical importance in the Feather River Watershed. The AI model may be used as one of the baselines against which to judge performance of the new RFC Sacramento hydrologic model.

Preliminary documentation of the CCSS volumetric water yield model prediction accuracy and prevision for the Feather River Watershed is available in Chapter 6, section 6.350. Further analysis of this procedure's performance will be conducted over the next year. Agreement has been reached with RFC to analyze the performance of their model, taking care to consider all the contextual assumptions involved in its use in water yield forecasting. This analysis will proceed this next winter. Performance documentation for the RFC AI model results for the 1973-74 water year for the Feather River Basin will be performed first. Then a performance evaluation, documenting real-time assumptions for AI and Sacramento hydrologic models operating in the 1974-75 water year, will be conducted. These performance analyses will provide a measure against which to judge water supply model performance when remote sensing data are included.

2.800b FUTURE RSRP GRANT WATER SUPPLY WORK

The six proposed aspects for such work are as follows:

1. Continued state-of-the-art water supply model definition and performance documentation. This effort, carried out in conjunction with the Algazi-Burgy Group, is necessary to fully refine the remote sensing-aided water loss estimation procedures and the set of variables considered. Both the California Joint Federal-State River Forecasting Center (RFC) Sacramento hydrologic model and the California Cooperative Snow Surveys (CCSS) hydrologic models will continue to be examined. Performance documentation will continue for the CCSS models and performance for the RFC model will be stated concisely in the context of the forecast assumptions. Inspection of current water quality prediction methodologies may also be begun.

2. Continued development and testing of the remote sensing-aided water loss estimation system. This work includes sample design plus technique development for estimation of watershed snow areal extent, snow water content, evapotranspiration, impervious surface area, and effective precipitation input. The data set will initially include the Spanish Creek Watershed

for efficiency testing purposes and then be expanded to include ultimately the entire Feather River basin.

3. Sensitivity analysis for critical parameters in water supply models. In coordination with the Algazi-Burgy Group, RSRP will develop water parameter (water loss) estimates to be included in current RFC and CCSS hydrologic models. The performance change in the models with and without these remote sensing-aided estimates as determined on the Davis system will be noted. Feedback on model performance will allow modification of the remote sensing-aided water parameter estimation sampling design and methodology so as to improve hydrologic model performance.

4. Determine the costs of information gathering using conventional and remote sensing-aided methods. This effort will continue especially in the context of the RFC Sacramento River model and the CCSS volumetric model. Cost data on semi-automatic remote sensing-aided basin snow areal extent, snow water content, evapotranspiration, and manual impervious surface area estimation will be especially emphasized.

5. Perform cost-effectiveness analyses with respect to conventional and remote sensing-aided water supply estimation systems. In the near run, systems for estimation of intermediate parameters used in ultimate water yield prediction will be compared. In the longer run, systems actually producing water runoff estimates will have comparative analyses performed. Coordination here will be especially strong between RSRP and Social Science Group personnel.

6. Contribute to cost-benefit studies to determine the impact on society resulting from changes in water supply information caused by the application of remote sensing techniques to water supply models. RSRP will contribute cost and performance data, in conjuction with the Algazi-Burgy Group, to the Social Sciences Group for cost-benefit impact studies.

2.900b FUTURE RSRP GRANT SPECIAL STUDIES WORK

With respect to special studies there are three areas of new study proposed: (A) the application of fuel mapping to urban zoning and fire management, (B) the mapping of poorly stocked or unstocked potential commercial forest land using ERTS data with quantification of site potential, and (C) the use of multistage procedures for determining consumptive use of water utilizing discriminant analysis of ERTS data as the initial data base. Details with respect to these three studies are as follows:

A. Fuel mapping

Using the results of the U.S. Forest Service-funded fuel mapping study, the Plumas National Forest timber resource inventory, and the BLM range resource study the Remote Sensing Research Program and the Santa Barbara Remote Sensing Group will develop standards for ERTS based multi-stage techniques for wildland fuel mapping of the entire State of California. After these standards have been established, data from the studies mentioned above will be converted to the proper output product. These products include digital tape for the counties with computer systems and hard-copy color coded maps for field use by the counties that do not have computer facilities available. The output products will be the results of combining the ERTS-aided multi-stage data with topographic information to produce mapped indices of fire hazard, resistance to fire control, and fire spread rates. Emphasis will be placed on parameters defined by the joint California Division of Forestry and HUD studies of 1971.

B. Mapping understocked or unstocked lands

A determination will be made of the usefulness of ERTS discriminant analysis results for mapping the understocked or unstocked lands in California that are economically and ecologically suitable for aforestation or reforestation. This study will also concentrate on determining site potential along with locating the areas that are understocked. This will be done using the existing results from the fuel mapping forest inventory, and range resource studies already conducted in California, with a small amount of new discriminant analysis work done in the North Coast area of California to provide an example in that timber type.

C. Estimating the consumptive use of water

This third study will be conducted jointly with University of California Remote Sensing Research Program, the Santa Barbara Remote Sensing Research Group, and the Riverside Research Group. This study will be aimed at determining the cost-effectiveness of using discriminant analysis procedures and multi-stage sampling for estimating the consumptive use of water. These estimates will be specific to administrative boundaries and environmental strata as defined by the California Department of Water Resources and through analysis of photographic data by photo interpreters.

APPENDIX I: DERIVATION, DESCRIPTION, AND DEFINITION OF INPUT PARAMETERS FOR CURRENT EVAPOTRANSPIRATION ESTIMATION EQUATIONS.

Siamak Khorram

Chapter 2(b) - Appendix I

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APPENDIX I: DERIVATION, DESCRIPTION, AND DEFINITION OF INPUT PARAMETERS FOR CURRENT EVAPOTRANSPIRATION ESTIMATION EQUATIONS.

I 1.00 INTRODUCTION

In order to understand the applicability of various types of evapotranspiration estimation equations to a remote sensing-aided system, a baseline definition and discussion of those equations is necessary at the outset. The information in this appendix forms a comprehensive review of current evapotranspiration methodologies. For efficiency, however, it focuses on those aspects of each approach which are either relevant to a remote sensing-aided multistage estimation procedure or which are important in understanding the appropriateness of such applicable techniques.

I 2.00 GENERAL CURRENT APPROACHES TO EVAPOTRANSPIRATION ESTIMATION

Various methods have been used to measure the amount of water consumed by natural vegetation. Regardless of the method used, numerous problems are encountered.

Evapotranspiration can be measured or estimated in both direct and indirect methods. The estimation of evapotranspiration by means of atmometers (to be defined later), pans or tanks, computational methods and water balances are considered to be "direct" methods. Other methods which are generally based on energy balance and aerodynamic approachs are considered to be "indirect" methods. Meteorological methods are those methods which are generally based on meteorological parameters, (e.g., solar radiation), as opposed to micrometeorological, (e.g., specific humidity) and are mostly applied to indirect and empirical methods.

Meteorological methods in general have several distinct advantages for determining evaporation and transpiration from natural or cultivated surfaces. Meteorological methods are generally nondestructive, and thus can be employed continuously, or they can be used for sampling at a given site. They do not contain assumptions concerning the wetness of the surface or the status of the soil water. They are capable of yielding relatively accurate short period rates, and, in addition, they supply part of the meteorological information mandatory to understand the results. Meteorological methods also have disadvantages. They are not integrating and require continuous measurement of several parameters, some of which are difficult to measure. The nature of the equations and parameters requires repeated solution rather than the use of long-period averages, and the initial cost of ground sensors and recording equipment is high.

Here is a brief discussion of some of the methods considered for evapotranspiration estimation.

I 2.10 Water Balance

This method is based on the hydrological equation, which is usually considered on a large scale or on a catchment basin basis. The basic equation is:

$$E = P - 0 - D - \Delta S$$

Where P is precipitation falling on the evaporating surface, 0 is the net surface runoff, D is the net underground drainage, ΔS is the change in soil water content, and E is evapotranspiration.

With the equipment such as evaporation pans, lysimeters, stream gauges, precipitation gauges, and soil moisture measuring devices, the parameters of interest can be controlled or measured accurately; therefore, a reliable measurement of point evapotranspiration can be gained. Methods of soil moisture measurement may be divided into two groups: in situ methods, in which observations are obtained with remote sensing-aided techniques, and the methods which necessitate taking a sample of soil.

I 2.20 Energy Balance

The radiant energy reaching the earth's surface consists of shortwave radiation from the sun (whether direct, scattered by the atmosphere and its pollutants, or reflected from clouds) and longwave radiation from the atmosphere and the clouds. The net radiation at the surface resulting from the difference between the incoming and outgoing quantities is then used:

(1) as sensible heat in raising the temperature of vegetation, soils, and other objects on the surface, which in turn transfer a proportion of this heat to the atmosphere;

(2) as latent heat in evaporating water from vegetation and surface, which is also transferred to the atmosphere; and

(3) as energy in the biochemical plant processes, photosynthesis and respiration.

The basic energy balance equation is:

$$Rn = H + LE + G + CP$$

Where Rn is the net radiation flux received at the surface, H is the sensible heat flux, LE is the latent heat flux (L being the latent heat of evaporation), G is the heat flux into the soil, and P is the net rate of photosynthesis (C being the chemical energy storage coefficient). It is usual to neglect CP but it can be measured if necessary.

I 2.30 Energy Balance with Bowen Ratio

As H is generally just as difficult to measure as E, it is expedient to use the Bowen ration $\beta = \frac{H}{LE}$, which can be evaluated in terms of the ratio of the vertical gradients of temperature and specific humidity. Considering

$$H = C_p \rho K_h \frac{\partial T}{\partial Z}$$

and

$$LE = L_\varepsilon K_w \frac{\partial e}{\partial Z}$$

$$\beta = \frac{H}{LE} = \frac{C_p \rho K_n \frac{\partial T}{\partial Z}}{L_\varepsilon K_w \frac{\partial e}{\partial Z}}$$

Where C_p is the specific heat of the air at constant temperature, ρ_a is the density of moist air, K_n is the eddy diffusivity of air, ε is the ratio of the mole weight of water vapor to that of dry air, and K_w is the eddy diffusivity of water vapor. Assuming K_h (heat) = K_w (water) we can replace the gradients by finite differences measured over the same distance. Therefore, the energy balance equation is

$$R_n = G + LE + \beta LE$$

and consequently

$$LE = \frac{Rn-G}{1+\beta}.$$

Another assumption involved in the Bowen ratio method is the constancy or similar variation with height of the fluxes H and E from the surface to the upper measuring point.

Use of the Bowen ratio eliminates any need for wind measurements, known heights, stability corrections, roughness length, or zero plane displacement; but determination of the difficult vapor concentration difference is required.

I 2.40 Aerodynamic Equations

This method is based on the similarity of heat, water vapor, and momentum transfer throughout the atmosphere. In each case, the flux in the equation is proportional to the vertical gradient of temperature, water vapor, and wind speed, respectively.

The equations governing these transfer processes are:

$$H = - C_p \rho K_h \frac{(\partial T)}{\partial Z}$$

$$E = -\rho K_w \frac{(\partial q)}{\partial Z}$$

$$\tau = \rho K_m \frac{(\partial u)}{\partial Z}$$

where H is the sensible heat flux, E is the water vapor flux, τ is the momentum flux. The terms in parentheses represent the vertical gradients or change with height Z, of air temperature, T; specific humidity, q; and wind speed, u. The density of the air, ρ, and its specific heat, C_p, are considered constants. The transfer coefficients or diffusivities, K_h (heat), K_w (water), and K_m (momentum), vary with wind-speed, surface roughness, height, and sensible heat flux.

The three transfer coefficients are closely related, since all are dependent on the turbulent properties of the atmosphere. Many experiments have shown that

$$K_m = k' U_* Z/\phi_m$$

where k is the von Kasman constant, ϕ_m is a stability correction, and U_* is a form of momentum flux called the friction velocity, which is defined as

$$U_* = (\tau/\rho)^{\frac{1}{2}} \qquad \text{eq. 1}$$

When the sensible heat flux, H, is zero (neutral or adiabatic condition), then the stability parameter, ϕ, is unity. This case is the regime of forced convection in which turbulence is produced only by friction due to wind movement over the rough surface. When H is positive (the unstable or lapse condition), free convection due to rising warm air and sinking cold air increases the turbulence, which effectively decreases ϕ to some value less than unity. When H is negative (the stable or inversion condition), the turbulence is damped and ϕ increases to a value greater than unity.

By an analogy called the similarity hypothesis, the other two diffusivities are similarly defined as

$$K_h = k\, U_* Z/\phi_h$$
$$\qquad \text{eq. 2}$$
$$K_w = k\, U_* Z/\phi_w$$

Many scientists assume $\phi = \phi_m = \phi_h = \phi_w$, and thus $K = K_m = K_h = K_w$ as a satisfactory first approximation.

Another unsolved micrometeorological problem is the form of ϕ under varying stability conditions. Usually ϕ is given as a function of other stability parameters such as the Richardson number or the Monin-Obukov dimensionless height.

The friction velocity, U_*, can be found from the integrated form of the combined equations of 1 and 2

$$U_* = \frac{R(U_2-U_1)}{l_n\,[(Z_2-D) / (Z_1-D)] - \Psi} \qquad \text{eq. 3}$$

where

$$\Psi = \int_{Z_1-D}^{Z_2-D} \frac{1-\phi}{Z} \quad \phi Z$$

and U_1 and U_2 are wind speeds measured at two heights above the canopy, Z_1 and Z_2. Ψ is the integrated form of the stability correction, which depends on Z_1 and Z_2. The zero-plane displacement, D, is a correction to the measured heights of the sensors above the ground, Z_1 and Z_2. D is approximately equal to the general height of the vegetation and allows for the fact that the top of the canopy, (not the ground level), influences the wind above the trees.

Substituting equation 3 into equation 2, and then substituting the result into

$$E = - \rho \; k_w \frac{\partial q}{\partial Z}$$

and integrating gives the mass transfer equation for E as

$$E = - \rho k^2 \frac{(U_2-U_1)\;(q_2-q_1)}{(l_n \frac{Z_2-D}{Z_1-D} - \Psi)^2}$$

in which (q_2-q_1) is the difference between specific humidity at heights Z_2 and Z_1 and ϕ_w is set equal to units for the neutral condition.

This equation can be used directly for finding evapotranspiration.

Bulk aerodynamic methods use surface values, $U_1 = 0$, $(Z_1 - D) = Z_o$, the roughness length, and $q_1 = q_o$, in the form of

$$E = - \rho k^2 \frac{U_2}{(l_n \left(\frac{Z_2-D}{Z_o}\right) - \psi)^2} \quad (q_2-q_o)$$

$$= f(U_2)\,(q_2-q_o)$$

This method involves only wind-speed on one height, but requires constancy of surface roughness.

I 2.50 Combination Methods

The best known methods combining energy balance and aerodynamic approach are those of Penman (1948), Budyko (1956), Ferguson (1952), and McIlroy

(Slatyer and McIlroy, 1961). The Penman and Ferguson methods give estimates of free water evaporation while that of McIlroy et al. can be used to estimate actual evapotranspiration. A later version by Penman (1961) also enables an adjustment for surface humidity but this remains primarily untested.

I 2.51 Penman Method

The original Penman equation has been applied fairly successfully in a range of climates (Hounam 1971).

The generalized equation is:

$$E = \frac{\Delta R_n + E_a}{\Delta + \gamma}$$

where E is the evaporation from free water surface, Δ is the slope of the saturation vapor pressure versus temperature curve (that is $\Delta = \frac{de_a}{dT_a}$ where e_a is the saturation vapor pressure at the air temperature T_a), R_n is the net radiation flux received at the surface, γ is psychrometric constant, and

$$E_a = f(U)\ (e_a - e_Z)$$

E_a is the aerodynamic component, where e_a is as defined previously, and e_Z is the actual vapor pressure of the air. The psychrometric constant may be expressed as

$$\gamma = \frac{C_p}{L}$$

where C_p is the specific heat of air at constant pressure and L is the latent heat of vaporization.

The form of aerodynamic term f (U) has been changed since the equation was first proposed but, for free water, Penman (1956) used

$$f(U) = 0.35\ (0.5 + U_2/100)$$

Where U_2 is the wind run in miles per day set two meters above the surface.

The above-mentioned version of the Penman equation gives an estimate of evapotranspiration from free surface, E_o, but by use of a factor $f=E_t/E_o$ an estimate of potential evapotranspiration E_t may be obtained. Values of F, deduced by Penman for West Europe are 0.80 for summer, 0.60 for winter and 0.70 for the equinoctial months.

I 2.52 McIlroy and Slatyer Method

The modified Penman, Mc Ilroy and other equations represent more realistic models of the transpiring plants in the atmosphere than does the original Penman type. The McIlroy version of combination method equation is:

$$E = \frac{S}{S+\gamma} \times \frac{(R-G)}{L} + \frac{h}{L}(D-D_o)$$

where S is the slope of the saturation vapor pressure curve for water vapor at the mean wet-bulb temperature of the two levels,

$$\gamma = \frac{C_P}{L},$$

C_p is the specific heat of air at constant pressure, R is the net radiation flux received at the surface, G is the heat storage, L is the latent heat of vaporization, h is the transfer coefficient, D_o and D are the wet-bulb depressions at the water surface and height respectively.

$\frac{h}{L}$ is the atmospheric conductance, the value of which depends on both the aerodynamic roughness of the evaporating surface and the turbulent transfer characteristics of the atmosphere.

Under conditions when the surface is saturated, D_o approaches D, and estimates of evaporation are virtually the same as those derived by Penman (1948). McIlroy (1968) calls this the potential evapotranspiration and it is given by:

$$E\ (\text{pot}) = \frac{S}{S+\gamma} \times \frac{(R-G)}{L} + \frac{hD}{L}\ .$$

An advantage of this method is that it has potential application to surfaces which are not saturated, and McIlroy (1968) gives the following expression which avoids the difficult measurement of D_o:

$$E = \frac{E\ (\text{pot})}{1 + \frac{\gamma}{s+\gamma} \times \frac{h}{h_i}}$$

where h_i is analogous to h but is applicable to the molecular diffusion of water vapor through stomata, or the dry top layer of soil as the case may be, and can be related to the soil moisture content.

I 2.53 Priestly and Taylor Model

Priestly and Taylor used the equation:

$$E = \frac{\alpha}{L}\ \frac{(S)}{S+\gamma}\ (R_N - G)$$

for estimation of evapotranspiration over the surfaces where surface resistance was expected to be negligibly small and Eo, (defined previously), was expected to be equal to the actual evapotranspiration rate. They used both terrestrial and oceanic data to determine the coefficient α for their equation, where the energy flux density terms were 24 hour integrals and S was calculated from the mean surface temperature. The best value of α was found to be 1.26. This estimate of α is the overall mean of land and water surface. They conclude that their values of α obtained by their method are intended primarily for apportioning the net radiation over substantially saturated land area.

I 2.54 McNaughton and Black Method

Another form of combination method is that used by McNaughton and Black (1971) for an experimental Douglas fir forest in British Colombia, Canada. They used the Van Bavel (1966) model, which can be written as

$$E_o = \frac{1}{L} \times \frac{S}{S+\gamma} \times (R_N - G - M) + \frac{\rho C_p}{(S+\gamma)} \frac{(e_Z^* - e_Z)}{r_a L}$$

where E_o is the free evaporation rate, e_Z^* is the saturation water vapor pressure at height Z, r_a is the aerodynamic diffusion resistance at height Z. It is assumed that r_a is equal to U_Z / U_*^2 where U_Z is the wind velocity at height Z, and U_* is the friction velocity.

Monteith (1965) introduced the effect of plant stomatal diffusive resistance to vapor flow by considering the vegatative canopy as a single extensive isothermal leaf. Following a similar procedure to that of Penman (1948), Monteith derived the expression for transpiration

$$E = \frac{Eo}{1 + \frac{(\gamma)}{S+\gamma} \frac{r_s}{r_a}}$$

where the surface resistance, r_s, is formally identified as the resistance of all the stomata of the leaves of the canopy acting in parallel.

For some forest situations, total evapotranspiration can be considered as entirely transpiration with only small error when intercepted water is not present since forest soil evaporation has been found to be small by many workers (e.g. Rutler, 1966).

Perhaps a realistic estimate of the influence of intercepted water can be obtained by comparison of the McNaughton and Black model with Priestly and Taylor (1972).

Measured evapotranspiration rates from the University of British Columbia forest site were plotted against $\frac{1}{L}\frac{(S)}{S+\gamma}(R_N-G)$. Neglecting the two days of rainfall in July, the slope α of the least-square line through the data was found to be 1.05. Alternatively stated, the value of α, to force a straight line with slope equal 1 through the data mass for measured evapotranspiration versus $\frac{\alpha}{L}\left(\frac{S}{S+\gamma}\right)(R_N-H)$ was calculated to be 1.05.

An estimate of the importance of interception losses by the forest was made by McNaughton and Black (1970). They considered firstly gross interception loss (GIL), the amount of precipitation onto the forest that is caught by the canopy and evaporates without reaching the ground. Then net interception loss was defined as the difference between gross interception loss and the reduction in transpiration caused by the presence of the intercepted water. According to this structure of analysis, McNaughton and Black (1970) found that only 17% of the gross loss can be considered to be net loss. In other words, GIL substantially reduces transpiration.

The best potential evapotranspiration relationship that can be suggested from their study is

$$PE = \frac{1.05}{L}\frac{(S)}{S+\gamma}(R_N-G) + 0.17\ GIL$$

I 2.60 Empirical Methods

A large number of empirical methods are used for estimating or predicting evapotranspiration when (a) inadequate meteorological and soil-crop data are available to apply complete rational equations based on the physical process involved, or (b) the absolute accuracy of the data needed may be adequate using simple empirical equations that require much less time and effort to solve, and or (c) complete rational equations often require greater technical ability and experience in meteorology, physics and forestry than many users of evapotranspiration data have or can justify attaining.

I 2.61 Thornthwaite Method

Thornthwaite, 1948, developed the equation

$$E_t = 1.6\ (10\ t/I)^a$$

Where E_t is the potential evapotranspiration for a 30-day month, t is the mean air temperature ($^{\circ}C$) for that period, I is a heat index which is the sum of 12 monthly indices,

$$I = (t/5)^{1.514}$$

and a is a cubic function of I.

Thornthwaite and Mather (1954) claim that mean temperature can serve as an index of evapotranspiration because there is a fixed relation between the net radiation used for heating and that used for evaporation when conditions exist to achieve the potential rate.

I 2.62 Blaney-Criddle Method

Blaney and Criddle (1950) developed the equation

$$e = k\ (tp)\ (114\text{-}h)$$

where e is monthly evaporation in inches, k is a monthly coefficient, t is the mean monthly temperature ($^{\circ}F$), p is the monthly percentage of day-time hours in the year, and h is the mean monthly relative humidity in percent.

This method has been used in most of the United States, and in many foreign countries. It has been found to be satisfactory for water consumptive use where measured water loss data are not available.

Phelan proposed a modification of the Blaney-Criddle formula as given by Quackenbush and Phelan (1965) where $k_c k_t$ is substituted for the k in the formula. The coefficient k_c is a strict empirical constant. Its values for each month are determined experimentally. Values of R_t are given by the equation

$$k_t = 0.0173t - 0.314 .$$

I 2.63 Hargreaves Method

Hargreaves (1956) developed the equation

$$E_v = 0.38\ (1-0.1H_n)\ D\ (T-32)$$

Where E_v is Class A pan evaporation in inches, D is a monthly daytime coefficient defined as the ratio of the daylength for the month to 12 hours (the values of D are equal to the values of P in the Blaney-Criddle formula multiplied by 0.12, H_n is the monthly relative humidity at noon (humidity at 1:00 P.M. can also be used satisfactorily), and T is the mean monthly temperature in °F.

One of the problems of using Hargreaves model is to be found in the difficulties encountered in locating published data for noon humidity. Chindasnguan (1966) found that humidity at noon is approximately the same as the daytime average (11 A.M. and 5 P.M.). Al-Barrak (1964) developed a formula for converting mean humidity for a 24-hour period to mean humidity at noon. This formula has been compared with data from Thailand and Columbia and somewhat modified. The revised formula can be written as follows:

$$H_n = 1 + 0.4\ H + 0.005\ H^2$$

in which H is mean humidity for a 24 hour period. Either daily values or monthly averages may be converted.

Mathison (1963) plotted relative humidity against temperature differences. The line of best fit can be expressed by the equation:

$$H_n = 113 = 2.5\ (\Delta T)$$

in which ΔT is the difference between the mean maximum and minimum temperature in °F.

$$\Delta T = T\ (\text{max.}) - T\ (\text{min.}).$$

All the formulas in this method are based on 60 miles of wind movement per day. Evaporation increases or decreases about 9% with each 30 miles per day increase or decrease in the wind.

This method is also based upon conditions of approximately 90% sunshine. The percent sunshine could be calculated or derived from cloud cover tables. In the present context, space imagery, especially data acquired from, meteorological satellites, might prove to be very useful for estimating cloud cover. Palayasoot (1965) developed the following formula

$$S = 74.5 + 9.5C - 2.0C^2$$

in which S is the percent sunshine and C is cloud cover, on a scale of 0-8.

This method's formula is based on data from locations with an average elevation of 500 feet. Since evaporation increases with elevation, the formula can be corrected by increasing the calculated values of 1.0 percent for each 300 feet increase in elevation or by 3.0 percent for each 1000 feet increase.

I 2.64 Christiansen Method

Christiansen and his graduate students at Utah State University (1966) developed a set of formulas for estimation of evapotranspiration. The approach was both rational and empirical. The basic formula developed can be written

$$E = K\ R\ C$$

in which E is the evaporation or evapotranspiration, K is a dimensionless constant, determined from an analysis of many data, R is the theoretical solar radiation reaching the earth's outer atmosphere, expressed in the same units as E, and C is a dimensionless empirical coefficient, which is the product of any number of subcoefficients each expressing the effect of given climatic or other factors. Thus,

$$C = C_T \cdot C_H \cdot C_W \cdot C_S \cdot C_E \text{ etc.}$$

where T, H, W, S, and E are mean monthly values of temperature, humidity, wind, sunshine, and elevation. The coefficients for these climatic factors were developed from an analysis of many data. In theory each coefficient represents the effect of a single factor considering all other factors constant.

Each coefficient has generally been expressed as a second degree equation of the form

$$C_X = A + B_X + C_X^2$$

except where the data suggested a different form of equation. In this equation X represents a dimensionless parameter of a climatic or other factor which is the ratio of the climatic factor to a standard value of the factor that forces the coefficient C_X to be unity. For example, the wind coefficients in the Christiansen-Mehta formula (1965) can be expressed by the equation

$$C_w = 0.790 + 0.222\ (W/W_o) - 0.012\ (W/W_o)^2$$

in which W is the mean monthly wind velocity in any desired unit, and W_o is the standard value of the wind velocity for which the value of the coefficient C_w is 1.0.

To obtain an estimate of the pan evaporation or evapotranspiration for a given month, mean values of each factor are tabulated. From the graphs, or tables, values of the $C_{(X)}$ coefficients, or logarithms of the coefficients, are next determined. The computation is then simply a matter of multiplying coefficients, or adding logarithms and taking the antilogs. Anyone using this formula must exercise good judgment in the selection of k values in order to obtain reliable values of E.

I 2.65 Jensen and Haise Method

The Jensen and Haise (1963) method uses total short-wave solar radiation (R_s), (expressed in inches of evaporation equivalent) as its climatic factor and a dimensionless crop coefficient (ET/R_s) to reflect the effect of crop type and stage of growth, as well as climatic factors not accounted for by solar radiation. Thus:

$$ET_p = (ET/RS)\ RS$$

In addition, the equation

$$ET_p = (0.014\ T - 0.37)\ R_s$$

is presented, where ET_p is potential evapotranspiration in inches, T is mean daily temperature in °F, and R_s is total solar radiation in inches of evaporation equivalent.

The linear temperature correction factor was derived by plotting ET/RS versus T for selected crops in which evaporating and transpiring surfaces were not limiting the vaporization of the water.

Somewhat similar equations have been proposed by Turc (1961) for computing evapotranspiration. For humid areas (average relative humidity greater than or equal to 50 percent), he proposes the equation

$$ET_P = 0.013 \frac{T}{T + 15} \quad (R_s + 50)$$

and for areas with less than 50 percent humidity the following:

$$ET_p = 0.013 \frac{T}{T + 15} (R_s + 50)(1 + \frac{50 - RH}{70}) ,$$

where ET_p is potential evapotranspiration in millimeters per day, T is mean daily temperature in degrees centigrade, R_s is solar radiation in Langleys, (calories per squared centimeter per minute) and RH is relative humidity in percent. Turc does not offer any crop factors and states that they should only be applied with prudence.

For areas where incident radiation values are not available, Jensen and Haise (1963) gave two equations

$$R_s = R_{so} \ (0.35 + 0.61S)$$

attributed to Fritz and McDonald (1949) and

$$R_s = R_{so} \ (1 - 0.ln \ (1 - k) \ )$$

from Budyko (1958).

In these equations, R_{so} is the solar radiation on cloudless days, S is the possible sunshine percentage, expressed decimally, k is the mean annual coefficient, varying with latitude from 0.35 at the equator, to 0.32 for latitudes of 2.5^{o} to 35^{o} north, then increasing to 0.40 for latitude 60^{o}

north, and n is the cloud cover in tenths (scale 0 to 10).

The solar radiation methods discussed above might be termed semi-empirical approaches. They are essentially energy balance methods, being based on the fact that the principal source of energy for evapotranspiration is incoming solar radiation. Empirically derived factors to account for other climatic effects and the effect of type and phenological n phase of vegetation are applied to reduce the total incoming solar radiation to evapotranspiration. The Jensen and Haise (1963) equation is rearranged by David and Robb (1966) to

$$ET = (1 - r)\, R_s - R_{et} - A - G,$$

where ET is evapotranspiration, r is reflectance or albedo, R_s is total shortwave solar radiation, R_{et} is effective thermal radiation, A is the sensible heat flux to the air (negative for flux from the air), and G is the sensible heat flux to the ground (negative for flux from the ground).

APPENDIX II: EVALUATION OF CURRENT MODELS FOR EVAPOTRANSPIRATION ESTIMATION

Siamak Khorram

APPENDIX II EVALUATION OF CURRENT MODELS FOR EVAPOTRANSPIRATION ESTIMATION

II 1.0 INTRODUCTION

The problem of obtaining an estimate of evaporation from an area is a very difficult task in most instances and is often simplified by using representative point estimates in catchments (watersheds) or sub-catchments. The estimation of areal evapotranspiration is more difficult because of diversification of evaporating surfaces in most catchments, and the consequent need for a proportionally large number of evaporation measuring points, which are often expensive to install and maintain.

Approximations and over-simplifications with regard to procedures of data are often made. For example, vapor pressure of the bulk air is sometimes substituted for surface vapor pressure, with considerable loss in realiability; net radiation may be estimated from sunshine or even cloudiness and air temperature, while the advection term, which can be quite significant in watershed evapotranspiration, is neglected in most methods.

The use of remote sensing techniques in cost-effective combination with a limited number of appropriate ground sensors, could solve some of the above-mentioned problems. This evaluation of current methods will help provide a baseline against which to judge the applicability of the various model types to each information resolution level of our proposed remote sensing-aided evapotranspiration estimation system.

Most of the computational methods are based on some form of meteorological observation, but they are "indirect" in the sense that evapotranspiration is computed from other meteorological elements. Practically all such methods make assumptions and must therefore by calibrated against a more reliable procedure.

II 2.0 WATER BALANCE

The water balance method may be classified as direct and considered as a possible absolute standard, but, unfortunately, the degree of accuracy is rather low. The large error often involved in measuring the other variables is then built-in to the residual term - evapotranspiration. This method has the considerable advantage that it integrates all spatial variations of evapotranspiration over a catchment without the need to know details in these variations. It can also be used on any scale ranging from continental land mass and hydrological catchment down to point observation.

Application of this method ordinarily involves setting up an expensive ground network to measure rainfall, runoff, underground drainage, and soil moisture changes. However underground drainage measurements are difficult to make. Soil moisture presents difficulties unless the water balance reporting time interval is selected to allow assumption of zero change in soil water storage over the period. Rainfall is sometimes assumed to be accurately observable, and estimated for the watershed, a situation unlikely in most cases.

Since the accuracy of the estimate of catchment evapotranspiration depends on the accuracy of the other terms in the water balance equation and in view of the probable inaccuracies in rainfall, runoff, deep drainage, and soil moisture measurement, reliable evapotranspiration values are not likely in most circumstances.

The primary use of this model in the remote sensing-aided system will be to provide a final basin-estimated water input versus loss equation. The difference will represent estimated water yield for the watershed or sub-watershed of interest. Predicted precipitation, snow water content loss, evapotranspiration, water loss and subsurface flow water loss based on the remote sensing-aided approach described earlier will be substituted into the water balance equation to give water yield.

II 3.0 Methods Using Energy Balance

The energy balance method has repeatedly been shown to be a reliable and conservative method of determining evapotranspiration for periods of time as short as one hour, Jenson (1966).

Net radiation is the key quantity in the energy-balance equation, and the degree of accuracy obtainable by the method depends mainly on the accuracy with which this can be measured. Although national networks for the measurement of total radiation have expanded steadily in recent years, the measurement of net radiation has not followed at the same rate. Two good reasons for this are the greater fragility of the equipment and the difficulty of determining a representative surface.

Empirical relationships have been developed for the estimation of total radiation, the most common using a cloud cover or sunshine correction to the radiation at the top of the atmosphere (solar constant). The relationships are usually easy to apply to catchments where climatological data are available, and estimates can be made of the areal variation of parameters; but the degree of accuracy is not high. The use of remote sensing techniques might improve considerable the accuracy of the radiation measurements.

In the energy-balance method the height at which observations are made above the surface is rather critical, as the equality assumption for the turbulent transfer coefficients in the energy-balance equation is not always justified beyond a certain distance from the surface. The difficulty increases with geometrically mixed stands of vegetation where, in addition to great surface irregularity, there are real spatial differences in evapotranspiration rates.

Under these conditions a sensor will be more influenced by heat and vapor sources in its immediate neighborhood and not by more distant sources which may be transpiring at a different rate. By raising the height of observation point the sensor will be influenced by a wider area of heat or vapor source and, as a result of turbulent mixing, an average value from the area will be sensed. The discussion on advection is relevant here, and it will be noted that only a small increase in height means that the sensor is looking a considerably further distance upwind. It may be concluded, based on stability and advection variation, that the energy-balance method is more appropriate in situations where the vegetation is reasonably homogeneous.

A suitable observational height over a fairly homogeneous forest might be two or three meters above the canopy with the second level some eight to ten meters above it. In this case the remote sensing-aided evapotranspiration system would provide estimates of the needed parameters at the various heights required by the energy balance model. These estimates would be obtained through the spatial and vertical canopy transformation functions described in Section 2.322b, particularly those of Section 2.523b

Similar parameter estimates would be made for heights required by other evapotranspiration models discussed in Appendix II.

A combination of energy-balance and Bowen ratio seems the most appropriate form of application of energy-balance for forest evapotranspiration estimation, although estimation of the Bowen ratio is a very difficult problem. Tanner (1963) has shown the practical advantage of determining the Bowen ratio by means of gradient measurements of temperature and humidity as those are not dependent on wind profile shape and generally change in similar fashion with changes in wind structure. This, of course, neglects the effect of advected energy.

Generally speaking, energy-balance techniques for estimating evapotranspiration have proven reasonably more accurate in the more humid regions of the country. It seems that this method is appropriate to be applied in the second level of information resolution in our proposed remote sensing-aided evapotranspiration estimation system. The results of application of the energy-balance method to a forest by McNaughton and Black (1972) were found to show a consistent pattern with two distinctive features that differentiate them from typical balances for low height agricultural crops. Short fluctuations in radiation did not produce corresponding proportional changes in the latent heat flux. This pattern may be contrasted with, for example, an energy balance of irrigated alfalfa-brome grass on a partly cloudy day as measured by Tanner and Pelton (1960) where changes in net radiation and latent heat flux are strongly coupled. Secondly, peak evapotranspiration rates in the McNaughton and Black model occured two or three hours after solar noon. Gay (1972) has reported a near identical pattern for a clear July day energy balance of a taller Douglas-fir forest at Cedar River, Washington. Fritschen (1973) has made lysimetric measurements of evapotranspiration from a single Douglas-fir tree in early May 19 72 on the same site as used by Gay. His results also show that the daily evapotranspiration maxima occur several hours after the net radiation maxima. These results show that forest evapotranspiration is not directly driven by net radiation in accordance with the approximation of Monteith's equation for rough surfaces.

II 4.0 Aerodynamic Methods

Aerodynamic techniques assume similarity in the mechanisms of the flux of momentum, heat, and water vapor. This assumption is not always justified and is almost always troublesome. It can be readily seen that evapotranspiration may be evaluated from the water vapor gradient if simultaneous measurements of the gradients of the temperature or wind movement and of the flux of sensible heat or momentum are made at the same site. However, independent measurements of sensible heat or momentum flux are difficult to achieve and have thus been used only rarely.

The assumption of similarity in eddy transfer coefficients for momentum, water vapor, and heat holds reasonably well only during near neutral of non-buoyant conditions of stability. These conditions do not commonly hold all the time. Evidence has been presently in the literature which both supports and condemns the assumption of equality of the transfer coefficients under various conditions of atmosphere stability.

To achieve more accurate estimates of evapotranspiration, it has become necessary to adjust aerodynamic calculations for their dependency on stability. There are several forms of stability correction forms, such as the Richardson number or the Monin-Obukhov (1945) mixing length.

The aerodynamic method will be combined with other methods such as energy-balance or empirical methods to produce a method for use at information levels two and three in our proposed remote-sensing-aided evapotranspiration system.

The aerodynamic equation, discussed in Appendix I, can be used for the direct estimation of evapotranspiration. It required wind and vapor concentration measurements at two heights above the surface and temperature measurements for the stability correction. The measurement accuracies required are high, since the differences are small.

II 5.0 Combination Methods

Perhaps the most widely used method for computing lake evaporation from meteorological factors is based on a combination of aerodynamic and energy-balance equations such as those as Penman, Ferguson, and Slatyer and McIlroy.

Combination methods are the only methods that are based on physical processes and yet do not require highly specialized measurements.

Several of these methods will be appropriate at information resolution levels two and three in our proposed remote sensing-aided evapotranspiration estimation system.

Penman's original equation has been applied fairly successfully in a range of climates, but it is only applicable to free water surface evaporation. The lake evaporation computed for short periods by this method would be appropriate only for very shallow lakes with little or no advection of energy to the lake.

According to Penman (1956) the potential transpiration rate is determined by the prevailing weather conditions and, for a crop completely covering the surface, the rate is about the same irrespective of plant or soil type. A corollary of his equation is that transpiration (from a short green cover) cannot exceed the evaporation from an open water surface exposed to the same weather. More recent research into aerodynamic roughness factors suggests some significant variations between crop types, while Tanner and Pelton (1960) indicate that crop transpiration can exceed free water loss particularly when there is appreciable advective transfer of heat. However, natural vegetations are taller and aerodynamically rougher than turf and the Penman equation estimates are usually too low under these conditions. On the other hand, estimates may be too high in windy regions.

Slatyer and McIlroy (1961), developed a formula which in form closely resembles Penman's original equation. Apart from using wet-bulb depression instead of saturation deficit, the essential difference is that several factors neglected by Penman are taken into account.

The McIlroy *et al.* equation represents a more realistic model of transpiring vegetation than the Penman type, but the introduction of crop surface and soil water parameters serves to complicate the model. Unless these parameters are evaluated for conditions at the site for which evaporation estimates are required, then the estimation is essentially empirical.

The major difficulty preventing this method's wide application is the difficulty in evaluating the wind function $h = a\ (b + u)$, as the empirical constants (a and b) depend on the nature of the surface. This requires some years of comparison with some standard method of evaluating evaporation such as lysimetry or energy balance.

The McIlroy *et al.* formula contains two quantities, h and D_o, which must be solved before it can be applied.

A commonly used method of estimating evapotranspiration is to determine potential evapotranspiration and then to use an empirical relationship of $ET_{actual}/ET_{potential}$. Micrometeorological studies of forests have already led to analysis of differences in evapotranspiration from different cover types. All the relevant surface variables - albedo, surface temperature, roughness, stomatal resistance, root and soil water properties - as well as necessary meteorological variables - cannot be considered altogether in any current model at the present time.

II 5.1 McNaughton and Black's Model

McNaughton and Black used Monteith's Canopy transpiration model (Monteith, 1955) for part of their model. Monteith (1965) determined the effect of diffusive resistance to water vapor from vegetation canopy by considering the canopy as a single extensive isothermal leaf. The McNaughton and Black's model considers only one-layer of the canopy and has attracted several criticisms (Philip, 1963, 1966 and Tanner, 1968). These criticisms arise from the observation that the simple one-layer model ignores leaf boundary layer diffusion resistances and aerodynamic diffusion resistances between different levels of the canopy. In general, the surface resistance cannot be vigorously identified with the stomatal resistance of all of the leaf surfaces acting in parallel and such interpretation must be justified by examination of the assumptions for each canopy studied.

Good wind profile data for calculation of r_a in the McNaughton and Black model is frequently unavailable.

In this method γ_s is computed from Monteith's canopy transpiration equation,

$$E = \frac{E_o}{1 + \frac{(\gamma)}{\gamma+s} \frac{r_s}{r_a}}$$

Therefore, the effect of an error in r_a term on the value of "r_s" calculated from the above equation can result in errors in the value of "r_s" as well.

Cowan (1968) and Thom (1972) have examined the assumption of similarity of the aerodynamic diffusion resistance for momentum and those for heat and water vapor. Both investigators consider that the assumption of similarity may not be appropriate for exchange within the canopies. However, in calculating r_s for forests from the above-mentioned equation, the major uncertainty will usually be caused by errors in the measured values of transpiration.

II 5.2 Priestly and Taylor Model

A more practical form of combination method is presented by Priestly and Taylor (1972), which gave reasonably good results when applied to a forest watershed. The value of the coefficient α in their model represents the only empirical coefficient and they found its best value to be 1.26; this is its mean value over terrestrial and water surfaces. The primary variable in their model is net radiation.

The apportionment of net radiation between heat flux and evaporation requires a knowledge of the distribution of net radiation itself. The problem of mapping net radiation is not different in kind from those of temperature, wind, rainfall, etc. However, the mapping of net radiation will be highly sensitive to the knowledge and predictability of cloud amount and type. In this case remote sensing seems to be an especially good and appropriate information gathering tool to use.

Given net radiation, potential evapotranspiration can be estimated from the Priestly and Taylor model.

II 6.0 Empirical Formulas

A large number of empirical methods have been developed for the estimation of evaporation from open water surfaces or from vegetation. With most of these procedures the objective has been to use commonly measured meteorological elements, and the equations range from those using simple mean dry-bulb temperature to sophisticated physical relationships which attempt to use all the parameters controlling evaporation.

Qualified technicians have little justification in using empirical methods when the basic meteorological parameters such as net radiation, vapor pressure and temperature gradients, wind speed at a prescribed elevation above the vegetative canopy or over a standard surface, and soil heat flux are available.

Empirical methods have been used to estimate evapotranspiration from measured evaporation loss of a pan or from standard surfaces such as short, smooth, and water saturated crops, or from one or a few meteorological parameters such as air temperature, saturation deficit, or solar radiation. But the applicability of these or any other such methods to the forest should be tested cautiously.

Several of these methods will find application in information level 1 of our proposed remote-sensing-aided evapotranspiration systems. That is, these models may be driven efficiently by information obtainable at the ERTS level of resolution.

II 6.1 Thornthwaite Method

Certain shortcomings are inherent in this method. For example, evapotranspiration lags the annual maximum heating during the late spring and is consequently out of phase in the fall as well. (Rosenberg, et al., 1968). Furthermore, application of the Thornthwaite concept to short time periods leads to significant errors as a result of the often excessive variation in mean air temperature during these periods.

Leeper (1950) obtained anomalous results with the Thornthwaite method applied to various Australian locations where mean temperatures were similar but where the actual climate differed greatly (two climates may have the same average temperature with different temperature variations, maximums and minimums) with consequent differences in known evapotranspiration as well.

Marlatt et al. (1961) found that the Thornthwaite method, applied to snap beans on sandy loam, gave good estimates of evapotranspiration until 25mm of water was removed. After 25mm of water loss, evapotranspiration proceeded asymptotically to a linear decrease in water loss.

II 6.2 The Blaney-Criddle Method

This method is based primarily on temperature and humidity data. It is easy to use. Necessary data are readily available from climatological stations, and results have been sufficiently accurate for many practical applications.

This method has been used by several researchers, and scientists around the world. It has been found to be satisfactory for computing water use where measured water consumption data are not available.

II 6.3 Hargreaves' Formula

Hargreaves' formula uses the same climatic factors as the Blaney-Criddle formula, but makes the evaporation proportional to the centigrade temperature. Hargreaves substituted a constant, (0.38), for the monthly coefficient, k, and thus does not leave this to the judgment of the user. According to Christiansen(1966), comparisons of Hargreaves formula by Patel and Christiansen (1963), Al-Barrak (1964), and Chindasnguan (1966) indicate that the Hargreaves formula gives fairly good results for normal wind values (average wind movement of 60 miles per day) when applied to a wide range of climatic conditions.

Hargreaves estimated evapotranspiration by multiplying the computed or measured pan evaporation by a monthly coefficient, k, which he determined for a wide variety of crops. Since pan evaporation integrates many of the effects of the different climatic factors, it provides a good base for the estimation of monthly evapotranspiration values.

The Hargreaves method is applicable to both arid and humid climates and to locations where data are quite complete as well as to those locations or projects for which only temperature and rainfall data are available.

II 6.4 Christiansen's Formula

Christiansen's formula produces good results when data are available for temperature, wind, humidity, percent of possible sunshine, and elevation. There seems, however, to be a real possibility that engineers and agriculturalists will at first glance assume that complete data are required in order to use this formula. This is not necessarily the case. By making use of the equation derived by Mathison (1963)

$$H = 113 - 2.5 \Delta T$$

in which H is relative humidity at noon in percent and ΔT is maximum temperature minus minimum temperature, in $^{\circ}F$, (average for the period considered), the Christiansen's formula can be used with only data for temperature and approximate elevation. Wind and percentage of possible sunshine can be estimated based upon their probable departures from normal or average conditions. Average conditions are represented in the tables by a coefficient of 1.00.

These average (normal) conditions are 60 miles of wind movement per day and approximately 90 percent sunshine.

II 6.5 Jensen and Haise Method

Jensen and Haise (1963) developed a rational empirical (semiempirical) method for estimating or predicting evapotranspiration, using solar radiation as the primary variable. Empirical methods using radiation are more reliable for both short and long-time periods than those using meteorological parameters that are not a measure of available energy or basic components of energy balance equations.

In this method heat flux to the vegetation and energy used for photosynthesis have not been included since they are a normally negligible part of the total energy required for evapotranspiration. Over time periods of a week or more the heat flux to the soil is also negligible. Heat flux to the air (the advective term) may be important, especially in areas with significant wind movement.

Improvements in the Jensen and Haise model could be gained by consideration of several meteorological parameter effects currently not incorporated in the method. For instance, improvements in estimated values of solar radiation by use of a temperature correction factor are not considered. For a given solar radiation value, temperature will normally show some correlations with latitude (effect on reflectance) and relative humidity (David and Robb, 1966). Temperature would be expected to vary directly with the amount of advected energy (-A) available also. Since transpiration is the major mechanism for plant cooling, the temperature of surrounding air has an important direct effect on the plant. This may be considered a shortcoming for this model. Relative humidity has a direct effect on the vapor pressure gradient and may also affect the amounts of short-wave solar radiation and thermal radiation reaching the plants. Wind has an important effect on the advective energy term because of its effect on the rate of convective cooling. The relative importance of these terms is greatly affected by plant canopy characteristics, so the ideal of defining a climatic factor which accounts for "all climatic effects" probably can never be achieved. The effect of soil moisture in this model has been considered negligible, but the effect of moisture stress on evapotranspiration could be evaluated.

APPENDIX III

PROCEDURE FOR MEASURING SECONDARY SAMPLING UNIT GROUND PLOTS FOR WATER LOSS ESTIMATION

Randall W. Thomas

Field Instructions for Water Related Variables

I. Non-Living Component

A. Fill in date, crew code, photo plot number, and note starting time on Sheet NL1.

B. Line Data for Sheet NL1.

1. Locate photo plot center; this will be point number 6 in a 100 foot line sectioned into 10 foot intervals and oriented along the topographic contour running through the photo plot center. Point number 1 will be located at the end of the line in the western hemisphere.

2. Record Azimuth of the line to the nearest degree.

3. Locate the exact photo center point, i.e. line point number 6. Record the surface for line point number 6 according to instructions contained in the recording form key.

4. At line point 6 determine and record the Munsell Color Code (hue, value, chroma from the soil booklet) for the surface litter, if any. This determination should be made with direct sunlight on both the organic material and color charts if possible. Use organic material lying directly on the surface.

5. Then at line point number 6 use the garden trowel to dig through the organic (or duff layer) just to the top of the mineral soil. Measure and record the depth of the organic layer to the nearest 1/16 inch.

6. Starting at line point number 6 (photo center) pace along the line in one direction, say towards line point number 7. Be sure to accurately calibrate your pace to 10 feet.

7. At the tip of the boot just touching the next 10 foot line point, in this case line point number 7, record the surface at that point according to instructions on the recording form key.

8. Repeat steps I.B. 4 and 5 at the position where the surface is described at line point number 7.

9. Mark the exact location of line point number 7 with a marker placed into the ground.

10. Standing at line point number 7, turn and face line point number 6. Proceed to make ocular estimates of the percent of bare mineral soil, rock, and dead organic matter greater than 1/4" along the line from line point number 6 to line point number 7 and record these values to the nearest 10%

in the appropriate columns of the data form for the row labeled 6-7. Where brush or other obstructions obscure the line between the two line points, then make ocular estimates from both points to obtain an average percent of line figure.

11. Turn again to face line point number 8 and pace 10' to line point number 8. Again record the surface at the tip of the boot touching line point number 8 and repeat steps I.B.4 and 5. Make ocular estimates as in step I.B.6 for the interval 7-8.

12. Proceed similarly for line points numbers 9, 10, and 11.

13. Locate line point number 11 exactly with a marker placed into the ground.

14. At line point number 11 turn and face line point number 6. Take a 35 mm photograph back along the line to illustrate the general vegetative and surface condition. Record roll and frame no.

15. Return to line point number 6 (the photo center).

16. Pace 10 feet to line point number 5. Proceed to record surface conditions, the surface Munsell Color Code, the organic matter layer thickness, and make ocular line estimates as in steps I.B.3, 4, 5, and 10 respectively.

17. Mark the exact location of line point number 5 with a marker placed in the ground.

18. Proceed as in step I.B.16. for line point numbers 4, 3, 2, 1.

19. Locate with a marker the exact location of line point number 1.

20. At line point number 1 turn and face line point number 6. Take a 35 mm photograph back along the line to illustrate the general vegetative and surface condition. Record roll/frame no.

21. At line point number 1 dig into the mineral horizon. Remove soil material from the depth of 1 1/2 to 2 inches (where 0" would be at the top of the mineral soil) and determine and record its Munsell color code. Please make the determination with direct sunlight on the soil and the color charts if possible.

22. Dig further to 3" depth within the mineral soil horizon at line point number 1. Place material from within the 0-3 inch mineral soil horizon zone in the soil sieve. Fill the sieve to the top and place the lid on it. Shake until no further significant soil (<2mm fraction) falls out the bottom. Remove the lid and check to see if the sieve is clogged by moist soil. If it is, please unclog the sieve, replace the lid and shake again. When no further soil can be removed by sieving, make an estimate of the volume of material remaining

in the sieve can to the nearest 10%. Then by moistening the "clumps" remaining in the sieve determine the percent volume (expressed as a fraction from 0 to 1.0) of the remaining material which is indeed rock. Then a calculation of the percent of 0"-3" mineral material volume greater than 2 mm will be formulated as

$$\begin{matrix}\text{\% vol.} \\ >2\text{ mm}\end{matrix} = \begin{pmatrix}\text{est. of \%} \\ \text{vol. remaining}\end{pmatrix} \begin{pmatrix}\text{Fraction (0-1.0)} \\ \text{of vol. remaining} \\ \text{which is rock}\end{pmatrix}$$

Record the final result as the percent of 0"-3" mineral material volume >2 mm.

23. Return to line point numbers 5, 6, 7, 11 (in that order) and repeat steps I.B.21 and 22.

24. Determine soil texture from line pt. no. 11 by utilizing material from the 1 1/2" to 2" depth in the mineral horizon. Place this material in the palm of the left hand and wet it until the mass behaves plastically. Check for small grittiness (by feel and by grinding sound when thumb and index finger are rubbed close to ear) indicating sand, or large grittiness indicating gravel (>2 mm - 3"). Slight sponginess yet failure to form significant cohesive ribbons will indicate loams (generally equal parts sand, silt, and clay), a slick feel without ribbons will indicate silts, and significant ribboning will indicate clay. See the recording form key for notation.

25. Repeat step I.B.24 at line points no. 7, 6, 5, and 1 (in that order).

26. When surface material prevents top soil horizon color, texture, and percent mineral material volume greater than 2 mm from being determined at the specified line point number, then proceed to the nearest line point number and make these determinations.

C. Additional Information for Sheet NL1.

1. From line pt. no. 6 determine the slope and aspect for the plot.

2. Characterize the general microrelief over the line.

3. Where a soil profile is exposed please obtain the information requested. All depths should be measured from the top of the mineral soil.

4. General comments: e.g. characterize the frequency (spacing), width, and depth of surface erosion features. Note whether gully or sheet (uniform surface) erosion, presence of pedestaled plants or rocks, presence of mini-alluvial fans, etc.

5. Locate a down log or large sharp angular rock near the center of the plot or preferably crossing the center of the plot which which lies in a significant forest canopy opening large enough

to allow the object to be imaged in sunlight from the air. Measure accurately the length of the log or an airphoto distinguishable section of it. In the case of a rock, measure its largest diameter. Measure also the slope along which the log long dimension or the rock largest diameter lies. Record this information (to be used to calculate photo scale) on the back of Sheet NL1.

6. Note time at which Non-living Component information recording for parts I.A,B,C is finished and record the total time taken to perform measurements on the Non-living Component for these parts.

7. Please remember to collect and check all equipment including line point markers before leaving the plot.

D. Soil Profile Information

1. Note and record the time on the back of Sheet NL1 at which soil profile information gathering was started.

2. If possible shelve with a shovel a soil profile four inches downslope from line point number 6. When shelving becomes unfeasible then continue vertically into the soil profile with an auger. If a surface rock or root prevents shelving or auguring then locate the soil pit at the point nearest the plot center which will allow the soil profile to be examined. Record the azimuth and distance to the center of the pit with respect to the plot center.

3. Be careful to evenly lay out each auger headful from top to to bottom, connecting the top of successive auger headfuls to the bottom of the previous one. The length of the excavated soil material pile for each auger headful should be equal to the length of the auger head containing soil for that headful. Please note when done the top and bottom ends of the profile.

4. Label the "Field Sheet for Recording Soil Characteristics" with the appropriate photo plot number and line point number.

5. Locate and mark the soil profile horizons along the excavated soil material profile.

6. Measure the length (depth) of the soil horizons and sketch the profile on the recording form.

7. Determine and record for each soil horizon the Munsell soil color code, the texture (code according to instructions in the key on front of sheet NL1), structure, consistence, reaction, and miscellaneous characteristics. Each information type requested should be determined according to the "Definitions and Abbreviations for Soil Descriptions" USDA-SCS publication dated Oct. 1966 in your possession. Notation should also be as given in this publication except for texture as noted above. If a more refined determination of texture is possible, then also record this more precise determination according to the notation given in the USDA-SCS publication.

8. Determine and code Drainage and Erosion according to the USDA - SCS publication. Enter the codes on the appropriate lines of the recording form (Field Sheet for Recording Soil Characteristics).

9. Measure and record the depth to water table (groundwater) if it is present in the profile.

10. Repeat all steps above at either line point numbers 5 or 7 if the soil type appears to be different at these locations from that examined at line point number 6. The decision as to whether the soil type is in fact different will depend on examination requested for Sheet NL of top soil texture, color, percent greater than 2 mm volume. Remember to offset the soil pit 4 inches downslope from these line points and also please remember to label each "Field Sheet for Recording Soil Characteristics" with the appropriate photo plot and line point number.

11. When finished with the three soil profiles please note and record the time on the back of Sheet NL1 and by subtraction determine and record the total time spent on the soil profiles.

II. Living Component

A. Fill in date, crew code, photo plot number, and record the starting time (remember to record finishing time at the end and then determine total time at plot for Living Component).

B. Locate a 0.01 acre circular plot centered at the selected photo plot center. Utilize the 0.01 acre plot rope with a radius length of 11.78 feet to accurately locate the plot boundary.

C. Please read the recording form definitions in Table I.

D. Sheet No. L1

1. Record on the azimuth marked circle diagram at the right of Sheet No. L1 (representing the 0.01 acre plot with a 11.78 foot radius) the crown outline at maximum crown perimeter for all trees (conifer and broadleaf) having main stem dbh $\geq$ 5.5 inches and which have part of their crown over the 0.01 acre plot. Be sure to locate trees according to their proper azimuth. Indicate by dotted lines boundaries for trees whose crowns are overtopped by others. Please extend the crown boundaries for trees satisfying the above criteria beyond the circle on the recording form to the extent that it is practical from ground observation and according to recording form space.

   Give each tree dealt with above an index number starting at one and continuing as 1, 2, 3, ... Indexing should start with the tree whose stem is closest to zero azimuth and then proceed clockwise. Draw an arrow from the index number to the crown boundary to which it belongs.

2. Enter in the left-most information column of Sheet No. L1 the index number used for each tree in the diagram at the right. Then place a "slash" mark and give the species code given in Table II. If the identity of a plant can not be determined, then use the code "UK" followed by a "/" and then the code for the plant taxon most closely resembling the unknown plant. Please record a zero in the left-hand index code columns (columns are indicated by "X's") that are not used.

3. Proceed through the remaining information columns from left to right.

a. dbh should be measured on the largest main stem of a tree with a D-tape. Observations should be recorded to the nearest 0.1 inch.

b. The heights requested should be estimated to the nearest 2 feet for conifers and the nearest 2 feet for broad-leaved trees.

c. Distances requested should be determined by pacing from the plot center. Values should be recorded to the nearest 0.1 foot.

d. When recording values for D_1 the approximate location of the main stem for the given tree should be located and annotated on the crown area diagram at the right.

e. Record vertical foliar density (viewed looking upwards) for broad-leaved trees to the nearest 10%.

For all information types above, please record a zero in left-hand data columns (columns are indicated by "X's") that are not used.

4. If two copies of Sheet No. L1 are needed, then record a "2" in the underlined portion of the "Page 1/__" data item located in the upper right-hand corner. Otherwise, record a "1". On the second page record "Page II/2".

E. Sheet No. L2

1. Complete the diagram for crown area at maximum perimeter for trees (conifer and broad-leaved) having largest main stem dbh < 5.5 inches and total height > 6 feet. Please follow instructions as outlined in II.D.1.

2. Proceed through information columns from left to right.

a. dbh should be measured to the nearest 0.1 inch.

b. All height information should be estimated to the nearest 1 foot. Record height information for the bulge point only if a definable bulge point exists.

c. All distance information should be determined by pacing to the nearest 0.1 foot. Please locate and annotate main stems on the crown area diagram as described in II.D.3.d. Distance to bulge point should be determined only if a definable bulge point exists.

d. Vertical foliar density (viewed looking upwards) should be estimated to the nearest 10%.

e. Leaf data should be recorded as indicated in Table I.

F. Sheet No. L3

1. Trees (conifer and broad-leaved) having largest main stem dbh < 5.5 inches and height 6 to 2 feet inclusive: Proceed as in the applicable steps from II.D. except that height information should be determined to the nearest half-foot and vertical foliar density may be determined by either viewing upwards or downwards through the crown. Please remember to locate and annotate main stems on the diagram.

2. Age for conifers (nearest year) should be determined by counting the number of major branch whorls starting from the main stem base and proceeding to the stem top.

3. Both horizontal and vertical foliar density should be estimated to the nearest 10 percent.

G. Sheet No. L4

1. Please do part E on Sheet L4 for shrubs whose vertical projection of continuous canopy exceeds 1 foot diameter at the widest point (project onto a level plane). A continuous canopy is defined as a leaf matrix with overlapping leaves when viewed vertically. Its vertical foliar density can be less than 100%. If the shrub's continuous canopy density is less than one foot at its widest point then the information for that shrub plant should be recorded under part D. on Sheet L4. Don't count shrub individuals or their crown area in part D. that were included under part E. For shrubs included in part E, proceed as in the applicable steps from II.D. Note that maximum brush height (nearest 1/2 foot) should be estimated for that part of the brush plant falling within the 0.01 acre plot.

2. For trees (conifer and broad-leaved) with largest main stem dbh < 5.5 inches and with height < 2 feet, the total number of individual plants by species should be recorded (use tally meter if necessary). Also include shrubs in this table whose vertical projection of continuous crown canopy is less than one foot diameter at the widest point (project onto a level plane) as described in II.G.1. above. The estimated crown area at maximum perimeter expressed as a percent of the 0.01 acre plot area for each plant of a given species should be added together to give the total cumulative crown area for that species. The data value should be expressed as a percent of the 0.01 acre plot area to the nearest 5 percent.

3. A total cumulative crown area estimate should be made according to the method of II.G.2.for each component of herbaceous vegetation. Note that a forb is defined to include broad-leaved non-woody vegetation commonly referred to as "weeds" and "wildflowers."

H. When finished with Sheet No. L4 note the time and return to Sheet No. L1 and record the total time taken to perform measurements on the Living Component. Also check to see that each Sheet has the correct photo plot number recorded.

Table I Definitions for Recording Form Sheet No.'s L1, L2, L3, and L4

Vegetation to be analyzed: Includes all plants whose vertical projection of crown area covers some portion of the 0.01 acre plot.

dbh: diameter at breast height (approximately 4.5 feet)

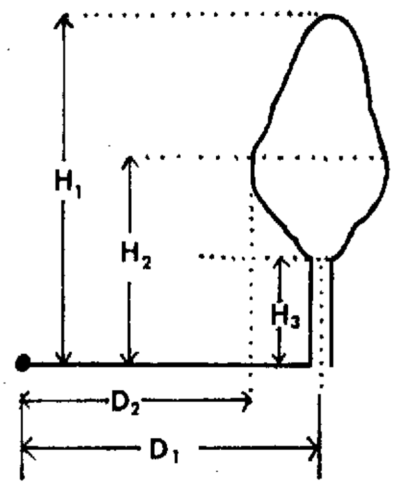
H_1 = estimate of height (vertical distance) from ground to plant top (see illustration)

H_2 = estimate of height (vertical distance) from ground to point of maximum canopy radius. The point of maximum canopy radius is defined as the bulge point.

H_3 = estimate of height (vertical distance) from ground to bottom of live crown defined by lowest location for a significant leaf mass.

D_1 = paced distance from 0.01 acre plot center to midpoint of largest main stem axis.

D_2 = paced distance from 0.01 acre plot center to a point on the ground defined by the vertical projection of maximum crown perimeter (bulge point) closest to the plot center, i.e. along the plot ray originating at the origin and passing through the main stem axis.



vertical foliar density: ocular estimate of percent background obscured by foliage when viewing vertically through the crown at an average crown thickness. The estimate must be made viewing upwards for large trees and may be made looking downwards for very small trees.

horizontal foliar density: ocular estimate of percent background obscured by foliage when viewing through the crown at average crown depth (direction parallel to slope).

vertical foliar and woody density: ocular estimate of percent of background obscured by foliage and woody plant parts when viewing vertically through the crown at average crown thickness.

horizontal foliar and woody density: ocular estimate of the percent background obscured by foliage and woody plant parts when viewing through the crown at average crown depth (direction parallel to slope).

herbaceous vegetation: living non-woody plants grass-like: includes grasses and sedges

forbs: includes broad-leaved non-woody plants commonly referred to as "weeds" and "wildflowers"

fern: a rhizomatous non-woody plant

Leaf Data

For firs, Douglas-fir, pines, yew, nutmeg and hemlock: Data for a single tree should be coded as:

I $[(u_1,\bar{u}_1,v_1,x_1,y_1,z_1)/(u_2,\bar{u}_2,v_2,x_2,y_2,z_2)/(u_3,\bar{u}_3,v_3,x_3,y_3,z_3)/\ldots]$OB,OL,n,a,b,c

II $[(u_2,\bar{u}_2,v_2,x_2,y_2,z_2)/(u_3,\bar{u}_3,v_3,x_3,y_3,z_3)/\text{maximum } t]$OB,OL,n,a,b,c

III $[(u_2,\bar{u}_2,v_2,x_2,y_2,z_2)/(u_3,\bar{u}_3,v_3,x_3,y_3,z_3)/\text{maximum } t]$OB,OL,n,a,b,c

where

I, II, III: represent branch sample number. Branch I is branch closest to the plot center at breast height. Branches II and III are located respectively clockwise 1/3 and 2/3 around the tree from Branch I. They are the branches closest to breast height at these locations.

a = azimuth of branch (nearest 5°) measured relative to the tree main stem (origin).

b = average tilt (nearest 5°) of overall branch leaf mass to right (positive) or to left (negative). Use "NA" if not applicable.

c = overall leaf covered branch slope (nearest 5°), with up positive, down negative. If more than one distinct slope, record each separately followed in parentheses by the t values corresponding to each segment.

n = width (nearest 1/2") of branch segment supporting emerging foliage.

u_t= average Munsell plant tissue color code for year t for upper leaf surface (make 4 to 5 estimates randomly located).

$\bar{u}_t$= average Munsell plant tissue color code for year t for lower leaf surface (make 4-5 randomly located estimates).

v_t= average needle width (nearest 1/32") for year t (take 4-5 random measurements).

x_t= yearly branch length (nearest 1/8") for year t; measured from end of previous year's needles to end of year t's needles.

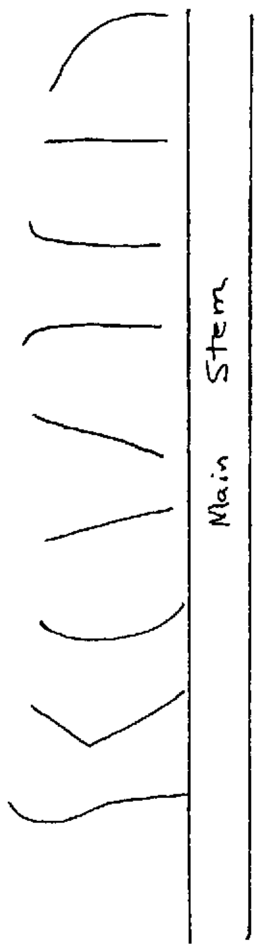
y_t= average needle length (nearest 1/8") for year t (take 4-5 random measurements)

z_t= average number of needles per inch along one side of branch for year t

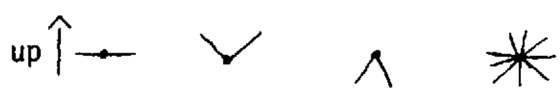
t = 1 (this year), 2 (last year), 3 (year before last),... until point at which no significant amount of needles remain.

OB= average leaf covered main branch axis shape when viewed from the side.

OB= 1 2 3 4 5 6 7 8 9 10



OL= average needle spray geometry when viewed in cross section.



1 2 3 4 5 6

Two trees for a given species should be selected for the above measurements. These two trees will be the ones with reachable needles located closest to the 0° and 180° azimuth and also with main stems closest to the plot perimeter.

<u>For cedar and juniper</u>: Data for a single tree should be coded as:

I $[OB, OL, a, b, c, m, n, (k_1, \bar{k}_1), (k_2, \bar{k}_2), \ldots, (k_8, \bar{k}_8)]$

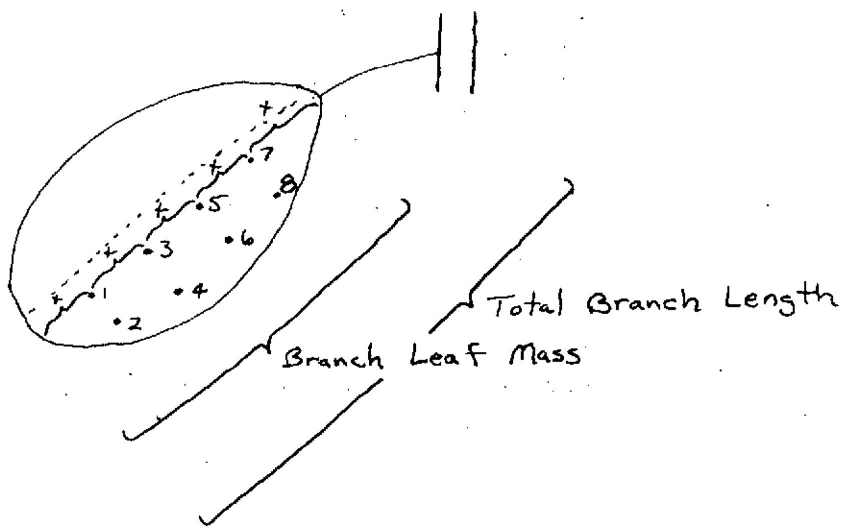
II $[OB, OL, a, b, c, m, n, (k_3, \bar{k}_3), (k_4, \bar{k}_4)]$

III $[OB, OL, a, b, c, m, n, (k_3, k_3), (k_4, k_4)]$

where

I, II, III: defined and located as in the case of fir

$k_1, k_2, \ldots k_8$ =Munsell plant tissue color code for the upper leaf surface measured at eight similarly located points shown below. The distance X should be constant. Each pair (e.g.1 and 2) should be located on a line perpendicular to the branch axis. The inner point should be 1/4 way to the branch leaf mass edge and the second point 3/4 way to the branch leaf mass edge.



$\bar{k}_1, \bar{k}_2, \ldots \bar{k}_8$ =Munsell plant tissue color code for the lower leaf surface measured at the same eight points as above.

m =length (nearest 1/2") of branch segment supporting emerging foliage.

Two trees should be selected for these measurements according to the criteria for fir.

For broad leaved trees: Data for a single tree should be coded as:

$$\text{I } [OB, OL, a, b, c, m, n, (r_1, s_1, p_1, d_1, l_1, \bar{l}_1), (r_6, s_6, p_6, d_6, l_6, \bar{l}_6), (r_{11}, s_{11}, p_{11}, d_{11}, l_{11}, \bar{l}_{11}), (r_{16}, s_{16}, p_{16}, d_{16}, l_{16}, \bar{l}_{16})]$$

II ["]

III ["]

where

I, II, III : defined and located as in the case of fir

g = leaf index number; "1" represents the leaf with petiole closest to the main branch tip, "6" represents the leaf with petiole 6th closest to the main branch tip, etc. Where leaves are simple opposite, count each pair as one leaf and flip a coin to determine which leaf of the 6th pair will be measured. If several side branches are attached to the main branch then proceed as before on the main branch, except that when a side branch is encountered go to the tip of that side branch and continue to count leaves down its length.

r_g = length (nearest 1/8") of selected leaf from leaf base to tip.

s_g = width (nearest 1/8") at maximum width of the leaf whose length (r_g) was measured.

p_g = percent (nearest 10%) of hypothetical maximum leaf area (no sinuses or indentations) actually taken up by leaf surface.

d_g = depth (nearest 1/32") of sinus or indentation nearest the maximum leaf width position.

l_g = Munsell plant tissue color code for the upper leaf surface.

$\bar{l}_g$ = Munsell plant tissue color code for the lower leaf surface.

Two trees for a given species should be selected for these measurements according to the criteria outlined for fir.

TABLE II

I. Tree Codes

Code	Scientific Name	Common Name
ABCO	Abies concolor	White Fir
ABMA-2	Abies magnifica	Red Fir
ACMA	Acer macrophyllum	Broadleaf Maple
ALN-2	Alnus species	Alder
ALRH	Alnus rhombifolia	White Alder
ARME-3	Arbutus menziesii	Madrone
BEOC-2	Betula occidentalis	Water Birch
CADE	Calocedrus decurrens	Incense Cedar
FRA10	Fraxinus species	Ash
JUN-5	Juniperus species	Juniper
JUOC	Juniperus occidentalis	Sierra Juniper
LIDE-2	Lithocarpus densiflora	Tan-bark Oak
PIAL	Pinus albicaulis	Whitebark Pine
PIAT-1	Pinus attenuata	Knobcone Pine
PICOM	Pinus contorta var. murrayana	Lodgepole Pine
PIJE	Pinus jeffreyi	Jeffrey Pine
PILA	Pinus lambertiana	Sugar Pine
PIMO-2	Pinus monophylla	Piñon Pine
PIMO-3	Pinus monticola	Silver Pine (also Western White Pine)
PIPO	Pinus ponderosa	Ponderosa Pine (also Yellow Pine)
PISA-2	Pinus sabiniana	Digger Pine

TABLE II (cont.)

Tree Codes Continued

Code	Scientific Name	Common Name
PLRA	Platanus racemosa	California Sycamore
PSME	Pseudotsuga menziesii	Douglas-fir
POFR-3	Populus fremontii	Fremont Cottonwood
POTR-3	Populus tremuloides	Quaking Aspen
POTR-4	Populus trichocarpa	Black Cottonwood
QUCH-2	Quercus chrysolepis	Canyon Oak (also Golden Oak)
QUKE	Quercus kelloggii	California Black Oak
QUWI	Quercus wislizenii	Interior Live Oak
TABR	Taxus brevifolia	California Yew
TOCA	Torreya californica	California Nutmeg
TSME	Tsuga mertensiana	Mountain Hemlock
UMCA	Umbellularia californica	California Laurel (also California Bay)

II. Shrub Codes

Code	Scientific Name	Common Name
ACE-1	Acer species	Maple
ADFA	Adenostoma fasciculatum	Chamise
ALN-1	Alnus species	Alder
ALTE	Alnus tenuifolia	Mountain Alder
AMPA-2	Amelanchier pallida	Service Berry
ARC-5	Arctostaphylos species	Manzanita
ARMA-3	Arctostaphylos manzanita	Common Manzanita

TABLE II (cont.)

Shrub Codes Continued

Code	Scientific Name	Common Name
ARME-2	Arctostaphylus Mewukka	Indian Manzanita
ARNE-2	Arctostaphylos nevadensis	Pinemat Manzanita
ARVI-3	Arctostaphylos viscida	Whiteleaf Manzanita
ART-5	Artemesia species	Sagebrush
ATR-3	Atriplex species	Saltbush
CAOC-2	Calycanthus occidentalis	Spice-Bush
CEA	Ceanothus species	California Lilac
CECO-2	Ceanothuscordulatus	Mountain Whitehorn
CECU-2	Ceanothus cuneatus	Buck Brush
CEIN-3	Ceanothus integerrimus	Deer Brush
CEJE	Ceanothus jepsonii	
CEPR	Ceanothus prostratus	Squaw Carpet
CEVE-3	Ceanothus velutinus	Tobacco Brush
CEOC	Cercis occidentalis	Redbud
CER-8	Cercocarpus species	Mountain-Mahogany
CHFO-2	Chamaebatia foliolosa	Kit-kit-dizze (also Mountain Misery or Bear Clover)
CHSE	Chrysolepsis sempervirens	Bush Chinquapin
CHR-9	Chrysothamnus species	Rabbit Brush
CLLI-2	Clematis ligusticifolia	Western Clematis
COR16	Cornus species	Dogwood
CONU-2	Cornus Nuttallii	Mountain Dogwood

TABLE II (cont.)

Shrub Codes Continued

Code	Scientific Name	Common Name
COST-3	Cornus stolonifera	American Dogwood (also Creek Dogwood)
COCOC	Corylus cornuta var. californica	Hazelnut
CYSC-2	Cytisus scoparius	Scotch Broom
DERI	Dendromecon rigida	Bush Poppy
DIP	Diplacus species	Bush Monkey-Flower
ERCA-6	Eriodictyon californicum	Yerba Santa
ERI21	Eriophyllum species	Yarrow
GAFR	Garrya Fremontii	Silk-Tassel
HEAR-2	Heteromeles arbutifolia	Toyon
HOL-3	Holodiscus species	Cream Bush
KAPOM	Kalmia polifolia var. microphylla	Alpine Laurel (also American Laurel)
LEGLC1	Ledium glandulosum var. californicum	Labrador-Tea
LEDA	Leucothoe Davisiae	Sierra Laurel
LON	Lonicera species	Honeysuckle
PHLEC	Philadelphus Lewissii ssp. californicus	Mock-Orange
PRU-2	Prunus species	Stone Fruits
PREM	Prunus emarginata	Bitter Cherry
PRVID	Prunus virginiana var. demissa	Western Choke Cherry
PRSU-2	Prunus subcordata	Sierra Plum
PUTR	Purshia tridentata	Bitterbrush

TABLE II (cont.)

Shrub Codes Continued

Code	Scientific Name	Common Name
QUE-1	Quercus species	Oak
QUDU-2	Quercus dumosa	Scrub Oak
QUVA	Quercus vaccinifolia	Huckleberry Oak
RHA-1	Rhamnus species	Cascara
RHCR	Rhamnus crocea	Redberry (also Buckthorn)
RHPU	Rhamnus Purshiana	Cascara Sagrada
RHRU	Rhamnus rubra	Sierra Coffeeberry
RHOC	Rhododendron occidentâle	Western Azalea
RHDI	Rhus diversiloba	Poison Oak
RHTR	Rhus trilobata	Squaw Bush
RIB	Ribes species	Currant (also Gooseberry)
RIDI	Ribes divaricatum	
RINE	Ribes nevadense	Sierra Currant
RIRO	Ribes Roezlii	Sierra Gooseberry
ROS	Rosa species	Rose
RUB-2	Rubus species	Blackberry (also Raspberry, etc.)
RULE	Rubus leucodermis	Western Raspberry
RUPA-2	Rubus parviforus	Thimbleberry
RUUR	Rubus ursinus	California Blackberry
SAL-1	Salix species	Willow
SAM-2	Sambucus species	Elderberry
SACA-4	Sambucus caerulea	Blue Elderberry

TABLE II (cont.)

Shrub Codes Continued

Code	Scientific Name	Common Name
SOR-4	Sorbus species	Mountain-Ash
SPI-3	Spiraea species	Spireae
STOFC	Styrax officinalis var. californica	California Storax
SYM-3	Symphoricarpos species	Snowberry
VAC-2	Vaccinium species	Huckleberry (also Bilberry or Blueberry)
VICA-3	Vitus californica	California Wild Grape

Plumas 1974 Hydrologic Resource Inventory — Sheet No. NL

Non-living Component for Water Yield Related Information — Place general comments on back

Date	Crew	Photo Plot	Time at Plot for Non-living Component

Azimuth of Line (1°) ________

Point Index (10' apart) (No. W to E)	Line Photograph Role No./ Frame No. XX/XX	Surface at Point	Surface Layer Color (Munsell Notation)	Surface Layer Thickness (1/16")	Top Mineral Soil Horizon Color (Munsell)	Texture of Top Mineral Soil Horizon	Percent of 0"–3" Mineral Material Vol. >2mm (10%)
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							

Interval a–b	% of Line with Exposed Mineral Soil (10%)	% of Line Covered by Rock (10 %)	% of Line Covered by Dead Organic Matter >1/4" (10 %)
1–2			
2–3			
3–4			
4–5			
5–6			
6–7			
7–8			
8–9			
9–10			
10–11			

Slope (1%)______ Aspect ________

Microrelief Over Line (circle one): smooth, rolling, gullied, hummocky (mounding), other ________

Where Soil Profile Exposed Please Note (nearest 1/2 inch)

1) Rooting depth ______
2) Depth to water impervious layer ______
3) Depth from top of mineral soil to bedrock ______
4) Bedrock type ______

Recording Form Key:

1) Surface at point
   - B ≡ bare mineral soil
   - R(X) ≡ rock
   - S(X) ≡ slash
   - X ≡ diameter of rock or slash to nearest 1/2"
2) Texture from soil in 1 1/2 – 2 inch top soil mineral horizon
   - 0 ≡ fragmental; stones predominate
   - 1 ≡ coarse-textured; sandy
   - 2 ≡ moderately course; sandy loams
   - 3 ≡ medium-textured; loam, silt loam
   - 3S ≡ silt
   - 4 ≡ moderately fine; clay loam, sandy clay loam, silty clay loam
   - 5 ≡ fine-textured; clay, silty clay, sandy clay
   - Modifers:
     - G ≡ gravelly, rock 2mm – 3"
     - C ≡ cobbly, rock >3" – 10"
3) Bedrock type
   - AI ≡ acid igneous
   - BI ≡ basic igneous
   - UBI ≡ ultrabasic igneous
   - MI ≡ meta-igneous
   - S ≡ sedimentary
   - MS ≡ meta-sedimentary

FIELD SHEET FOR RECORDING SOIL CHARACTERISTICS

No. ______

Soil Type ______

Location ______

Geographical Landscape ______

Elevation ______ Slope ______ Aspect ______ Erosion ______

Groundwater ______ Drainage ______ Alkali ______

Mode of Formation ______ Parent Material ______

Climate ______

Natural Cover ______ Soil Region ______

Profile Group ______ Higher Categories ______

Genetically Related Soil Series ______

PROFILE SKETCH	COLOR	TEXTURE	STRUC-TURE	CONSISTENCE	REAC-TION	MISC: Roots, Pores, Clay films, Concretions

Natural Land Division ______

Soil Rating (Storie index) ______ Soil Grade ______

Land Use Capability Unit ______

Present Use ______

Suitability: Irrigated Crops ______ Range ______

Nonirrigated Crops ______ Timber ______

Soil Management ______

Remarks ______

Plumas 1974 Hydrologic Resource Inventory

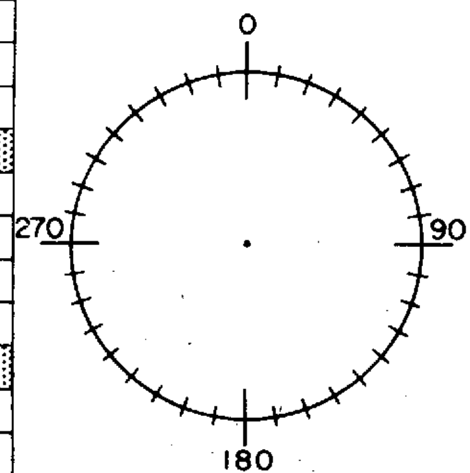
<u>Living Component</u> Water Yield Related Information

Sheet No. L1
Page 1/___

Date	Crew	Photo Plot	Time at Plot for Living Component

A. Trees Having Largest Main Stem dbh <u>Greater</u> Than or <u>Equal</u> to 5.5 Inches

Index No./ Species Code XX/XXXX	dbh of largest stem (0.1") XX.X	H_1 (tree top) (2' for C) (2' for B) XXX	H_2 (bulge pt) (2' for C) (2' for B) XXX	H_3 (crown btm) (2' for C) (2' for B) XXX	D_1 (trunk mdpt) (0.1') XX.X	D_2 (bulge pt) (0.1') XX.X	Vertical Foliar Density for Broad Leaved Species (% sky obscured by leaves) (10%) XX	Diagram for Crown Area at Maximum Perimeter



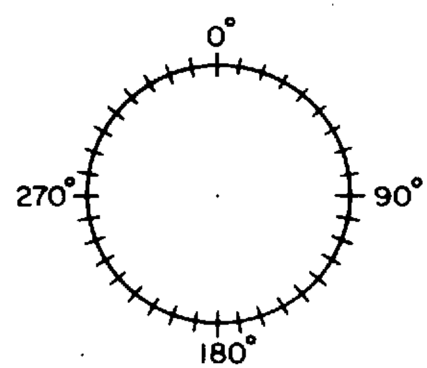
Plumas 1974 Hydrologic Resource Inventory

Photo Plot ____ Sheet No. L2

Page 1/ ____

B. Trees Having Largest Main Stem dbh <u>Less</u> Than 5.5 Inches And Greater Than 6 Feet Tall.

Index No./ Species Code XX/XXXX	dbh of Largest Stem (0.1") XX.X	H_1 (Tree Top) (1') XX	H_2 (Bulge Point) (1') XX	H_3 (Crown Bottom) (1') XX	D_1 (Trunk Midpoint) (0.1') XX.X	D_2 (Bulge Point) (0.1') XX.X	Vertical Foliar Density for Broad Leaved Trees (10%) XX	Leaf Data	Diagram for Crown Area at Maximum Perimeter



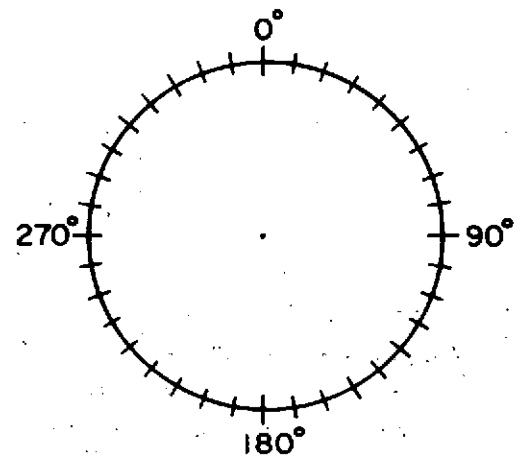
Plumas 1974 Hydrologic Resource Inventory

Photo Plot_____ Sheet No. L3

Page 1/_____

C. Trees Having dbh Less Than 5.5 Inches And 6 Feet To 2 Feet Tall Inclusive.

Index No. / Species Code XX / XXXX	H_1 (Tree Top) (1/2') XX.X	H_3 (Crown Bottom) (1/2') XX.X	D_1 (Trunk Midpoint) (0.1') XX.X	Age for Conifers (1 Year) XX	Horizontal Foliar Density (% Background Obscured by Leaves) (10%) XX	Vertical Foliar Density (10%) XX	Diagram for Crown Area at Maximum Perimeter



Plumas 1974 Hydrologic Resource Inventory

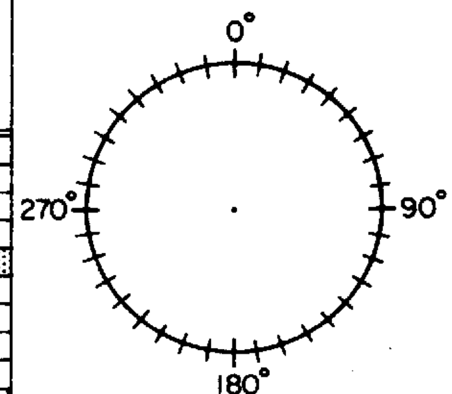
Photo Plot ____

Sheet No. L4
Page 1/ ____

E. Shrubs (Generally Less Than 7 Feet)

Index No./ Species Code	H_1 (Highest pt of shrub plant in 0.01 ac. plot) (1/2')	Horizontal or Vertical Foliar Density (Record whether Vertical (V) or horizontal (H)) (10%)	Horizontal or Vertical Foliar & Woody Density Combined (Record whether V or H) (10%)
XX/XXXX	XX.X	XX	XX

Diagram for Crown Area at Maximum Perimeter (Shrubs)



D. Trees Having dbh Less Than 5.5 Inches And Less Than 2 Feet Tall.

Species Code	Total No. of Individuals	Total Cumulative Crown Area as a Percent of the 0.01 Ac. Plot Area (5%)
XXXX	XXX	XX

F. Herbaceous Vegetation Component	Total Cumulative Crown Area as a % of 0.01 Ac. Plot (5%) XX
Grass-like	
Forb	
Fern	

APPENDIX IV

PROCEDURE FOR MEASURING SECONDARY SAMPLING UNIT PHOTO PLOTS FOR WATER LOSS ESTIMATION

David Marc Huston

CONTENTS

I. INTRODUCTION

The secondary sampling unit discussed in section 2.110b contains information which is used to refine estimates of evapotranspiration made from the primary sampling unit. Some of the data from the SSU is in the form of large scale aerial photographs. The photo interpreter's task is to identify and quantify on these large scale photographs various features of the living and non living component in and about .01 acre plots selected by probability sampling.

The following sections describe the methods that the photo interpreter will follow to measure and describe the .01 acre plots.

The ensuing methodologies are based on the information that field crews extracted from .01 acre plots in the Spanish Creek Watershed in August, 1974. Where applicable the information sought by the photo interpreter is much the same as the information collected by the field crews.

The photgraphs used to develop these methodologies were obtained from five flight lines over the Spanish Creek Watershed. Each line was flown in April, May, and August. The plane was equipped with two 35mm cameras, one with a 24mm lens and the other with a 200mm lens, which contained Kodacolor II film. The cameras were synchronized so that the camera with the telephoto lens would take 3 frames for each frame taken through the wide angle lens. Therefore, each stereo triplet from the telephoto was located at the center of the wide angle photo.

Corresponding photographic products consisted of wide angle stereo pairs and telephoto triplets in 3R format ($4\frac{1}{2}$ x $3\frac{1}{4}$") and 7" x 10" stereo pairs made from telephoto negeatives. U.S. Geological Survey topographic maps and small scale 9"x9" highflight transparencies were also used. The approximate location of each of the wide angle photo centers were plotted on the USGS maps.

II. Photo Interpretation Tools

The photo interpreter will need the following tools:

1. mirror stereoscope
2. 2-4 power Abrams stereoscope
3. rulers, to $\frac{1''}{100}$ detail, or metric equivalent
4. point marker
5. light table
6. ink pen
7. dot grids (1 mm spacing)
8. protractor
9. parallax bar
10. stereo slope comparator
11. clear acetate sheets

III. Non-Living Component, Line Data

A. Fill in the information requested at the top of Sheet NL1.

B. Line Data for Sheet NL1.

1. Locate the prepunched photo center of the middle large scale 3R stereo triplet. Find the corresponding point on the 7" x 10" stereo pair enlargement and the small scale 3R (wide angle) photo. Mark these locations with a point pricking needle. A point pricking needle is used as measurements to be made are critical and should be unaffected by the size of the point.

2. Locate and code the plot center on a USGS topographical map using the largest scale map available. Record the elevation of the plot center on line 5.

3. Determine the scale of the 3R wide angle, the 3R telephotos, and the 7" x 10" enlargements. Record the scale of each in lines 7, 8, and 9. Factors that must be shown are:

plane's altitude - from Table 1. (Record on line 6)

plot center elevation - determined in step 2 above.

focal length:

wide angle lens = 24 mm = 0.94"
telephoto lens = 200 mm = 7.87"

all units must be the same

a 3R print (from a 35 mm negative) increases scale by a factor of 3.40 (this figure should be derived)

a 7" x 10" print increases the scale of a 35 mm negative by a factor of 8.42 (this figure should be derived as the amount of enlargement during processing may not be consistent).

$$\text{scale} = \frac{\text{camera focal length}}{\text{plane's altitude above ground}}$$

4. Draw a true north-south line through the plot center. True north (or azimuth 0°) is found after a line of true direction is found. The line of true direction may be obtained by taking the azimuth reading of a line drawn through two points which can be located on both the USGS map and the wide angle or supporting high-flight photos. True north is determined by offsetting from this line the appropriate number of degrees.

5. Draw a circle about the plot center which encloses an area of .01 acre. This is the photo plot. On the ground the radius of a .01 acre circle is 11.78' or 141.36'. The radius of a circle on the photographs is:

$$R = \frac{141.36}{\text{scale (in inches)}}$$

The circle should be drawn so that the inner edge of the ink line is distance "R" from the plot center. Record the radius of the circle on line 10.

6. The azimuth of a line to be drawn through the plot center is located along a topographic contour running through the plot center.

Record the azimuth in relation to the north-south line determined in step 4 on line 11. Ten points are to be located and marked along the azimuth line, the plot center is point #6. The distance between each point, 10' on the ground, is:

$$D = \frac{120''}{\text{scale (in inches)}} \qquad \text{on the photo}$$

Record the calculated D value on line 12.

The points are enumerated 1 to 11, with #1 in the azimuth hemisphere to the west (180° to <360°) of the plot center point (point #6).

7. When crown canopy and shadow conditions permit, the ground cover at each of the 11 points should be described as either rock, slash, snow, or bare soil. Record this information in Column A. If the ground isn't visible, enter the code for either shade or plant cover.

8. Munsell soil color readings[1] should be taken at all sunlit points. Munsell readings are taken by laying the appropriate color chip over the area to be measured. The light source, angle of light source, and distance to the light source used to illuminate the photos should be kept constant and recorded. Suggested constants are:

angle of light - 45°

wattage of light - 100 watts

distance, bulb tip to measured area - 1 foot

Record these readings in Column B.

---

[1] Munsell Soil Color Charts - Munsell Products, Macbeth Color and Photometry Division of Kolomorgen Corp., Baltimore, Maryland. 1973.

9. Measurements of the ground cover characteristics between two consecutive points are to be expressed as a percentage of the distance between the two points. Percents of bare mineral soil, rock, slash, and snow between two consecutive points should be determined by measurement if the ground can be seen. Measure the percent shadow or plant cover between each two points. Take a Munsell reading between consecutive points on sunlit ground. Record these measurements in Columns C - H.

10. Record the average aspect (to the nearest degree) for the photo plot on line 13. Aspect is the direction that a viewer looking downhill faces, or geometrically, aspect is the azimuth direction of a line perpendicular to a plane paralleling the average ground surface.

11. Determine the average slope of the photo plot with a stereo plot comparator. Record this figure on line 14.

12. General Characteristics. Comment on microrelief and erosional features described in Table 2.

IV. Non-Living Component, Plot Data

A. Fill in the information requested at the top of Sheet NL2.

B. Plot Data for Sheet NL2

1. Using an appropriate (1 mm spacing), randomly located dot grid over the photo plot, count the number of dots falling on snow (excluding snow on the canopy cover), rock, and bare mineral soil within the photo plot for points where the ground is visible. Record these measurements on lines 5 - 7 as a fraction: the numerator is the number of dots falling on the item of interest and the denominator is the total number of ground visible photo plot dots. On line 8 record the number of dots falling on snow including both canopy and ground locations. On line 9 record the total number of dots falling in the photo plot.

2. Measure and determine the pattern, the direction, and the number, average length and width of cracks and fissures in areas of exposed bedrock. Record these measurements on lines 10a, 10b and 10c.

3. Take Munsell readings at these locations when the ground surface is visible and sunlit:

Azimuth		Distance from Plot Center
0°	-	1.00 X R, .75 X R, .50 X R, .25 X R
90°	-	1.00 X R, .75 X R, .50 X R, .25 X R
180°	-	1.00 X R, .75 X R, .50 X R, .25 X R
270°	-	1.00 X R, .75 X R, .50 X R, .25 X R

Record these readings in Table NL2 1.

4. General comments: describe the landform characteristics seen in the wide angle photo surrounding the photo plot based on the descriptions in Table 3.

V. Living Component. Tree Growth Forms (woody shrubs and herbaceous vegetation excluded)

A. Fill in the information requested at the top of Sheet L1.

B. Photo Plot Data for Sheet L1

1. For each tree whose main stem and/or crown area falls within the .01 acre plot perform the following. For trees very near the photo center appearing nearly vertical, locate and mark the estimated true planimetric position of the tree trunk-ground interface point. This point may be approximated by the location of the tree crown apex. If trees don't appear vertical due to radial or relief displacement and the trunk-ground interface isn't visible under the stereoscope due to shading or plant cover, then estimate the location of the trunk-ground interface point and mark that point.

2. Identify each tree by species according to the keys and environmental information in Table 4. Identify and index each tree in the following manner. Give each tree dealt with an index number starting at one and continuing as 1, 2, 3 . . . Indexing starts with the tree whose stem is closest to zero azimuth and proceeds clockwise. Enter in Column A the index number used for each tree. Then place a "slash" mark and give the species code from Appendix 5. If the identity of a tree cannot be determined than use the code XXXC for conifer and the code XXXH for hardwood. Make another "slash" and enter the azimuth which runs through the trunk-ground interface point relative to the plot center.

3. Measure the distance between each of the points located in step 1 (the trunk-ground interface points) and the plot center. Record these measurements in Column B and convert to ground distance.

4. Measure the distance from the plot center to the bulge point for each tree on a line from the plot center to the trunk-ground interface point. Record these measurements in Column D and convert to ground distance.

5. Measure the crown diameter of each tree at its widest and narrowest points. Record these measurements in Column F and Column G and convert these figures to ground distance.

6. Measure the height of each tree with a parallax bar. Record these measurements in Column J.

7. Measure the height of the bulge point of each tree with a parallax bar. Record these measurements in Column K.

8. Measure the height of the crown bottom of each tree with a parallax bar. Record these measurements in Column L.

9. Estimate the canopy area of each tree in relation to the .01 acre plot area. Proceed by drawing each tree crown perimeter, and the plot circle, on an acetate overlay. Randomly locate (by a slight tossing motion) an appropriate density (1 mm spacing) dot grid over this overlay. Non-permanently, tape the dot grid to the overlay. The dot grid must cover the plot circle and all

crowns delineated on the overlay. Count the total number of dots falling within each tree's crown perimeter (including any portion that may be outside the plot). Record this information in Column M as the numerator of a fraction: the denominator of this fraction is determined by counting the number of dots that fall on the portion of the tree crown that is inside the photo plot. When dot counting the inclusion or exclusion of dots falling on the crown boundary is decided by coin flipping. "Heads" decides dot inclusion and "tails" decides dot exclusion.

10. Without moving the dot grid, count the total number of dots falling in the photo plot. Record this figure on line 5.

11. Without moving the dot grid, count the number of dots on the randomly located grid covering the photo plot which fall on the portions of the trees measured in this section which are within the plot circle. Record this figure on line 6.

12. Without moving the dot grid, count the number of dots falling on any leaf surface within the photo plot circle. Record this figure on line 7.

13. Describe the physiological state for each tree, referring to the description in Table 6. Record this information in Column N.

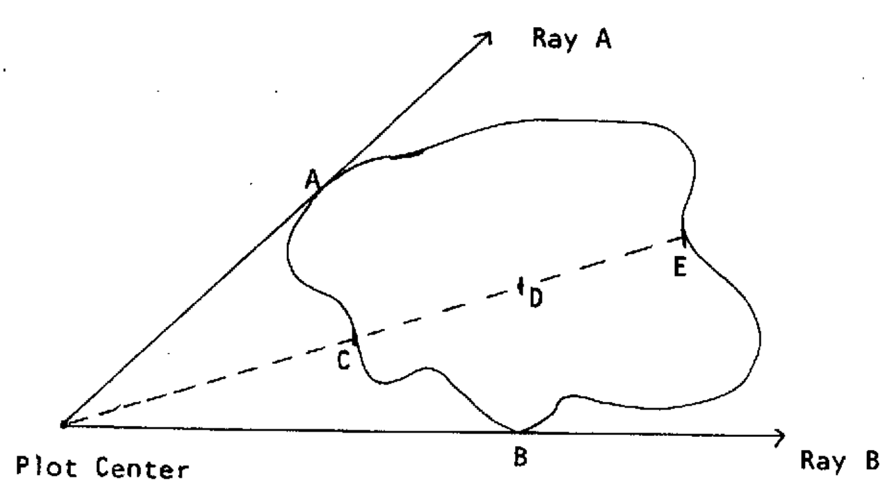
IV. Living Component - Woody Shrubs and Herbaceous Vegetation

A. Fill in the information requested at the top of Sheet L2.

B. Photo Plot Data for Sheet L2.

1. Mark the center of the shrub clones whose crowns fall in the .01 acre plot. Give each shrub clone dealt with an index number starting at one and continuing as 1, 2, 3, . . Indexing starts with the clone whose center is closest to zero azimuth and proceeds clockwise. Enter the index number for each clone in Column A. Then place a "slash" mark and enter the species or genus code applicable (found in Table 5) if the clone can be identified. If the shrub clone can't be identified denote whether the clone is evergreen or deciduous. If evergreen write XXXE. If deciduous, write XXXD. If this information can't be determined write XXXU.

2. Take azimuth readings on two rays from the plot center that are tangent to the widest extent of the clone within the photo plot. Measure the distance from the plot center to the points on the clone tangent to the two rays. Also measure the nearest distance and farthest distance of the shrub clone on a line from the plot center, through the center of the clone marked in step 1 above.



Record this data in Columns C and E.

3. Estimate the height of the shrub clone in relation to a relatively shorter measured tree coded on Sheet L1. Record this figure in Column G.

4. Describe the physiological state of each shrub clone. Refer to Appendix 6 for the appropriate descriptions. Record these measurements in Column H.

5. Randomly locate (by a slight tossing motion) the dot grid over the photo plot. Non-permanently tape the dot grid to the photo. Count the number of dots falling on any shrub clone leaf surface within the photo plot circle. Record this figure on line 5.

6. Without moving the dot grid and in the same manner described in step 5 above, count the number of dots falling upon grasses, ferns, and forbs within the photo plot. Record this figure on line 6.

7. Without moving the dot grid, count the total number of dots falling within the photo plot. Record this figure on line 7.

Table 1: Pilot's Data for Flight Lines

Date	Flight Line No.	Description	Approx. Terrain Elev.	Flying Altitude Above MSL (± 100')
April 4, 1974	1	Silver Lake	4700'	7200'
	2	Gold Lake	4700'	7150'
	3	Schneider Creek	4900'	7350'
	4	South of Quincy	5500'	7950'
	5	Squirrel Creek	5500'	8000'
May 9, 1974	1	Silver Lake	4700'	7100-7200'
	2	Gold Lake	4700'	7050-7150'
	3	Schneider Creek	4900'	7400'
	4	South of Quincy	5500'	7850-7900'
	5	Squirrel Creek	5500'	8000'
May 30, 1974	1	Silver Lake	4700'	7300'
	2	Gold Lake	4700'	7250'
	3	Schneider Creek	4900'	7300'
	4	South of Quincy	5500'	7550'
	5	Squirrel Creek	5500'	8000'
August 21, 1974	1	Silver Lake	4700'	7250'
	2	Gold Lake	4700'	7100'
	3	Schneider Creek	4900'	7400'
	4	South of Quincy	5500'	8000'
	5	Squirrel Creek	5500'	8000'

Table 2: Microrelief and Erosional Feature Description

There are five general types of erosional features that the photo interpreter may see on large scale imagery. They are due to the following erosional processes.

1. sheet erosion (fluvial)
2. wind erosion (eolian)
3. rilling (fluvial)
4. gullying (fluvial)
5. mass wastage (mass wasting)

The first two, sheet erosion and wind erosion, are more likely to occur and be identified in arid and semi-arid areas. The latter three, rilling, gullying, and mass wastage, may be observed in humid areas such as the Spanish Creek Watershed.

gully A gully is defined as an eroded trench greater than 2-3 feet in depth resulting from water-cutting force aided soil erosion. Recently formed gullies can be differentiated from summer dry stream beds by the fact that there is only sparse woody riparian vegetation along gully banks.

rill A rill is defined as a shallow trench less than one foot in depth resulting from water-cutting force aided soil erosion.

mass wastage Mass wastage can take the form of landslides or slumps. Mass wastage can be revealed by low pressure mounds and ridges along a slope, by twisted tree trunks and the curling of soil material over road beds.

Table 3: Description of Landform Characteristics[1]

alluvial fan	a cone-shaped deposit of alluvium made by a stream where it runs out onto a level plain and meets a slower stream. The fans generally form where streams issue from mountains upon the lowland.
alluvial plain	A plain resulting from the deposition of alluvium by water.
arete	An acute and rugged crest of a mountain range, or a subsidiary ridge between two mountains or of a mountain spur such as that between two cirques.
canyon	A steep-walled chasm, gorge or ravine; a channel cut by running water in the surface of the earth, the sides of which are composed of cliffs or series of cliffs rising from its bed.
cirque	A deep steep-walled recess in a mountain, caused by glacial erosion.
col	A saddle or gap across a ridge and between two peaks; also, in a valley in which streams flow both ways from a divide, that part of the valley at the divide, especially if the valley slopes rather steeply away from the divide.
hill	In general, the term hill is properly restricted to more or less abrupt changes in elevations of less than 1,000 feet, all altitudes exceeding this being mountains.
moraine	Drift, deposited chiefly by direct glacial action, and having constructional topography independent of control by the surface on which the drift lies.

mountain	A tract of land considerably elevated above the adjacent country. The term is usually applied to relatively abrupt elevation changes of more than 2,000 feet.
plain	A region of general uniform slope, comparatively level, of considerable extent, and not broken by marked elevations or depressions.
ravine	A depression worn out by running water, larger than a gully and smaller than a valley.
talus	A collection of fallen disintegrated material which has formed a slope at the foot of a steeper declivity.
tarn	A small mountain lake or pool, especially one that occupies an ice gouged basin on the floor of a cirque.

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1. American Geological Institute Dictionary of Geological Terms Dolphin Books, Doubleday and Company, Inc., Garden City, New York 1962

Table 4 - Tree Species Keys, Photographic Examples and Environmental Description

This table is comprised of the following components which will aid the interpreter in the identification of tree species in the Spanish Creek Watershed:

1. A summary of identifying characteristics to forest species which includes:
   a) average heights for mature trees.
   b) the color of trees on Kodacolor II prints.
   c) a crown description
   d) a crown margin description
   e) branch characteristic description
   f) listing of soils on which the tree occurs.
2. An ecological summary and aerial description of tree species which describes:
   a) tolerance to shade
   b) occurence with other species
   c) a description of aerial characteristics (from Lauer, 1966)
3. A dichotomous key developed by Lauer, (1966)
4. Photographic examples in 3R stereo pairs with accompanying written descriptions

The photo interpreter should familiarize himself/herself with the preceding identification aids. Most mature trees can be identified by their morphological characteristics on the large scale photos. When confusion exists, as between white fir and red fir and between ponderosa pine and Jeffry pine, other plot information such as elevation,aspect, and ecological characteristics should enable the interpreter to make the differentiation with confidence.

Summary of Identifying Characteristics of Forest Species in the Spanish Creek Watershed[1]

Species	Tree Height	Color on Kodacolor II Prints	Crown Description	Crown Margin	Branch Characteristics	Soils
Abies concolor	60 - 180'	whitish green	mature irregular, round topped; live crown to ground in open stands	crenate	short stiff branches, mature trees lower and middle crown branches droop, upper stay upright	deep, rich, moist loams, frequent among disintegrating granite
Abies magnifica	60 - 200'	whitish green	mature short, narrow, round topped; brittle top often broken; young extend to ground	crenate	mature branches droop except at crown top	moist, porous
Calocedrus decurrens	50 - 150'	yellow green	mature open, irregular; young narrow, pointed, extends to ground	denticulate	dense tufts of foliage	deep, acid loams
Juniperus occidentalis	15 - 30'	yellow green	round topped, open crown	dentate	branches large, spreading foliage at end of branches, leaving interior stems foliage free	similar to Pinus jeffreyi
Pinus lambertiana	60 - 200'	whitish green	mature flat topped young open & narrow	parted	mature well spaced wide spreading	well drained sandy loams
Pinus jeffreyi	125 - 140'	yellow green	long, narrow crown	denticulate	branches less stout and angled than Pinus ponderosa	well drained loose, coarse, sandy, or gravelly loams

Pinus ponderosa	125 - 140'	yellow green	long, narrow crown	denticulate	short, pendulous branches which are upturned at ends	well drained loams
Pseudotsuga menziesii	70 - 250'	blue green	mature rounded or flattened; young broad, sharp pyramid	dentate	numerous long side hanging branchlets	loose, well drained
Quercus kelloggii	50 - 75'	light green	irregular, broad, lobed open rounded			dry loams

* See Figure 1 for sketches of crown margins

1. Lauer, Donald T. The Feasibility of Identifying Forest Species and Delineating Major Timber Types in California by Means of High Altitude Small Scale Aerial Photography. School of Forestry, University of California, Berkeley, California. September 30, 1966

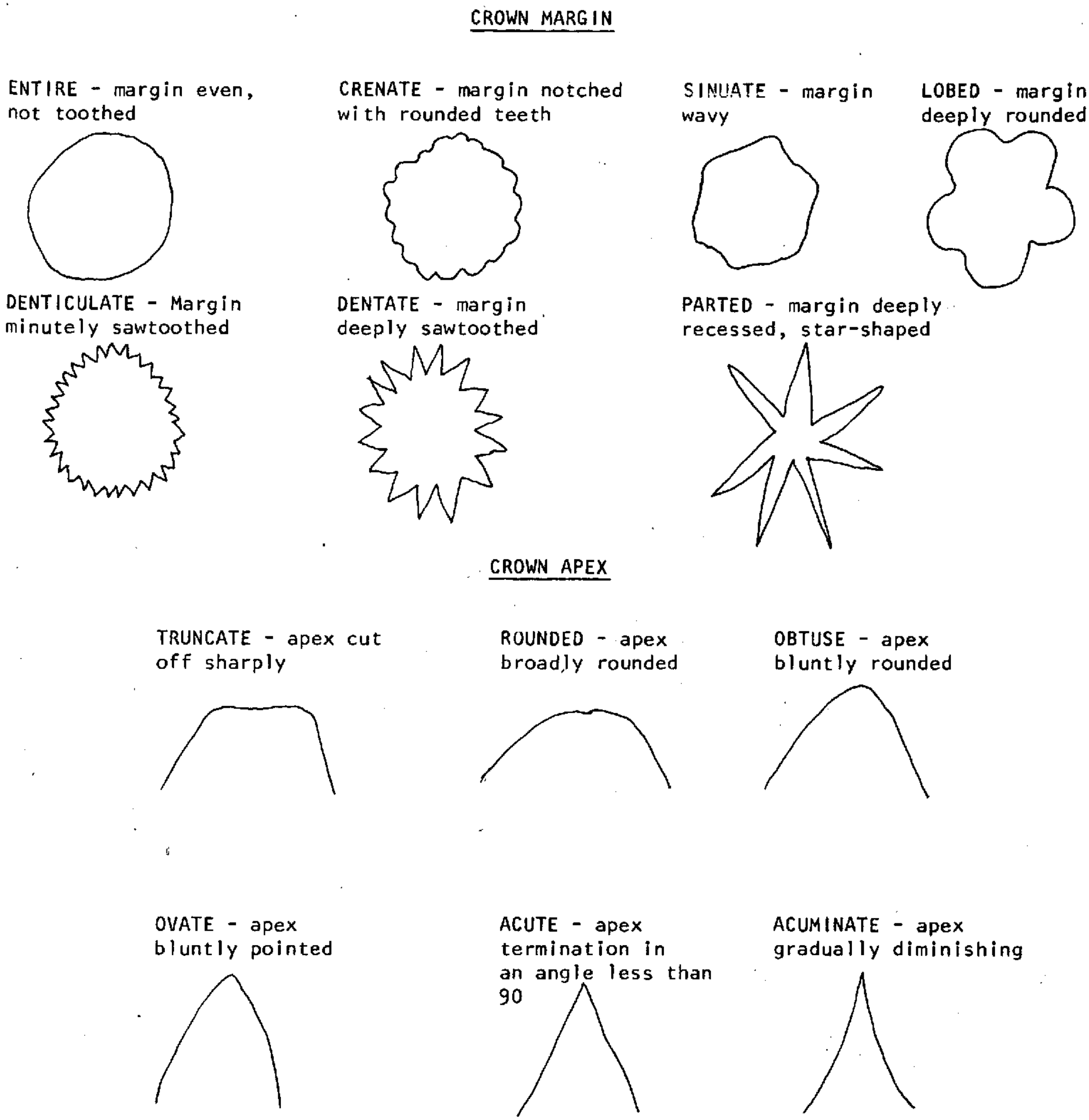

Figure 1: Schematic drawings of tree morphology as seen on aerial photography.

C-3

Ecological Summary and Aerial Description of Plumas County Forest Species

Species	Tolerance to Shade [1,2]	Occurence [1,2]	Aerial Characteristics [3]
Abies concolor	very, more so than associated species, slow progress under heavy shade	moderate elevations (4000-7000'); N&E aspects; w/ PIPO, PILO, CADE ABMA	A 60 to 200 foot evergreen tree with a straight trunk. Whorled branches form a cylinder-shaped crown with a very pointed top. A heavy cone crop in the top of the tree crown is often discernible on fall photography.
Abies magnifica	very moderately tolerant, rarely in subordinant positions in even aged stands	above 5000' in Plumas, to timber line; N&E aspects; nearly pure stands; w/PILA, PSME and sometimes ABCU, PIPO.	A 60 to 200 foot evergreen tree with a straight trunk. Whorled branches form a cylinder-shaped crown with a very pointed tip which is very brittle and ofter broken. A heavy cone crop in the top of the tree crown is often discernible on fall photograhy
Calocedrus decurrens	more tolerant than PILO, PIPO, PSUE; subordinate due to slower growth and greater tolerance	E rather than W aspect; w/PILO, PIPO	A 50 to 150 foot tree with a tapering trunk from a thick base. Spreading and slightly drooping branches form a broadly rounded to obtuse crown apex. Difficult to separate from ponderosa pine.
Juniperus occidentalis	intolerant	Similiar to Pinus jeffreyi	A 15 to 30 foot evergreen tree with large spreading branches and open crown. A distinct yellow-green color, interior branch stems are devoid of vegetation.
Pinus lambertiana	very intolerant when mature; requires partial shade when young	N slopes, benches, ravines; S&W slopes at higher altitudes; w/ PIPO, CADE, PSME, ABCO, ABMA; never in pure stands	A 60 to 200 foot evergreen with a straight trunk. Huge branches spread outward horizontally and often form a flat-topped crown. The deeply parted crown is the primary characteristic discernible on aerial photos.

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Pinus jeffreyi	similar to Pinus ponderosa	on dry, Eastern slopes 5200 to 9000' elevation w/ PIPO, ABMA, CADE, JUOC	similar to Pinus ponderosa but with a larger more symmetrical crown
Pinus ponderosa	greater than 20' needs unbroken light; trees of this species in mature stands rarely touch crowns	dry and moist slopes; pure & mixed stands; w/ PILO, CADE, PSME, ABCO; brushy ground cover when young	A 60 to 200 foot evergreen tree with a straight trunk. Spreading and slightly drooping branches form a broadly rounded to obtuse crown apex. A slightly brownish cast due to needle dieback can be detected in fall photography. Separated from incense cedar only by its superior height, occurence in pure stands, or occurence on drier sites.
Pseudotsuga menziesii	moderately tolerant: more than PIPO, PILA, but less than ABCO, CADE	prefers N than S aspect; at higher elevations: E than W S than N aspects	A 70 to 250 foot evergreen tree with a straight trunk. Irregular whorled branches spread horizontally with pendulous branchlets forming a deeply saw-toothed crown margin.
Quercus kelloggii	moderate when young; tolerance subordinate to that of PIPO	slopes, valleys, benches, w/ PSME, PIPO, CADE	A 30 to 80 foot deciduous tree with stout spreading branches forming a broad round topped crown. The foliage on each branch gives the crown margin a lobed or billowy appearance. Its fall color appears yellow to yellow-green.

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1. Munz, Phillip A. A California Flora and Supplement University of California Press, Berkeley and Los Angeles, California. 1968

2. Sudworth, George B. Forest Trees of the Pacific Slope, Dover Publications, Inc. New York, New York, 1967.

3. Lauer, Donald T. (ibid)

DICHOTOMOUS PHOTO INTERPRETATION KEY FOR
FOURTEEN CALIFORNIA FOREST SPECIES FOUND TO OCCUR
IN THE BUCKS LAKE-MEADOW VALLEY AREA (MIXED CONIFER FOREST TYPE);

1. Tall (100 feet) evergreen trees with bluntly rounded (obtuse) to pointed (acute) crown apexes 2

1. Medium tall (100 feet) deciduous trees with broadly rounded crown apexes 8

   2. Crown apexes are sharply pointed 3

   2. Crown apexes are bluntly rounded 4

3. Mature stands are whitish-green on aerial Kodacolor II prints. Cone crop is often discernible in the Fall . . . <u>Abies concolor</u>

3. Mature stands are whitish-green on aerial Kodacolor II prints. Cone crop is often discernible in the Fall. Generally is found at higher elevations . . . . <u>Abies magnifica</u>

   4. Trees often taller than 100 feet. Mature stands are yellow-green or whitish-green on aerial Kodacolor II prints. Generally is found on a variety of well-drained soils 5

   4. Trees rarely taller than 100 feet. Mature stands are brownish-green on aerial Kodacolor II prints. Generally is found on wet flats or poorly drained soils <u>Pinus contorta</u>

5. Mature stands are yellow-green or blue-green on aerial color prints. Crown margins are minutely sawtoothed (denticulate) or deeply sawtoothed (dentate) 6

5. Mature trees are whitish-green on aerial Kodacolor II prints Crown margins are deeply parted . . . . <u>Pinus lambertiana</u>

   6. Mature stands are yellow-green on aerial Kodacolor II prints. Crown margins are minutely sawtoothed (denticulate) 7

   6. Mature stands are blue-green on aerial Kodacolor II prints. Crown margins are deeply sawtoothed (dentate) <u>Pseudotsuga menziesii</u>

7. Mature stands rarely occur on serpentine soils . . . . . *Pinus ponderosa*

7. Mature stands often occur on serpentine soils . . *Libocedrus decurrens*

8. Trees are non-riparian; genearlly occuring on dry, well-drained soils 9

8. Trees are riparian; generally occuring on moist alluvial soils 10

9. Trees often taller than 40 feet. Mature stands are bright yellow or brownish-red during fall color change . . . . *Quercus kelloggii*

9. Trees rarely taller than 40 feet. Mature stands are bright-red during fall color change . . . . *Cornus nuttallii*

10. Trees often taller than 40 feet 11

10. Trees rarely taller than 40 feet . . . . *Alnus tenuifolia* and *Salix sp.*

11. Crown apexes are broadly rounded and crown margins are deeply rounded (lobed) . . . . *Acer macrophyllum*

11. Crown apexes are bluntly rounded (obtuse) and crown margins are notched with rounded teeth (crenate) . . . . *Populus tremuloides*

Height and Occurence of Several Shrubs of the Spanish Creek Watershed

Species	Height[1,2]	Occurence[1,2]
Amelanchier pallida	3 - 15'	2500' to 9000' elevation; moist habitats; dry, gravelly and rocky slopes; with ponderosa & lodgepole; often in large thickets; deciduous
Ceanothus cordulatus	2 - 6'	3500' to 9000' elevation; rocky ridges and pine habitats; up to 12' diameter; can form continuous ground cover; evergreen
Ceanothus prostratus	2 - 6"	2100 to 7800' to 8' diameter; usually grows under pines, mixed conifer; forms dense mats; evergreen
Chrysolepsis sempervirens	1 - 8'	1500' to 12,500' elevation; thickets on dry mountain ridges; rocky places of open forests; evergreen
Cornus species	4 - 15'	to 6000' elevation stream banks and moist flats deciduous
Prunus emarginata	3 - 18'	4000' to 8000' elevation; extensive thickets on moist slopes, stream beds; deciduous
Quercus dumosa	2 - 9'	western, middle elevation slopes of Sierra; evergreen
Quercus vaccinifolia	1 - 4'	5000'to 10,000' elevation; mountain ridges, rocky situations; mainly west aspect; often prostrate; evergreen
Ribes nevadense	1 - 6'	3500' to 8500' elevation; canyons, moist slopes; deciduous

Rhamnus purshiana	6 - 36'	along creek banks, seepages; deciduous
Rubus parviflorus	3 - 6'	0 to 9000' elevation; near water courses; deciduous
Symphoricarpos species	2 - 6'	5000' - 10,000' elevation; deciduous

1. Munz, Phillip A. (ibid)

2. McMinn, Howard E. An Illustrated Manual of California Shrubs University of California Press, Berkeley, Los Angeles, California, 1970.

TABLE 5 - Tree and Shrub Codes

I. Tree Codes

Code	Scientific Name	Common Name
ABCO	Abies concolor	White Fir
ABMA-2	Abies magnifica	Red Fir
ACMA	Acer macrophyllum	Broadleaf Maple
ALN-2	Alnus species	Alder
ALRH	Alnus rhombifolia	White Alder
ARME-3	Arbutus menziesii	Madrone
BEOC-2	Betula occidentalis	Water Birch
CADE	Calocedrus decurrens	Incense Cedar
FRA10	Fraxinus species	Ash
JUN-5	Juniperus species	Juniper
JUOC	Juniperus occidentalis	Sierra Juniper
LIDE-2	Lithocarpus densiflora	Tan-bark Oak
PIAL	Pinus albicaulis	Whitebark Pine
PIAT-1	Pinus attenuata	Knobcone Pine
PICOM	Pinus contorta var. murrayana	Lodgepole Pine
PIJE	Pinus jeffreyi	Jeffrey Pine
PILA	Pinus lambertiana	Sugar Pine
PIMO-2	Pinus monophylla	Piñon Pine
PIMO-3	Pinus monticola	Silver Pine (also Western White Pine)
PIPO	Pinus ponderosa	Ponderosa Pine (also Yellow Pine)
PISA-2	Pinus sabiniana	Digger Pine

Table 5 (cont.)

Tree Codes Continued

Code	Scientific Name	Common Name
PLRA	Platanus racemosa	California Sycamore
PSME	Pseudotsuga menziesii	Douglas-fir
POFR-3	Populus fremontii	Fremont Cottonwood
POTR-3	Populus tremuloides	Quaking Aspen
POTR-4	Populus trichocarpa	Black Cottonwood
QUCH-2	Quercus chrysolepis	Canyon Oak (also Golden Oak)
QUKE	Quercus kelloggii	California Black Oak
QUWI	Quercus wislizenii	Interior Live Oak
TABR	Taxus brevifolia	California Yew
TOCA	Torreya californica	California Nutmeg
TSME	Tsuga mertensiana	Mountain Hemlock
UMCA	Umbellularia californica	California Laurel (also California Bay)

II. Shrub Codes

Code	Scientific Name	Common Name
ACE-1	Acer species	Maple
ADFA	Adenostoma fasciculatum	Chamise
ALN-1	Alnus species	Alder
ALTE	Alnus tenuifolia	Mountain Alder
AMPA-2	Amelanchier pallida	Service Berry
ARC-5	Arctostaphylos species	Manzanita
ARMA-3	Arctostaphylos manzanita	Common Manzanita

Table 5 (cont.)

Shrub Codes Continued

Code	Scientific Name	Common Name
ARME-2	Arctostaphylus Mewukka	Indian Manzanita
ARNE-2	Arctostaphylos nevadensis	Pinemat Manzanita
ARVI-3	Arctostaphylos viscida	Whiteleaf Manzanita
ART-5	Artemesia species	Sagebrush
ATR-3	Atriplex species	Saltbush
CAOC-2	Calycanthus occidentalis	Spice-Bush
CEA	Ceanothus species	California Lilac
CECO-2	Ceanothuscordulatus	Mountain Whitehorn
CECU-2	Ceanothus cuneatus	Buck Brush
CEIN-3	Ceanothus integerrimus	Deer Brush
CEJE	Ceanothus jepsonii	
CEPR	Ceanothus prostratus	Squaw Carpet
CEVE-3	Ceanothus velutinus	Tobacco Brush
CEOC	Cercis occidentalis	Redbud
CER-8	Cercocarpus species	Mountain-Mahogany
CHFO-2	Chamaebatia foliolosa	Kit-kit-dizze (also Mountain Misery or Bear Clover)
CHSE	Chrysolepsis sempervirens	Bush Chinquapin
CHR-9	Chrysothamnus species	Rabbit Brush
CLLI-2	Clematis ligusticifolia	Western Clematis
COR16	Cornus species	Dogwood
CONU-2	Cornus Nuttallii	Mountain Dogwood

Table 5 (cont.)

Shrub Codes Continued

Code	Scientific Name	Common Name
QUE-1	Quercus species	Oak
QUDU-2	Quercus dumosa	Scrub Oak
QUVA	Quercus vaccinifolia	Huckleberry Oak
RHA-1	Rhamnus species	Cascara
RHCR	Rhamnus crocea	Redberry (also Buckthorn)
RHPU	Rhamnus Purshiana	Cascara Sagrada
RHRU	Rhamnus rubra	Sierra Coffeeberry
RHOC	Rhododendron occidentâle	Western Azalea
RHDI	Rhus diversiloba	Poison Oak
RHTR	Rhus trilobata	Squaw Bush
RIB	Ribes species	Currant (also Gooseberry)
RIDI	Ribes divaricatum	
RINE	Ribes nevadense	Sierra Currant
RIRO	Ribes Roezlii	Sierra Gooseberry
ROS	Rosa species	Rose
RUB-2	Rubus species	Blackberry (also Raspberry, etc.)
RULE	Rubus leucodermis	Western Raspberry
RUPA-2	Rubus parviflorus	Thimbleberry
RUUR	Rubus ursinus	California Blackberry
SAL-1	Salix species	Willow
SAM-2	Sambucus species	Elderberry
SACA-4	Sambucus caerulea	Blue Elderberry

Table 5 (cont.)

Shrub Codes Continued

Code	Scientific Name	Common Name
COST-3	Cornus stolonifera	American Dogwood (also Creek Dogwood)
COCOC	Corylus cornuta var. californica	Hazelnut
CYSC-2	Cytisus scoparius	Scotch Broom
DERI	Dendromecon rigida	Bush Poppy
DIP	Diplacus species	Bush Monkey-Flower
ERCA-6	Eriodictyon californicum	Yerba Santa
ERI21	Eriophyllum species	Yarrow
GAFR	Garrya Fremontii	Silk-Tassel
HEAR-2	Heteromeles arbutifolia	Toyon
HOL-3	Holodiscus species	Cream Bush
KAPOM	Kalmia polifolia var. microphylla	Alpine Laurel (also American Laurel)
LEGLC1	Ledium glandulosum var. californicum	Labrador-Tea
LEDA	Leucothoe Davisiae	Sierra Laurel
LON	Lonicera species	Honeysuckle
PHLEC	Philadelphus Lewissii ssp. californicus	Mock-Orange
PRU-2	Prunus species	Stone Fruits
PREM	Prunus emarginata	Bitter Cherry
PRVID	Prunus virginiana var. demissa	Western Choke Cherry
PRSU-2	Prunus subcordata	Sierra Plum
PUTR	Purshia tridentata	Bitterbrush

Table 5 (cont.)

Shrub Codes Continued

Code	Scientific Name	Common Name
SOR-4	Sorbus species	Mountain-Ash
SPI-3	Spiraea species	Spireae
STOFC	Styrax officinalis var. californica	California Storax
SYM-3	Symphoricarpos species	Snowberry
VAC-2	Vaccinium species	Huckleberry (also Bilberry or Blueberry)
VICA-3	Vitus californica	California Wild Grape

Table 6

Description of Physiological State Conditions Evident in Plants on Aerial Kodacolor II Prints

A. Conifers and Evergreens

1. cone crop - a cone crop is present and visible on conifers
2. new growth - a ring of new growth on conifers which shows up in contrast to the older foliage which is inward from the perimeter of the crown
3. dead - a conifer has no foliage and appears dead.
4. normal - the tree has no characteristics visible which indicate special phenological events.

B. Deciduous Trees and Shrubs

1. pre-foliage - in spring imagery there is no foliage apparent on the bare branches.
2. flowering - flowers are apparent.
3. foliage - plants have foliage in summer growing season.
4. autumn foliage - deciduous trees have turned to their fall colors.
5. post-foliage - in fall imagery there is no foliage apparent on bare branches.

Plumas 1974 Hydrologic Resource Inventory

Sheet NL1 (Line Data)

Non-Living Component for Water Related Information from Photo Interpretation

1) Date 2) Photo Interpreter _______ 3) Photo Plot No. _________ 4) Date Flown ________
5) Elevation of Photo Plot _____ 6) Altitude of plane _______ 7) Scale of 3R wideangle _________
8) Scale of 3R telephoto ________ 9) Scale of 7" x 10" enlargement ________ 10) Radius of Circle(R)_________
11) Azimuth of line (1°) ________ 12) Photo distance between line points (D)_________
13) Aspect (1°)_________ 14) Slope (5%)________

Point Index No. W to E	A Surface Point	B Munsell Color Notation	Interval a-b	C % of line covered with mineral soil	D % of line covered by rock	E % of line covered by snow	F % of line covered by slash	G % of line covered by plants, shade	H aver. Munsell color over line excluding plants, shade
1			1-2						
2			2-3						
3			3-4						
4			4-5						
5			5-6						
6			6-7						
7			7-8						
8			8-9						
9			9-10						
10			10-11						
11			11-12						

Recording Form Key:

1) Surface at Point
   B = bare mineral soil
   R = rock
   S = slash
   Sn= snow

11) Vision Obstructions
   NVSH = not visible, shade
   NVPC = not visible, plant cover

Place general comments on back

Non-Living Component for Water Related Information from Photo Interpretation

1) Date _____ 2) Photo Interpreter ______ 3) Photo Plot No. ______ 4) Date Flown ______

Areal Extent of Ground Features within Plot
(based on portion of plot where ground surface is visible)

5) no. of bare, mineral soil dots/no. of ground visible dots ___
6) no. of rock dots/no. of ground visible dots _____
7) no. of snow dots/no. of ground visible dots ______
8) no. of dots falling on both surface and plant canopy snow ______
9) no. of dots falling within the photo plot ______
10) Cracks and Fissues

a) General pattern (circle the appropriate) parallel, dendritic, trellis, ______

b) direction of cracks or fissures as a percent of the total number of cracks for the following azimuth classes: 315° - 45° _____, 45° - 135° ______, 135° -225° _____, 225° - 315° ______

c) total number of cracks or fissures, and average length and width for the following azimuth classes:
315° - 45° No. = ______, L = ___, W= _____
45 -135° ______, _______, _______
135° -225° ______, _______, _______
225° -315° ______, _______, _______

Table NL2 1 - Munsell Readings

	1.00 X R	.75 X R	.50 X R	.25 X R
0°				
90				
180				
270				

Plumas 1974 Hydrologic Resource Inventory Sheet L1 page 1

Living Component Water Related Information from Photo Interpretation

A. Tree Growth Form. All trees, excluding woody shrubs and herbaceous vegetation, within the plot

1) Date ______ 2) Photo Interpreter ______ 3) Photo Plot No. ______ 4) Date Flown ______

A	B	C	D	E	F	G	H
Index No./ Species Code/ Azimuth	D_1 Plot center to trunk ground interface distance on photo	D_{1-c} conversion to ground distance	D_2 plot center to bulge point distance on photo	D_{2-c} conversion to ground	C max maximum crown diameter	C min minimum crown diameter on photo	C max-c conversion to ground distance
XX/XXXX/XXX	X.XX(.01")	XX.X	X.XX(.01")	XX.X	X.XX(.01")	X.XX(.01")	XX.X

CONTINUED ON NEXT PAGE

5) total no. dots within photo plot ________

6) total no. dots falling on overstory trees within photo plot ________

7) total no. dots falling on any leaf surface within plot ________

Physiological State Code

Evergreens

cc = cone crop

d = dead

ng = new growth apparent

n = normal appearance

Deciduous

pf = pre foliage

f = foliage

af = autumn foliage

pof = post foliage

n = flowering

I	J	K	L	M	N
C min-c conversion to ground distance	(tree top) ± 5%	(bulge point) ± 5%	(crown bottom) ± 5%	dots in crown in in photo plot	physiological state (see code)
XX.X	XXX	XXX	XXX	XXX/XXX	

Plumas 1974 Hydrologic Resource Inventory

Sheet L2

Living Component Water Related Information from Photo Interpretation

B. Woody Shrubs and Herbaceaous Vegetation with in the plot

1) Date _______ 2) Photo Interpreter ________ 3) Photo Plot No. ______ 4) Date Flown_________

A	B	C	D	E	F	G	H
Index No./ Species Code/	Azimuth reading to shrub extent	Da/b plot center to points a and b a/b	Da-C/b-c conversion to ground distance	Dc/d/e plot center to points cde	Dc-c/d-c/e-c conversion to ground distance	H_1 height of shrub clone	physiological state (see code)
XX/XXXX/XX	XXX/XXX(.01")	X.XX/X.XX(.01")	XX.X/XX.X	X.XX/X.X/X.XX (.01")	XX.X/XX.X/XX.X	XX (2')	

2b-177

5) no. of dots falling on shrub clones within the photo plot __________

6) no. of dots falling on grasses, ferns, and forbes within the photo plot __________

7) no. of dots falling within the photo plot __________

Physiological State Code

Evergreens	Deciduous
cc = cone crop	pf = pre foliage
d = dead	f = foliage
ng = new growth apparent	af = autumn foliage
n = normal appearance	pof= post foliage
	fl = flowering

CHAPTER 3

WATER DEMAND STUDIES IN CENTRAL CALIFORNIA

Co-Investigator: John E. Estes, Santa Barbara Campus

Contributors: J. Jensen, L. Tinney, T. Hardoin, E. Lytle, S. Lytle, J. McCaslin, D. Whitmore, B. Yackle

CHAPTER 3

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Chapter 3

WATER DEMAND STUDIES IN CENTRAL CALIFORNIA

Co-Investigator: John E. Estes, Santa Barbara Campus

Contributors: J. Jensen, L. Tinney, T. Hardoin, E. Lytle, S. Lytle, J. McCaslin, D. Whitmore, B. Yackle

3.00 INTRODUCTION

Research activities conducted by the Geography Remote Sensing Unit (GRSU) for this reporting period include: (A) The development and analysis of remote sensing techniques for generating data as input to water demand models; (B) Comparison between conventional techniques and remote sensing techniques in terms of time, cost, and accuracy; and (C) Analysis of the economic impact resulting from changes in remote sensing water demand information.

During this reporting period, GRSU has focused a major portion of its research on the Kern County Water Agency (KCWA) hydrologic model; specifically our efforts have been directed toward four critical input parameters capable of being monitored by remote sensing techniques. These parameters are irrigated croplands, crop type, soil salinity, and perched water. Care has been taken to make our studies complementary to, rather than competitive with, those being conducted under this integrated project by our colleagues on the Riverside Campus of the University of California.

3.01 WORK PLAN

Figure 3-1 locates the test areas for the Santa Barbara and Riverside water demand studies. A listing of the tasks and the anticipated temporal framework within which they are being accomplished can be seen in Figure 3-2. With the remote sensing inputs to the KCWA hydrologic model identified, GRSU personnel have been concentrating their research activities on work items 4, 5, 6, and 7 listed in Figure 3-2. During the forthcoming period it is expected that the GRSU will expand its research in these areas as the remote sensing inputs to the KCWA model are analyzed and compared to conventionally derived data.

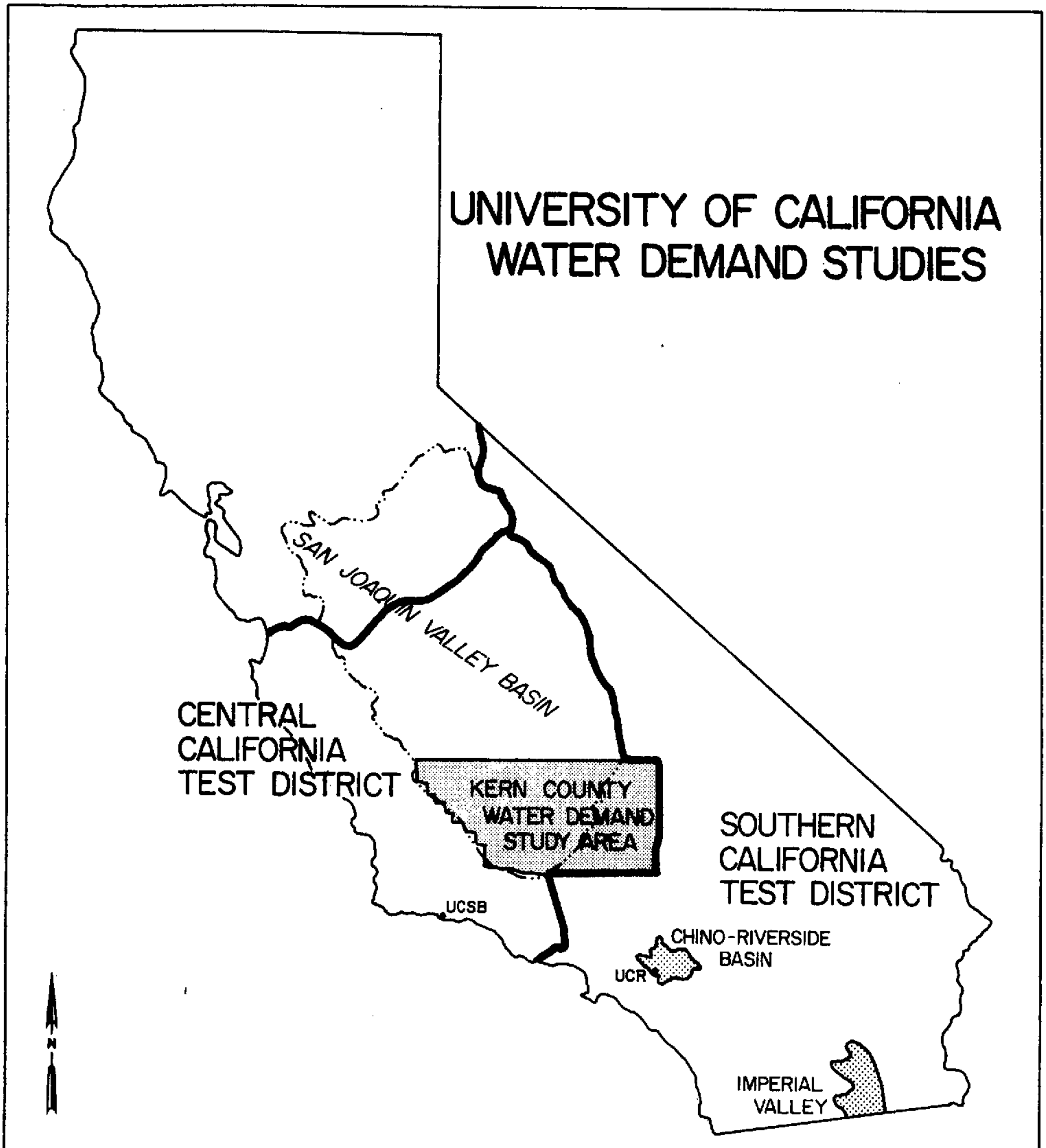

FIGURE 3-1. Central and Southern California Regional Test Districts, and the areas of more specific focus of Water Demand Studies. Kern County, San Joaquin Valley Basin, the Chico-Riverside Basin, and the Imperial Valley.

Work Item	Investigators	Present Funding Year 74 75 M J J A S O N D J F M A	Next Funding Year 76 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 Assessment of Water Demand by Means of Remote Sensing. (1) Indicates primary responsibility; (2) Indicates secondary responsibility.

3.02 AGENCY CONTACT

Agency contacts during the earlier stages of this project were aimed primarily at establishing working relationships with those agencies that have a direct and major interest in, and responsibility for, the coordination and planning for water supply, distribution, and allocation. In the GRSU's intensive test region, which is predominantly agricultural, these agencies are (1) Kern County Water Agency (KCWA), and (2) California Department of Water Resources (DWR). These agencies, and particularly KCWA, have continued to play an important and interactive role in our research activities. They have done so by detailing their current water resource activities, suggesting potential remote sensing applications, providing "ground truth" data, and evaluating the potential utility of our methodologies to meet their present and projected data requirements.

In addition to these two major agencies other agencies and organizations concerned with water-related parameters, or having an expertise in crops, soil, hydrology modeling, etc., have also been 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 contacts have been:

1. University of California Agricultural Extension Service at Bakersfield

2. United States Salinity Laboratory at Riverside

3. Kern County Water Association (at their request a slide discussion of GRSU activities in Kern County was presented to the Board of Directors)

4. United States Department of Agriculture's Soil Conservation Service

5. Kern County Agricultural Commission

6. Tempo Center for Advanced Studies[1]

3.03 KCWA HYDROLOGIC MODEL

The computer model of the Kern County ground water basin is not a demand model *per se* in that its major purpose is the total simulation of water storage and movement throughout the ground

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1. Tempo received the original $500,000 contract for the development of the KCWA ground water basin model and continues to be responsible for its operation.

water basin. The model might therefore, be more appropriately referred to as a "water flow" model. As Kern County is basically a "water demanding" environment (i.e., its arid climate and widespread agriculture requires extensive water importations), it seems appropriate to examine all model inputs for possible remote sensing applications to the determination of water demand.

Based upon an analysis of the model, listings of all external qualities that serve as inputs to the model were compiled and analyzed with the aid of KCWA and Tempo personnel. The following steps were involved in the analysis:

1. Data inputs were precisely defined

2. Related inputs were grouped and categorized

3. Present sources of inputs were identified

4. Preliminary determinations were made as to which inputs might be generated more efficiently using remote sensing techniques.

The complete results of this analysis were included in the last Annual Report. A summary of critical parameters which are amenable to remote sensing techniques, as identified by KCWA, Tempo, and GRSU personnel, is presented in Table 3-1.

Construction of the KCWA model is based upon the following assumptions: (1) That a real-world water basin consists of interbedded layers of sands, clay, silt and gravels which are saturated to some level with water and upon which a variety of land uses are superimposed; and, (2) That the mathematical modeling of such a complex, heterogeneous mass requires that the total complex be subdivided into more workable units of smaller size and greater homogeneity, for each of which valid generalizations can be 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 15 square kilometers; (2) the designation of a center point in each polygon which is terms 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 inset 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. The final model also

TABLE 3-1.

KERN COUNTY WATER AGENCY: CRITICAL HYDROLOGY MODEL INPUTS

AMENABLE TO REMOTE SENSING TECHNIQUES

EXTERNAL QUANTITIES	DEFINITION	SOURCE(S)	REMOTE SENSING CAPABILIT (IDENTIFY-MEASURE)
Agriculture Usage			
gross irrigated acres	total amount of irrigated acreage	periodic air surveys, modified in districts	irrigated croplands
unit agricultural consumptive use	acre-feet per acre irrigation requirement by individual crops for evapotranspiration	Department of Water Resources, experimentation with individual crops	crop identification
Surface & Groundwater Movement			
volume of moisture-deficient soil	volume of unsaturated soil	calculated from field work (soil surveys)	soil moisture
% to perched water table	% of node overlying perched water table x nodal deep percolation	field investigations	perched water table area
External Quantity not yet incorporated into model			
soil salinity	salinity of soil as measured by electrical conductivity	field investigation	salinity damage assessme soil salinity prediction

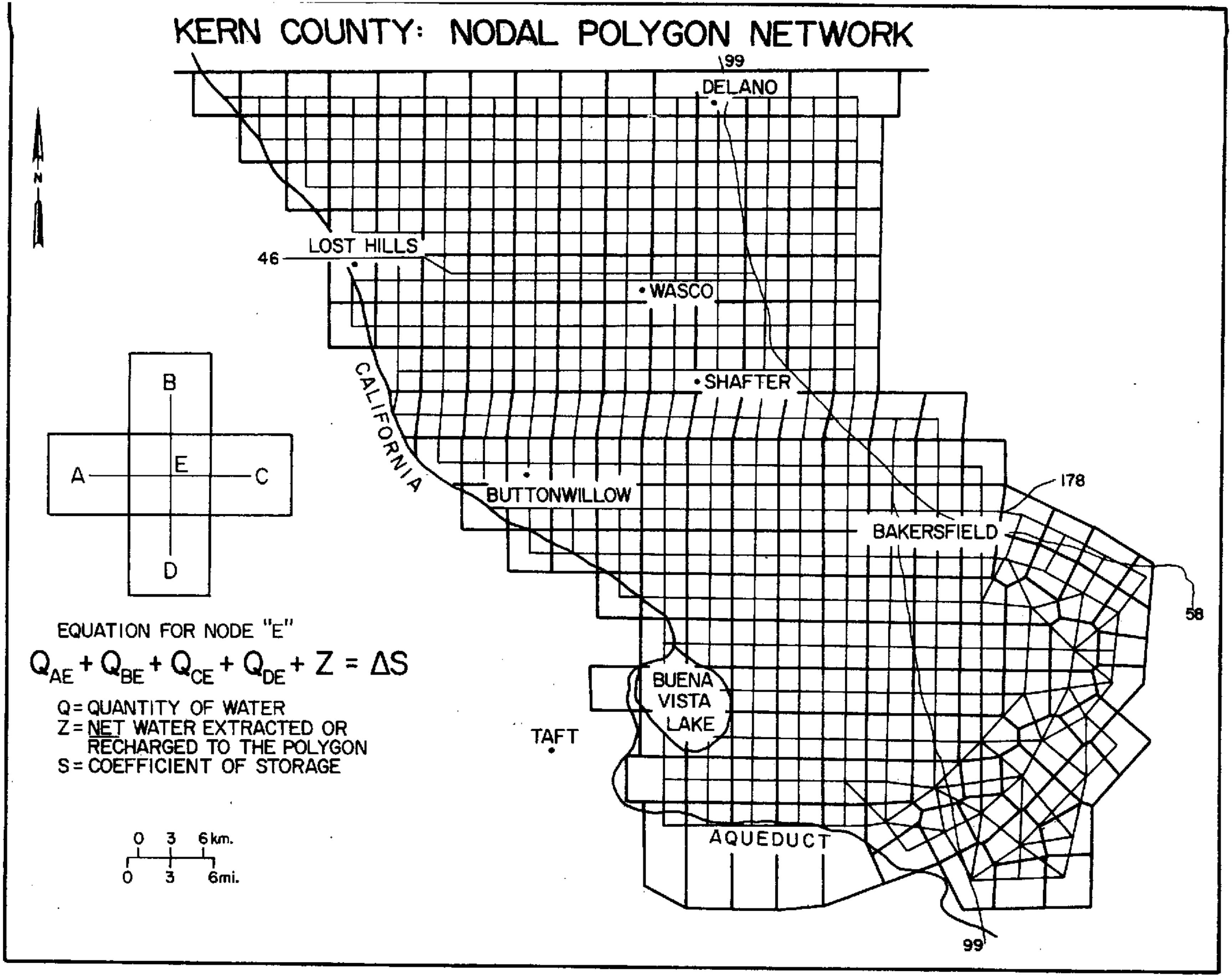

FIGURE 3-3. Kern County Nodal Polygon Network Used to Guide Remote Sensing Studies.

takes into account complications resulting from the existence of multilayered aquifers, subsidence, perched water tables and other water related phenomena.

It is important to note [and recognize the importance of the fact] that data are collected and inputed to the model on a nodal basis. As the model is spatially oriented, its effective operation requires that input data maintain proper spatial dimensions and not be aggregated beyond the nodal level. As will be discussed later, this requirement effectively eliminates most sampling procedures for data collection.

In addition to water flow studies, the KCWA hydrologic model has been adapted to delineate zones of equal benefits resulting from KCWA activities. This information is being developed to provide taxation schedules in an attempt to insure that those who benefit from water management policies will pay accordingly. The zones of equal benefit taxation schedules are based upon the following principles:

* Not all farmers in the region managed by the KCWA are involved in or pay for KCWA activities. These activities include the importation of water, the transfer of water from one water district to another, and the recharging of ground water.

* By raising the ground water level, these activities benefit non-participants as well as participants.

* Accordingly, the fairest taxation schedule should incorporate these benefits and be applied to non-participants as well as participants.

As this type of taxation is new it is easy to appreciate that KCWA is hesitant to apply it until it has confidence that the model will withstand any legal challenge to its validity. This application once again stresses the importance of accurate and timely model input data.

Specific determinations as to the benefits that accrue by using remote sensing techniques are difficult to make principally because the model is still in an advanced developmental state. Therefore a fixed set of input data, with specific associated costs for all parameters, is not as yet available. However, it is hoped that in the near future it will become possible to operate the model in two modes, one with strictly conventionally gathered data and the other augmented by remote sensing data. This should allow some estimates to be made as to the sensitivity of the model to various accuracies of remotely sensed data and thus create the foundation of work items 2 and 3, i.e. the analysis of economic impact resulting from changes in the estimation of critical parameters.

Although research on these two work items is just beginning to reach a productive stage the magnitude of potential benefits is readily apparent. There are currently about 800,000 acres (323,756 hectares) under irrigation in Kern County out of 1,600,000 potentially irrigable acres (647,511 hectares). The countywide crop value for a section of land (640 acres or 259 hectares) is approximately \$500,000 (\$800 crop value/acre X 640 acres/section).[2] Therefore, in principle, for each 1% of increased efficiency in the application of irrigation waters that results from the use of the hydrologic model, approximately 12.5 additional sections (3258 hectares) can be brought into production. An addition of this magnitude would represent a crop value of approximately \$6,250,000 dollars.

At the present time, Kern County is overdrafting its ground water basin. Even with the maximum supplies of imported water contracted for in 1990 (the demand for which will be realized in 1980) Kern County will be overdrafting its basin if irrigated agricultural lands are expanded beyond their present areal extent. The situation is critical and the potential benefits which may occur as a result of increased efficiencies derived through the utilization of remote sensing techniques can be significant.

Finally, another extension of the model proposed by KCWA which is currently under investigation involves the incorporation of water quality variables into the present quantity formulations. A major input to water quality determinations will be soil salinity, a topic that is currently being extensively investigated by the GRSU.

3.10 CROPLANDS MAPPING[3]

3.11 Statement of the Problem

The most dynamic element of water movement into and through the

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2. This is an estimate of the 1974 crop value per acre based on a projection from the 1973 crop value per acre rate of \$720.

3. The term "croplands" as used here is synonomous with "irrigated acreage" as used within the model region of Kern County where it is estimated that 99% of the croplands are actually irrigated (Michael Rector, KCWA Geologist, personal communication).

Kern County ground water basin occurs as a result of the application of irrigation water on agriculture lands. In comparison to an average Southern San Joaquin Valley precipitation rate of 3 to 5 inches (8 to 11 centimeters) per year, the average irrigation rate is approximately 32 inches (81 centimeters) which corresponds to 2.7 acre-feet per acre per year (.82 hectare-meters). Irrigation water may be pumped from the ground water basin itself or imported from other regions of the state. Presently, approximately 1,150,000 acre-feet (866,419 hectare-meters) of water is imported yearly while future contractual agreements call for 1,650,000 acre-feet (1,243,123 hectare-meters) by 1990.

An estimate of the "modelwide" water flow resulting from irrigation activities can be generated from knowledge of the total irrigated acreage and the average application rate. By subtracting the amount of imported water, a known value, an estimate can also be obtained of the county's ground water pumpage. If the KCWA model operated only at a general modelwide scale, effective use could be made of multi-stage sampling techniques combining ground sampling and remote sensing to estimate total irrigated acreage. However, the model most typically does not operate at such a general level and, except for providing a method for monitoring general trends, such information is of little value. As mentioned earlier, it is a model requirement that the spatial dimension of data be retained at least to the nodal level of aggregation, i.e., sampling has to be extensive enough to assure high accuracies within each node. While most sampling techniques are impractical under these restrictions, mapping approaches, such as those explored by the GRSU, have been found both accurate and cost-effective for such a task.

3.12 Goal

In recognition of the important role played by irrigated water in the KCWA model, the GRSU has been involved in research which seeks to utilize remote sensing techniques to generate croplands (irrigation/non-irrigation) maps of the model region. The goal of our research continues to be the refinement and documentation, in terms of accuracies, time, and monetary costs, of promising remote sensing techniques applicable to supplying the needed information in a cost-effective manner. Although this cropland data will almost certainly become a "nested by-product" of our research in crop identification, the maintenance of croplands mapping as a separate research entity appears justified by the need of many users who do not require greater detail or cannot justify the costs of generating specific crop type data. Although past mapping has relied very heavily upon potentially cost-ineffective highflight photography its use has been seen as ancillary to and as a logical first step in the development of techniques applicable to ERTS-type imagery.

3.13 Methodology

Considerable progress has been made in the croplands mapping methodology during the present reporting period. Present procedures are both more accurate and more timely than procedures employed earlier and continue to be as cost-effective. In the past, difficulties have been encountered in assuring geometric fidelity and interpreting from photographically enlarged ERTS-1 imagery. The base map methodology discussed below, and optical enlargement[4] have largely eliminated these two problems.

Croplands mapping is currently being accomplished by two interpreters using independent data sources. One interpreter generates data strictly from 1:125,000 highflight photography while the other, operating independently, produces cropland information from 1:1,000,000 ERTS-1 imagery. Once our cost-benefit analyses of these two scales are completed a third procedure, potentially the most accurate, will be initiated utilizing both sources interactively. Highflight photography should provide more accurate delineation of field boundaries while multi-date ERTS-1 imagery should facilitate the generation of cropping data. A minor problem with single-date highflight photography has been that abandoned fields are difficult to discern from fallow ones and uniform grasslands completely enclosed by croplands are sometimes misinterpreted as an irrigated crop.

To assure a uniform scale in these and all other maps generated for the KCWA, acetate copies upon which mapped data are placed have been made of a photogrammetrically controlled and rectified 1:125,000 basemap. These maps include all nodal and section boundaries in the valley portion of Kern County and, because the highflight scale corresponds almost exactly with that of the base, the transfer of detail can be accomplished with relative ease, visually, and without ancillary equipment. Since a majority of field boundaries and roads follow section lines, whenever a difference between photo and map scale exists, the photography (or map) can be adjusted section-by-section to refine the compilation accuracy. Normally realignment is necessary only at intervals of every few townships if the major portion of the area under investigation is in the central portion of the photography. The applicability of this technique to other irrigated agricultural regions will necessarily be dependent upon how faithfully croplands follow a

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4. Enlargement is accomplished by means of a recently acquired Bausch and Lomb Zoom-Transfer Scope.

known survey network. In Kern County the technique is quite successful. Two dates of highflight photography have been used to compile croplands data with this procedure, viz. November 27, 1973 (Flight #73-194) and April 4, 1974 (Flight #74-049). Data presented in Figure 3-4 represent a synthesis of the information concerning the total irrigated agricultural lands in Kern County compiled from highflight imagery taken on the two dates listed above.

In comparison to the one month period required for generating the November map (over half of the time spent was for cartographic work on final copy) the second map for April was available after less than two days labor. The use of an intermediary acetate "rough draft" copy of the original map allowed the second map to be generated by merely "updating" the first. Changes, corrections and/or additions/subtractions were noted upon the rough draft allowing a "change" map to be quickly produced whenever desired. It is considered as significant that, in addition to KCWA, interest in such information has also been expressed by the Kern County Planning Department. Actual costs and accuracies are detailed below.

Once an ERTS image is enlarged the procedure used to generate cropland information is essentially the same as that employed with highflight photography. The major difference is that the 18-day sequential coverage of ERTS-1 results in a capability for more frequent updates if desired. As mentioned earlier, difficulties have been encountered in the past when photographic methods have been used for enlarging ERTS-1 imagery, an approximately 8x enlargement in this application. The making of one-step enlargements of this type, using low contrast ERTS-1 imagery, has resulted in very low contrast enlargements that are difficult to work with and require constant checking against the original imagery to insure accuracy. The recent acquisition by the Geography Program at UCSB of optical enlarging and overlaying equipment (Zoom-Transfer Scope) has eliminated the necessity for photographic enlargement. Hopefully, though, research can still continue to develop economic procedures for photographic enlargement as many potential users of the croplands mapping methodology may not be able to justify such large equipment expenditures (approximately $5,000).

Other more sophisticated techniques for croplands mapping, including the video digitization of imagery or direct use of multidate, multi-band ERTS-1 tapes and automatic pattern recognition programs, are being investigated, these fall mainly within the context of crop identification research, however (next section), and are probably not yet cost-effective in comparison to manual techniques for this application.

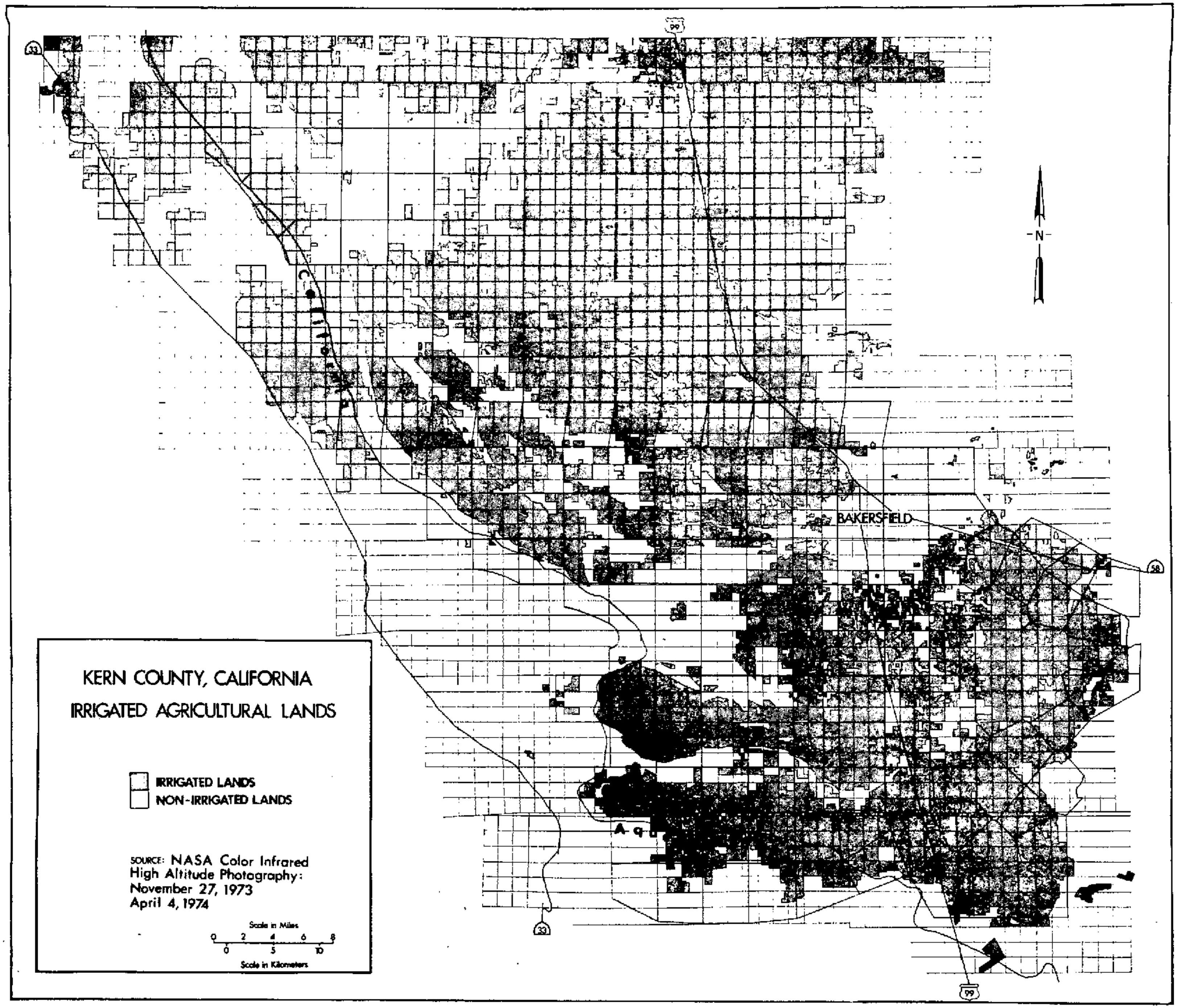

FIGURE 3.4. Kern County Irrigated Agricultural Lands (Croplands)

3.14 Results

The techniques developed by the FRSU for croplands mapping, from both highflight photography and ERTS-1 imagery, have proven to be cost-effective alternatives to the conventional techniques currently in use. Past sources used by the KCWA for estimating irrigated acreages have included:

California Department of Water Resources Surveys

Method: Low altitude oblique color photography (35mm) surveys with ground checking, undertaken approximately once every 5 years. It was last completed in Kern County in 1969.
Cost: \$3-5,000 for irrigated vs. non-irrigated information and \$34,000 for general land use/crop group survey (seven group classification).[5]
Time: Three months and ten months respectively.

California Department of Agriculture's Yearly Crop Reports

Method: Use of grower contacts, trips to produce plants, etc., and limited conventional field surveys, undertaken yearly. Estimates are on a countywide basis, hence of little value to the KCWA hydrology model.
Cost: \$20-25,000 for drop type and yield/value information
Time: Continuous

Individual Water District (15 in Kern County)

Method: Conventional field surveys.
Cost: \$1-3,000 for crop or crop group information (districts are of various sizes).
Time: Extremely variable

These surveys are at once both expensive and time consuming. For example, the Yearly Crop Reports are commonly not available until May of the following year. Updating by individual water districts is accomplished on a volunteer basis, with many districts financially unable to cooperate. Many other agencies, besides those mentioned, are currently involved in data gathering that would directly or indirectly benefit from accurate croplands maps. A complete cost-benefit analysis of remote sensing techniques for croplands mapping will require that these other users be examed. There is an apparent duplication of effort by many agencies in the gathering of crop related

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5. Revised estimate by DWR based upon the use of higher altitude photography than their conventional land use/crop group surveys.

data and it will be important to correctly assign benefits that result directly from the use of remote sensing techniques separate from benefits resulting from the elimination of duplicated efforts.

The irrigated vs. non-irrigated survey for which the DWR has estimated a cost of $3-5,000 most closely resembles those surveys undertaken by the GRSU from highflight photography and ERTS-1 imagery. At this estimated cost a time span of 3 months is involved for completion of the survey. In comparison, the initial GRSU highflight and ERTS-1 survey cost between $4-500 and span less than 1 month for the first maps. Once these first maps have been generated updates are extremely economical, with less than 2 man-days labor involved. Additionally, accuracies should improve upon the addition of each update. Accuracies currently obtained are extremely encouraging and have already received the endorsement of several district managers as being equal to ground methods.

In an effort to determine the accuracies of our methods the KCWA has distributed copies of the April 4, 1974 map (Figure 3-4), generated from highflight photography, to the individual water districts within Kern County. The districts were asked to ground check the accuracies. To date, only 4 districts have completed this task. The results are included in Table 3-2.

As shown, the GRSU cropland inventory frequently exceeded 96% accuracy when compared with the water district ground truth. Although the ERTS-1 cropland inventory is not yet sufficiently advanced to make definitive statements concerning relative accuracy, preliminary results (such as that shown in Table 3-2) are encouraging. These results indicate that the ERTS data may provide as accurate a base of information to work from as the highflight data. By the next reporting period a detailed error analysis on a per node basis will be accomplished which will provide a more accurate test of the utility of both the highflight and ERTS-1 data.

3.20 CROP IDENTIFICATION

3.21 Statement of the Problem

The identification and mapping of croplands in Kern County allows a necessary first-order approximation of water demand. However, the different irrigation requirements of various crop types introduces substantial error in the individual nodal demand values if a countywide average application rate is assumed representative of the average application rate within each node. By examining Table 3-3 one can see that if areal concentrations of these three major crops occur and the countywide application rate of 3.38 acre-feet/gross acre (1.03 hectare-meter/gross hectare) is assumed, potential errors approaching 150%

TABLE 3-2

Estimates of the Relative Accuracies of Cropland Data Derived from Field Verification, Highflight Photography and ERTS-1 Imagery

WATER DISTRICT	DISTRICT FIELD CHECK		HIGHFLIGHT		ERTS - 1	
	Cropland	Non-Cropland	Cropland (% error)	Non-Cropland (% error)	Cropland (% error)	Non-Cropland (% error)
BELDRIDGE	45,883	42,187	45,883 (0.0%)	42,187 (0.0%)	not yet available	
LOST HILLS	50,742	38,406	50,552 (-0.38%)	38,596 (+0.49%)	not yet available	
SEMITROPIC	119,437	99,426	115,616 (-3.12%)	103,247 (+3.84%)	121,147 (+1.41%)	97,716 (-1.74%)
WHEELER RIDGE - MARICOPA	113,448	44,231	113,291 (-0.14%)	44,388 (-0.36%)	not yet available	

overestimation and 15% underestimation can result. Even larger errors can result if concentrations of some other crops occur.

KCWA has eliminated a large portion of this potential error by utilizing the DWR 1969 crop group[6] survey and various updates made available by individual water districts. The use of such dated information as this, however, still introduces some error whenever the yearly crop type composition within a node varies. This is especially true of the newer croplands within the county where crop experimentation is being conducted to determine which crops are well adapted to the region. KCWA personnel have specifically stated that the generation of accurate and timely crop type maps should be a major concern of GRSU water demand research.

Although KCWA cannot currently fund such surveys, crop type information is still considered an important input to the ground basin model. The DWR estimated cost of $34,000 for these surveys makes it highly infeasible that the KCWA will be able to undertake crop surveys in the near future as an individual effort. With many agencies (including among others all those previously mentioned in the croplands mapping section) constituting potential users of crop identification information, the KCWA envisions a cooperative effort in the near future. Preliminary discussions have already begun among some of these potential user agencies to define their individual information requirements. It will be important to consider the multiple uses of this type of information in our cost-benefit analysis of remote sensing techniques.

TABLE 3-3

Yearly Crop Irrigation Requirements for Kern County

Crop	Requirement	Percent Total County Irrigated Acreage
Barley	1.4 acre-feet (0.43 hectare-meters)	7%
Cotton	2.6 acre-feet (0.79 hectare-meters)	24%
Alfalfa	4.0 acre-feet (1.22 hectare-meters)	12%

6. A "crop group" is an aggregated classification scheme that generalizes specific crop types into useful groups, e.g., row crops, orchards, field crops, etc.

3.22 Goal

The major aim of this portion of our research is to develop a procedure capable of cost-effectively utilizing remote sensing techniques to generate crop type data, on a nodal basis, as input to the KCWA model. From the beginning of this work it was, and still is, believed that the temporal nature of this task would require multi-date imagery. This is a task that only an ERTS-type satellite appears able to provide in a cost-effective manner.

At present, this work is oriented less than the croplands mapping, toward KCWA implementation. At this time it appears evident that requirements for sophisticated techniques and their associated costs can only be borne by a cooperative inter-agency endeavor. Even at anticipated costs the need for and usefulness of crop type maps on a periodic basis seems to warrant furthur study.

3.23 Methodology

The validity of using multi-spectral and temporal analysis techniques for crop identification from ERTS type imagery has been proven. Multi-spectral analysis is based upon the premise that tonal differences typically exist between objects (in this case crop types) within some portion of the electromagnetic spectrum. Optimum use of these differences as a means of identifying the objects depends upon the exploitation of many variables, of which the band width and spectral sensitivity of the remote sensing system are typically the most controllable.

Temporal analysis, as it pertains to crop identification, commonly involves the use of a "crop calendar" such as that included in our last Annual Report for the major crops in Kern County. With knowledge as to the types of crops present in a region and their respective planting-growing-harvesting cycles probabilistic statements can be generated as to the likelihood of a field appearing in a given condition on any certain date, or set of dates, and belonging to a given crop class. The extension of these analysis techniques into an operational procedure for a region as large as that encompassed by the KCWA model (approximately 900,000 acres or 364,225 hectares) is a difficult task, however. This is especially true in this particular region where a large variety of crops are grown and the informational requirements of the hydrologic model demand data that are accurate at the nodal level.

Due to the costs involved when handling ERTS computer-compatible tapes (CCT) the GRSU approach to crop identification, to date, has been basically bulk-image oriented. The procedures developed for this task may be subdivided into three section, viz. multiple-image-correlation, data extraction and classification. The need for multiple-image-correlation results from the need to register in some manner the same point, or in our case the same field, on each of the images used in the multi-band and/or multi-date analyses. Most manual techniques for field identification typically involve the enlargement of 1:1,000,000 ERTS images (better results might be obtained from larger scale originals) to a more operable scale of approximately 1:100,000. However, any photographic enlarging process will entail a decrease in resolution and a loss of information while optical projection enlargement limits the methods available for data extraction.

To alleviate this situation the GRSU has been investigating techniques for operating at the original image scale of 1:1,000,000 under optical as well as video magnification. The task of identifying individual fields has been accomplished by producing field boundary maps for each node or group of nodes and then reducing this map to the exact scale of ERTS imagery. A schematic diagram of the procedure involved was included in the last Annual Report. The inclusion of prominent features in the map, such as canals and highways, makes alignment of the reduced overlay upon the imagery a relatively simple task. The most important requirement for this approach is that precision photographic facilities be available to insure correct reductions.

The use of a manual microdensitometer and, more recently, a video image analyzer capable of point optical density measurements has facilitated the extraction of tonal density values on a per field basis. These systems have been used in conjunction with the field boundary overlays to extract "training" data from each set of imagery for which GRSU has ground truth information of where adequate inferences can be made as to the individual field crop condition. A systematic survey of over 700 fields on the West side of the San Joaquin Valley has been undertaken over the last 4 years in anticipation of the need for adequate, accurate ground-truthed crop information.

A cooperative effort by the UCSB Geography Department and the Computer Systems Laboratory should allow image digitization capabilities in the near future. An analysis of the cost and benefits involved in the redigitization of ERTS imagery with the field boundary overlay versus an ERTS CCT approach hopefully will be available by the next reporting period and will include a comparison of both accuracies and equipment costs.

The final stage of crop identification involves the analysis of field spectral signatures to determine whether individual crop types exhibit adequate uniqueness (and uniformity) to allow accurate classification. Sorting and plotting programs have been developed by the GRSU and provide rapid and economical visual analysis of field data. Another program developed by our group determines optimum dates for pairwise crop discrimination by analyzing the amount and degree of spectral overlap between pairs of crop types.

A more thorough discriminant analysis program seeking to achieve maximum accuracy of identification has recently been made available to the GRSU by our colleagues on the Berkeley Campus. Preliminary results are encouraging but too tentative for inclusion in this report. Fairly conclusive results should be available by the next reporting period, however. Negotiations are also currently underway between the UCSB Geography Department and the CRSR (Center for Remote Sensing Research) at Berkeley that will hopefully result in the installation of a remote terminal with access to all of the CALSCAN programs.

3.30 SALINITY

3.31 Statement of the Problem

The Kern County area has salinity problems that are common to many arid environments. Under humid conditions soluble salts originally present in soil materials, and those formed by the weathering of minerals, are generally leached downward into the ground water and ultimately transported by streams to oceans. Saline soils are, therefore, practically nonexistant in humid regions. In arid regions leaching is generally local in nature, and leached solutes may not be transported far. This occurs not only because there is less rainfall available to leach and transport the salts but also because the high evaporation rates, characteristic of arid climates, tend to further concentrate the salts in soils and in surface waters.

Although weathering of primary minerals is the indirect source of nearly all soluble salts, there are few instances where sufficient salts have accumulated from this source alone to form a saline soil. Instead, saline soils generally occur in areas that receive salts from other locations with surface or ground water as the primary carrier. In arid regions water used for irrigation may contain from 0.1 to as much as 5 tons of salt per acre-foot of water, and the annual application of water may amount to 5 feet or more. Therefore, large quantities of soluble salts may be added to irrigated soils over relatively short periods of time. In Kern County, considerable expense has been taken to route irrigation waters onto the lands; presently, however, only minimal consideration has been directed toward the removal of saline drainage water from the land. In many arid regions, when bringing new lands under irrigation, farmers have frequently failed to recognize the need for establishing artificial drains to care for the additional water and soluble salts.

In Kern County the ground basin transfer of salt-bearing waters away from higher lands raises the ground water level on the lower lands, which often results in the perching of water tables or the temporary flooding of an area if enough water and a subsurface aquaclude are present. Perched water tables arise when a tongue or lens of impermeable fine-grained material restrains the normal downward percolation of ground water. When these aquacludes have a slope component, as with the westward sloping alluvial fans from the Sierra Nevada Range in Kern County, the ground water will tend to migrate under the influence of gravity and accumulate in topographic lows, analogous to that of surface water flowage. If impermeability is severe enough and the aquaclude is relatively near the surface, water occasionally will even pond on the surface during times of high water input. Under such conditions the upward movement of saline ground water or evaporation of surface water may result in the deposition of soluble salts. In our study area along the west side of the San Joaquin Valley, because of the presence of both aquacludes and large scale irrigation, both ground water and irrigation water may contribute to the salinization of the soil.

In any effective land management program in an arid region the salinity variable must be given significant attention especially in regards to water resource management. For an effective management plan to be developed an accurate inventory of the areal distribution of saline soils is needed. If management decisions are to be assessed, coverage through time is also required. At present in Kern County no such program exists. The most recent county-wide soil salinity survey was conducted over 12 years ago by the Department of Water Resources.

A major responsibility of the KCWA is the application of preventative water management techniques such as leaching and drainage to improve the productivity of the soil. In conjunction with this the KCWA requires data which will serve the following purposes:

1) Locate those agricultural areas that are, at present, suffering the most severe stress due to the saline environment. Such areas would be designated as priority areas in terms of the application of leaching and/or drainage water management measures. Included here would hopefully be a plan to monitor stress by developing a salinity prediction model.

2) Locate those areas of natural vegetation that are not in cropland because of excessive concentrations of salts but which could be brought into production if proper leaching and drainage practices were implemented. In Kern County every acre of land brought into production generates, on the average, an income of approximately \$800 per year. (The crop value of a section of land would therefore be approximately \$500,000.)

3) Plot the distribution of salt damaged areas in relation to topographic relief, soils, geology, and proximity to natural drains. Such data will enable KCWA to select the optimum locations for a series of lateral drains

that will hopefully alleviate both the perched water and salinity problems for many areas.

4) Provide soil salinity data on a nodal basis which will serve as input to the KCWA Hydrologic Model.

3.32 Goal

With respect to this phase of our integrated study, the goal of the GRSU is to develop a methodology whereby remote sensing techniques can monitor soil salinity in the KCWA area. A predictive technique is being developed which, hopefully, will facilitate the identification and monitoring of subtle changes in soil salinity before they become serious management problems. This predictive technique will use crop identification data in combination with actual field sampled salinity data, damage data, and known crop salt tolerance thresholds as input variables. In conjunction with this work GRSU personnel are in the process of developing soil salinity keys. These keys will facilitate the differentiation between crop types as they are subjected to various salt concentrations at different dates in the phenological cycle. If successful, the methodology developed could easily be applied to other arid agricultural environments.

In conjunction with the above research, GRSU will be generating salinity data that will "drive" the KCWA model to determine the additional amount of water that will be demanded to maintain productive land and reclaim unproductive saline land by leaching.

3.33 Methodology

General Field Methodology:

For the purposes of this report a "saline" soil will be defined as a soil which has an electrical conductivity saturation extract (Ece)[7] of more than 4 mmhos/cm adjusted to 25 degrees C., the exchangeable-sodium-percentage is less than 15, and the pH is less than 8.5.

In order to accurately identify the spatial distribution of the saline environment in Kern County it was necessary to conduct extensive field sampling as a check on the accuracy of the photo-interpretations. Field surveys took the form of 5 east-west transects across the San Joaquin Valley. Each transect was approximately 20 miles in length and wide enough to include fields immediately to left and right of a central road. The ground truth data acquired along these transects then functioned as a control for the photo-interpre-

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7. Ece represents Electrical Conductivity of the soil Extract measured in millimhos/cm adjusted to 25 degrees C.

tations that were made of salinity damage and for the salinity prediction investigations.

Extensive field sampling for soil salinity was conducted on two separate occasions. Enlargements of each transect were made at a scale of 1:15000 from 1:125,000 CIR highflight imagery. The enlargements were used to orient the workers in the field. These prints were taken to the field in August, 1974 and soil salinity samples were systematically collected for each section of land on both sides of the road. This first survey was to determine the feasibility of using crop type data as a surrogate for soil salinity. Concurrent with the taking of soil samples, the crop type, height, and general condition of the field were noted. In September, 1974, a more intensive field-by-field sample was taken along transect Highway 119. This was done to determine the range of variation in the point sampling data which might obscure the correlation which exists between soil salinity and crop type. In August, 1974, only surface samples 1-6" in depth had been taken, but many of them were near the road. More rigorous standards were maintained in the September sampling with each soil sample collected from a depth of at least 1.5'. This is the depth suggested by the University of California Agricultural Extension Office in Bakersfield as being adequate for measuring the salinity of the active root zone. Each field along Highway 119 was spot sampled at a distance of approximately 200' from the road to insure a representative field sample.

On both sampling occasions the soil samples were returned to Santa Barbara where salinity was determined by measuring the electrical conductivity of a soil extract. The electrical conductance "EC" is the most suitable measure of salinity because the readings increase with the greater soluble salt content of the soil. The opposite is true if electrical-resistance measurements are made. Therefore, electrical conductance, which is the reciprocal of resistance, simplifies the interpretation of the readings.

The procedure for measuring soil salinity involves preparing a saturated soil paste by stirring in distilled water until a characteristic endpoint is reached. A suction filter is then used to obtain a sufficient amount of the extract for making the conductivity measurement.

PH was also measured for each saturated soil paste sample. These data are significant because when coupled with the Ece readings, pH can determine whether the soil is saline, saline/alkali, or non-saline/alkali. To review briefly, saline soils have an Ece value greater than 4 mmhos/cm at 25 degrees C. and the exchangeable-sodium-percentage is less than 15. Saline/alkali soils have an Ece value greater than 4 mmhos/cm at 25 degrees C., and the exchangeable-sodium-percentage is greater than 15. Non-saline/alkali soils exist when the exchangeable-sodium-percentage is greater than 15 and the Ece is less than 4 mmhos/cm at 25 degrees C.[8]

PH values of 8.5 are needed to indicate an exchangeable-sodium-percentage of 15 or more. Soils having pH values of less than 7.5 almost always contain no alkaline-earth carbonates and those having values of less than 7.0 contain significant amounts of exchangeable hydrogen. None of the pH samples that were taken had a pH reading of greater than 6.0. This is significant because it eliminates saline/alkali and non-saline/alkali soils from the interpretation of the Kern County saline environment. Thus any salt presence, damage, etc., can truthfully be called "salinity." This reduces the number of variables that must be considered when developing remote sensing saline monitoring techniques for this area.

3.34 Interpretation and Compilation of the Salinity Damage Map

KCWA requested that the GRSU identify areas of salinity stress in the study area. This information is being used by KCWA as justification for the reactivation of the master drain proposal. KCWA is literally going door to door with the map and apprising land owners of the problem areas. This is being done to raise support for the construction of the master drain.

Trained photo interpreters were assigned the task of identifying and mapping those areas undergoing salinity stress. This interpretation was made from multi-date CIR 1:125,000 scale photography with April, 1974 being the most recent data. Figure 3-5 depicts a representative sample of the KCWA area (transect Highway 119) in terms of CIR imagery, crop type, salinity damage and soil type.

Interpreters identified, on a field-by-field basis, the percentage of each field that expressed salinity stress (Figure 3-6). This analysis included damage to croplands as well as naturally vegetated lands. It is acknowledged that the stress categorized as salinity damage may be in reality due to other factors, i.e., water application procedures, pests, etc., however, salinity damage represents the major agent for yield decrement in Kern County and creates very diagnostic stress signatures. The accuracies of annotations appearing on this map are at present being field checked by GRSU and KCWA personnel and will be reported in the June Annual Report.

Interpreters used two major surrogates to aid in identification of the salinity stressed environment, i.e., native vegetation and

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8. L.A. Richards (Editor), Diagnosis and Improvement of Saline and Alkali Soils, Agriculture Handbook No. 6, Washington D.C.: USDA, p. 5, 1969.

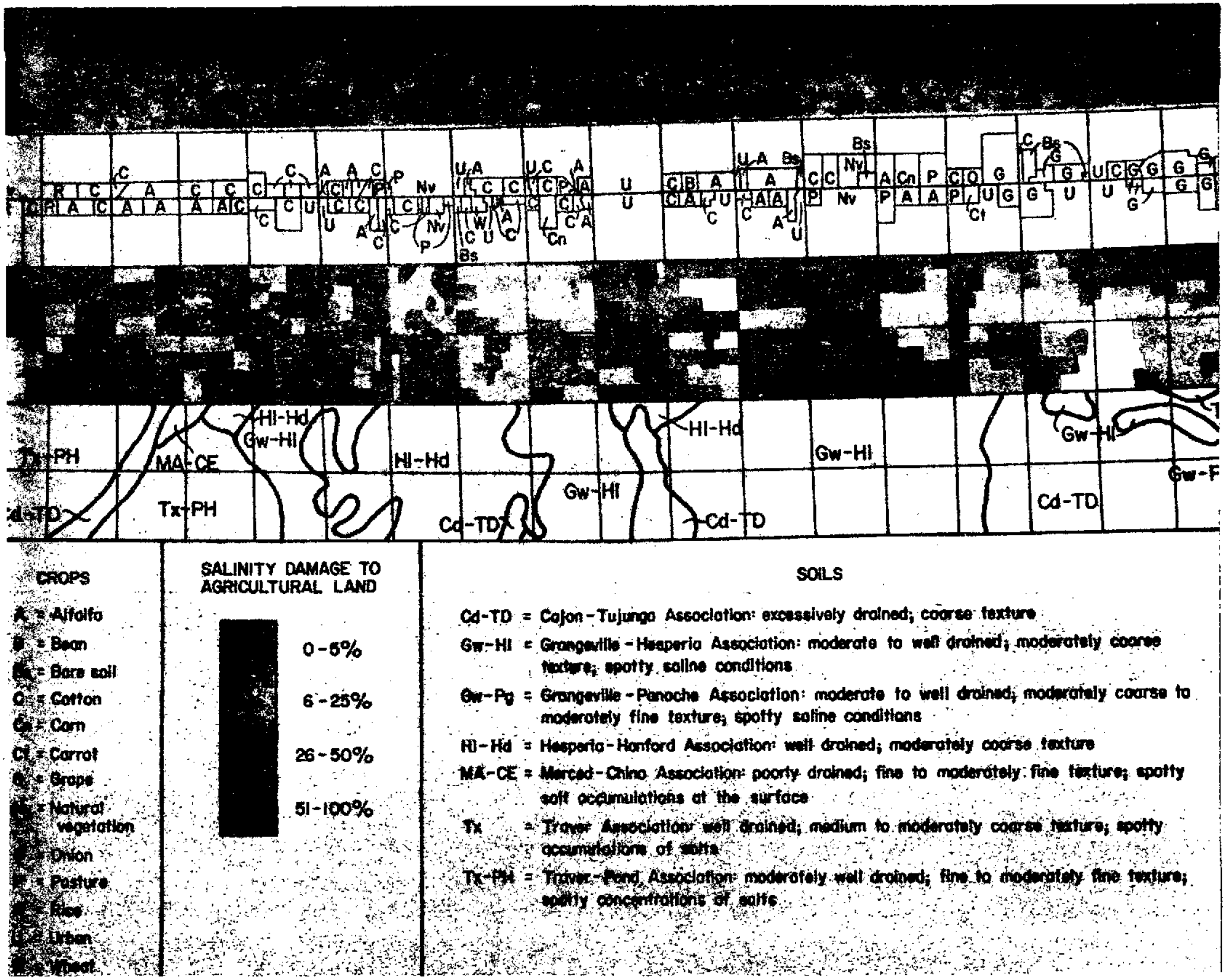


FIGURE 3-5. In the top half of this Figure, progressing from top to bottom the following kinds of information are shown for a representative transect along Highway 119, as of August 15, 1974: color infrared 1:125,000 scale imagery, crop type for fields next to the road, salinity damage and soil type. The white area on the damage map represents either rice cultivation, continuous multi-date bare soil, or urban areas that are not capable of expressing salinity damage.

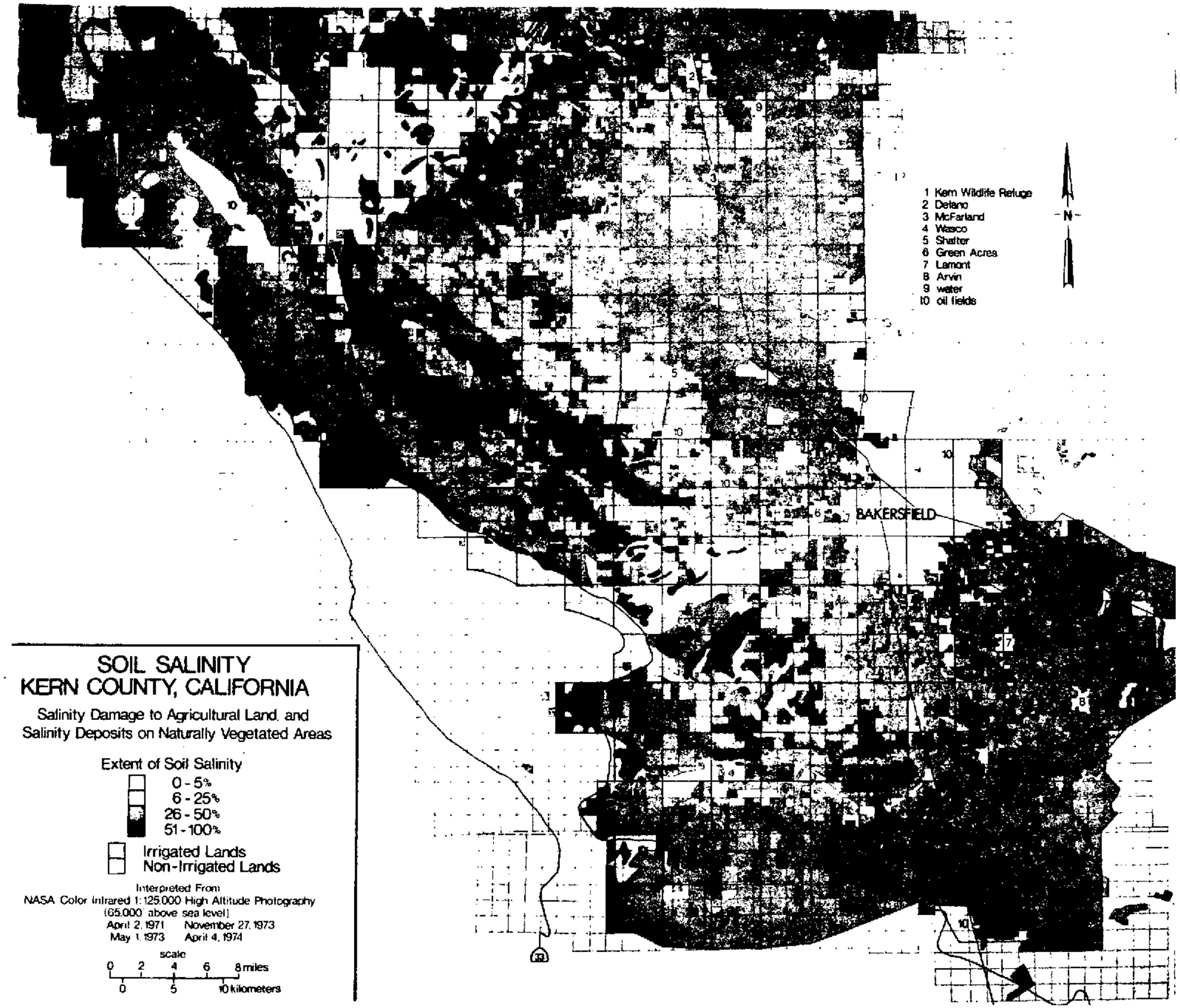


FIGURE 3-6. Salinity Damage Map of Kern County.

crop cover. Many native areas are covered by extensive caliche deposits. There is no question regarding the salinity of these areas which usually show up in the 50-100% category on the damage map. However, in many less severe areas, the presence of halophytic vegetation created an interpretation problem by masking the true saline condition. However, it was found that this problem could be overcome by field checking and by exploiting the fact that these naturally vegetated areas tend to be nucleated in areal extent. This basically is a result of the intensive use of the land in Kern County and, thus, areas of natural vegetation are typically found in conjunction with the caliche deposits. GRSU personnel have done extensive sampling in these native vegetation/caliche areas and are confident of the interpretation.

The second and major method of identifying salinity stress was to examine the agricultural crop cover. Multi-date imagery analysis techniques were used to identify crops in most fields. Hot spot scalding, caliche deposits, and a mottled appearance of the crop cover represented the major image interpretation surrogates used to detect salinity damage. The ability of the interpreters to verify and accurately classify those areas undergoing salinity stress was possible largely owing to the extensive ground truthing undertaken by GRSU personnel. The 5 transects with their known crop type, soil type, and salinity data allowed the interpreters to use this regional information to guide their classification procedure. It is significant to note that in many instances a field may be excessively saline, however, with a salt tolerant crop growing in it. For example, if the crop is cotton, the field may show only 25-50% damage. If instead a nontolerant bean crop were to be planted on the same field, however, it might register as much as 50-100% damage. This characteristic will be considered in more detail in the salinity prediction sub-section.

Probably the greatest handicap encountered in compiling the Kern County Soil Salinity Map was the interpretation of salinity damage for bare soil agricultural fields. In this case the multi-date approach was used to alleviate the problem. As might be expected there are optimum time periods throughout the year when a maximum percentage of the fields in Kern County are being cultivated and have crop cover. For the present damage map (Figure 3-6) the imagery used exhibited approximately 55% crop cover. That is, about 55% of the agricultural land contained some type of crop. However, recently acquired August, 1974 highflight imagery will be used to accurately update the damage map as approximately 75-80% of the agricultural land will be found to be under crop cover on this date.

It was also concluded that the best time for determining salinity stress was in the early stages of the phenological cycle. The relatively young fields do not possess a coalescing canopy of vegetation complete enough to mask the effects of salinity.

Finally, the GRSU in conjunction with the KCWA, has begun extensive field checking to determine the accuracy of the damage map. These findings will be given in the next Annual Report, together with a comparison between conventional and manual costs for acquiring the same data. Eventually, with the aid of KCWA personnel, a cost-benefit analysis will be developed by GRSU that will state the benefits derived by using the salinity damage data in the model and also as an educational tool to generate interest in the proposed master drain.

At present the greatest problem encountered is the point sampling methodology used to gather ground truthed salinity values. In Figure 3-7 it is evident that the correlation between the damage class and the actual point salinity values is not consistent. Examination of the red (50-100%) damage class shows that actual field sampled salinity values as low as 0.2 (Ece) have been classified in this category. Although a general increasing trend exists from the lower to higher damage classes, the extreme overlap of the higher damage classes upon the lower classes (especially in the lower soil salinity values, where all damage classes include salinity values $\leq$ 1 mmho/cm Ece) was not expected. Field sampling to date suggests that this is the result of the variable distribution of salinity. For example Figure 3-8 illustrates how multiple samples from a single field of cotton or alfalfa can result in higher Ece values (2.6, 3.6, 5.5) in a hot "scald" spot while a nearby non-damaged area may exhibit low Ece values (.96, .68, .78).

Based on this investigation it has become clear that the point samples for ground control fields should be clearly identified and annotated on enlarged imagery prior to the actual soil sampling. In this manner fields can be systematically sampled in both damaged and non-damaged regions to determine the best average salinity value to be used for the particular field if a correlation between damage, crop type, and salinity value is to be made.

The image interpreters here did not use sample salinity values to determine damage classes. Each field was analyzed individually to determine the percent of visible damage present. Another method of assessing the accuracy of the percent damage map is to compare this areal analysis with some other areally dimensioned data, such as soil type. Soil type classifications are typically general in nature. Table 3-4 plots the four major soil types and the number of times a particular damage class was assigned to each soil type. Upon inspection, 59% of the samples taken in Tx-PH (a typically high saline soil) were classified by the interpreter as being red (50-100%) damage. Similarly, 21-47% of these samples taken within the Cd-TD (a low potential saline soil) region were found to exhibit green and blue (0-25%) damage. When one considers that almost 75%

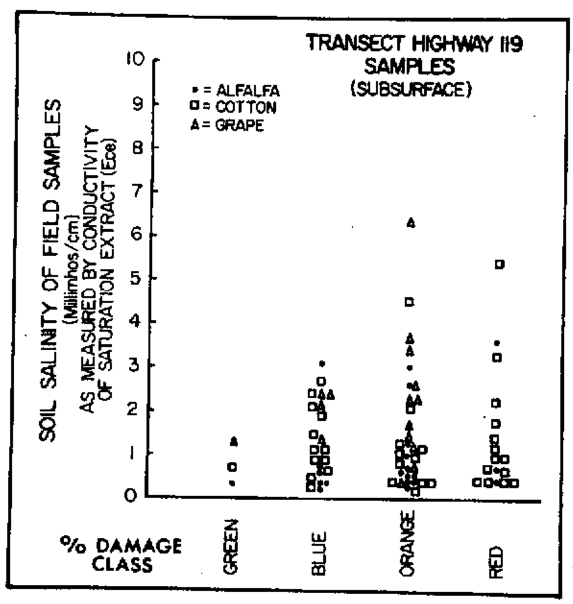
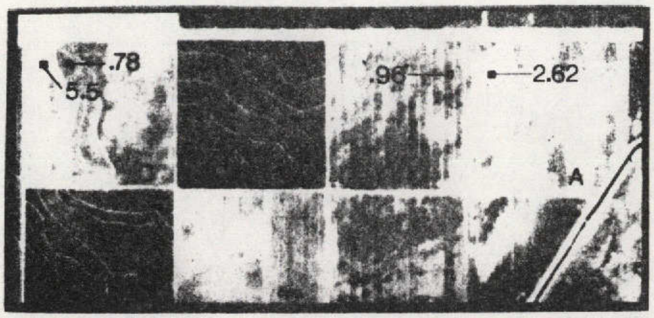


FIGURE 3-7. Subsurface soil salinity samples taken along transect Highway 119 and the corresponding damage classification.



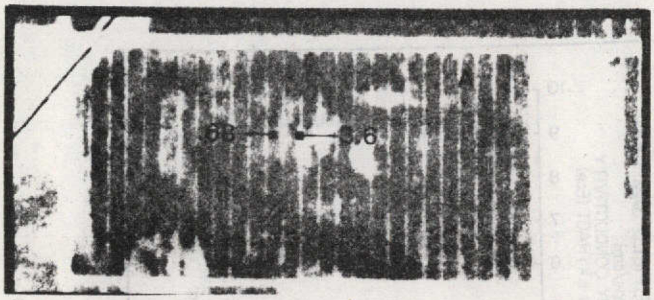


FIGURE 3-8. Salinity point sampling in single fields (along transect Highway 119) can yield unrepresentative salinity values when the researcher is not aware of where he is sampling within a given field. The alfalfa and cotton fields each exhibit high salinity values in "hot" scald spots and much lower values in nearby non-damaged areas. The dark fields with linear white lines are terraced rice paddies.

TABLE 3-4

Soil Types and Damage Classes for Salinity Samples Along

Transect Highway 119

SOIL TYPE

% SALINITY DAMAGE	High Salinity Potential: Tx-PH	High Salinity Potential: Gw-HL	Low Salinity Potential: HL-HD	Low Salinity Potential: Cd-Td
RED 51-100%	(10) 59%	(12) 29%	(7) 26%	(2) 11%
ORANGE 26-50%	(4) 24%	(10) 24%	(7) 26%	(4) 21%
BLUE 6-25%	(2) 12%	(15) 36%	(11) 41%	(9) 47%
GREEN 0-5%	(1) 6%	(5) 12%	(2) 7%	(4) 21%

of the orange and red salinity damage (25-100%) occurs in Tx-PH soil, which has the highest potential for salinity, the interpreter is certainly approaching an acceptable standard of accuracy in his classification. This examination serves to bring out the following point: The present synoptic, areal perspective of the interpreter is probably more accurate in delineating salinity damage than present point sampling might suggest.

Future research will include intensive point sampling in restricted regions to test this hypothesis. The development of efficient salinity point sampling procedures utilizing remote sensing techniques may be one of the major by-products of this salinity research. Finally, in relation to damage assessment, work has recently begun on automatic imaging analyzing techniques that will extract more quantitative damage data. Results of these investigations will be reported in the future.

3.35 Salinity Prediction

Salinity data at present must be obtained by costly field sampling procedures. The GRSU is developing a remote sensing methodology whereby salinity data may be generated on a field-by-field basis for the KCWA area. Such data would serve as input to the hydrology model by providing an estimate of the amount of water necessary to effectively leach saline soils and keep land in production.

The original hypothesis of the salinity prediction procedure was based on the assumption that there is a correlation between the type of crop present in a field and the soil salinity of that field. The University of California Agricultural Extension Service has published reports which state the yield decrement to be expected for certain crops due to specific soil salinity values. Table 3-5 depicts the 0%, 10%, 25% and 50% yield decrement threshold values for the major crops found in Kern County. Assuming that a given distribution of salinity exists, one would expect that in the areas of higher soil salinity farmers would tend to plant the more salt tolerant crops. The "natural" crop selection process may occur even though the farmers are not cognitively aware of the saline condition or relate yield decrements due to salinity for a given field. Figure 3-9 shows that a general tendency does exist in terms of the more salt tolerant crops being planted in more saline regions. The graph should only be considered preliminary, however, because of the problems encountered with point sampling as discussed above.

The basic assumption that there is a correlation between crop type and soil salinity becomes more complicated in low saline areas. Salt tolerant crops, i.e., cotton, barley, etc., can be planted not only on the more saline soils which require a salt tolerant crop, but also on non-saline soils. Cotton, for example, can be planted

TABLE 3-5

YIELD DECREMENT TO BE EXPECTED FOR CERTAIN CROPS

DUE TO SOIL SALINITY[9]

Crop	0% ECe[10]	10% ECe	25% ECe	50% ECe
Barley	8	12	16	18
Sugarbeets	6.7	10	13	16
Cotton	6.7	10	12	16
Safflower	5.3	8	11	14
Wheat	4.7	7	10	14
Sorghum	4	6	9	12
Soybean	3.7	5.5	7	9
Rice (paddy)	3.3	5	6	8
Corn	3.3	5	6	7
Beans (field)	1	1.5	2	3.5
Beets	5.3	8	10	12
Tomato	2.7	4	6.5	8
Barley (hay)	5.3	8	11	13.5
Alfalfa	2	3	5	8
Grape (Thompson)	2.7	4	-	8
Almond	1.7	2.5	-	5
Peach	1.7	2.5	-	5

9. University of California Agricultural Extension Service, Kern Crop Information, U.S. Department of Agriculture, November 15, 1973.

10. Ece means electrical conductivity of saturation extract in millimhos per centimeter (mmho/cm).

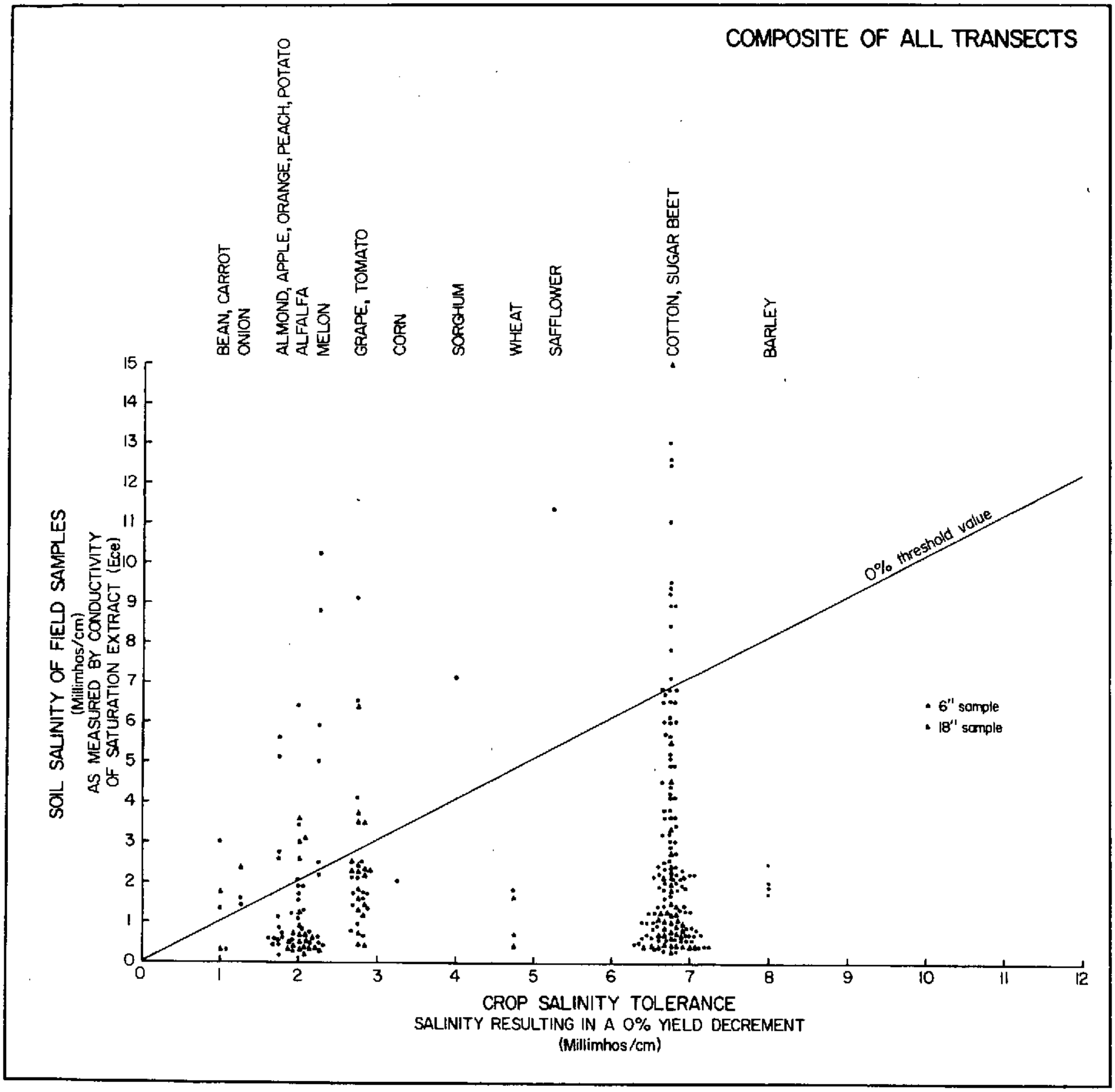


FIGURE 3-9. Composite of all 5 transects showing the value of the soil salinity field samples and the crop salinity tolerance above which a yield decrement will result for each crop type.

on both the best and poorest soils in the valley, a fact which complicates the original hypothesis.

A method of alleviating this problem entails the inclusion of another variable in the analysis, viz. crop damage. If both crop type and crop damage are known for a specific field then a refined prediction may be made in terms of soil salinity. Figure 3-10 is a theoretical diagram for which three crops, beans, sorghum, and barley, have their 0% yield decrement threshold limits, actual field sample salinity values, and damage assessment given. If barley exhibits a yield decrement (damage) whenever its threshold value of 8 (Ece) is exceeded, our tests to date indicate that the interpreter will classify this field as being damaged. If the field expresses no damage then the assumption must be that the value is ≤ 8 (Ece). If the actual point sampled salinity value for the yield was 9 (Ece) then the prediction error based on crop type would be -1. However, since damage is expressed quantitatively, an incremental value could be added to the threshold value. In this case, 1 Ece unit, the ideal corrective value, has been added making a refined salinity prediction of 9 (Ece) and a prediction error of 0. It remains to be evaluated just how much of an Ece increment should be assessed as corresponding to the minimum threshold value for each level of damage and how accurate the resulting prediction will be.

Once again, a major problem results from the field point sampling. In order to accurately gauge the success of the salinity prediction it is obvious that the field salinity value must reflect the average field salinity. If the ground truth sample is not representative it can invalidate any attempt to test the accuracy of the refined salinity estimate. The salinity prediction methodology, like the salinity damage mapping, is therefore awaiting more study as to the nature of the variables inherent in the point sampling problem.

Probably the weakest aspect of the soil sampling prediction will be for fields that do not possess any visible damage. In this case the only assumption that can presently be made is that the soil salinity of the field is $\leq$ the 0% threshold salinity value for that particular crop. Possible alternatives to this assumption, based upon average salinity values for each crop or soil type, are currently being investigated.

The predictive model as outlined thus far has been concerned only with the analysis of soil salinity based on an examination of a single date of imagery. The use of multi-date imagery for crop damage mapping was primarily to assure the presence of crop cover on at least one date. By using a multi-date approach it is believed that the predictive methodology will be able to effectively "bracket in" the soil salinity of a field by analyzing the crops planted and the damage present as a function of time. In this manner subtle

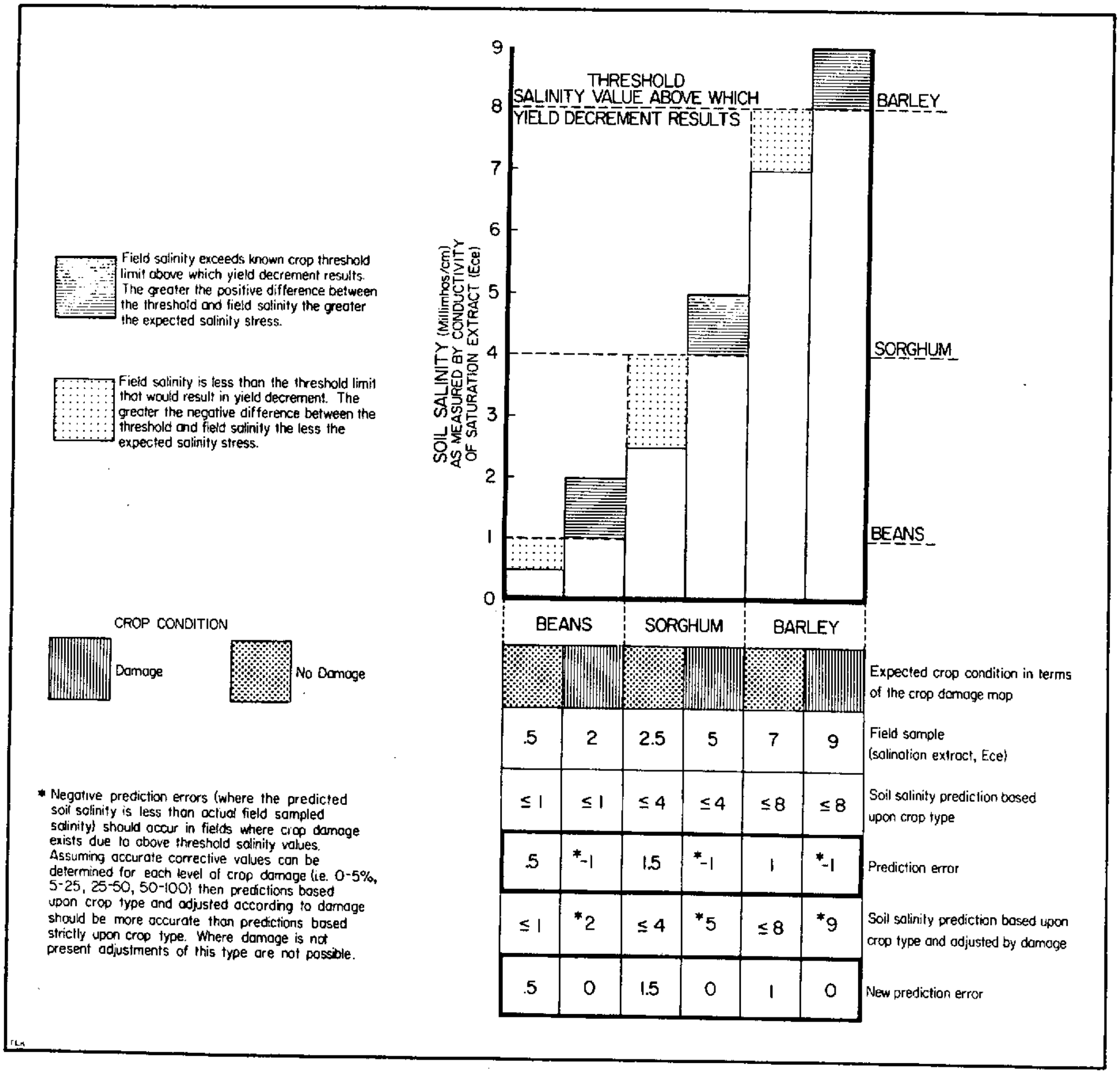


FIGURE 3-10. Salinity prediction theory diagram.

changes in soil salinity in a region might be identified long before detection by field point sampling. If the interpreter consistently begins to see more salt tolerant crops (cotton, etc.) being planted in an area and consistently sees damage increasing on the less tolerant crops (beans, etc.) such observations are very likely to be reflecting a gradual change in soil salinity. The reverse can be stated as well in terms of a greater percentage of non-tolerant crops with less visual damage being introduced into the area.

Once we understand more about both the nature and range of variables inherent in the point sampling problem, work will proceed in the direction of actual salinity predictions based upon crop type and crop damage information, "bracketed in" by the use of multi-date imagery. Initial testing will begin utilizing highflight data and when satisfactory results are obtained (for damage assessment) ERTS imagery will be examined to test the feasibility of utilizing this type of data for damage assessment.

3.40 PERCHED WATER

The KCWA has just completed a major phase of its brackish water investigation in Kern County. A shallow hole drilling program was carried out utilizing a power auger to drill 152 holes (10" diameter) to depths of up to twenty feet. The investigation identified "perched" water accumulations within ten feet of the ground surface over an area of about 37,000 acres, an increase of approximately 35,000 acres since 1963. Within this same area, water was encountered at depths of less than five feet on nearly 7,000 acres of land. In 1963, only 120 acres were placed in this category. It is anticipated by the KCWA that in the immediate future drainage problems will continue to develop within that area identified as having brackish water within ten to twenty feet of the ground surface (47,000 acres). Earliest problems can be expected within the zones where the depth to water is now ten feet or less (37,000 acres).[11]

The area covered by this survey included the Kern River flood channel area, Goose Lake Bed and adjacent areas between Buena Vista Lake Bed and Kern Wildlife Refuge, all of which have been identified as being potential perched water areas by GRSU research.[12] GRSU work on the remote sensing of perched water was halted until this substantive drilling work conducted by KCWA personnel could be completed. The previous delineation of the suspected perched water area was based on a one-date highflight interpretation. A major

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11. Michael R. Rector, Brackish Water Investigation Shallow Water Table Survey, Kern County Water Agency, Bakersfield, 1974.

12. June, 1974 NASA Grant Report.

difficulty in this delineation was related to the task of differentiating between soil types and soil moisture regimes, especially from one date of imagery. The GRSU is now attempting a multi-date approach utilizing imagery from the Earth Resources Technology Satellite ERTS-1. Perched water areas will be monitored throughout the coming year in an attempt to identify any visible fluctuations in the areal dimensions of the perched water regions. The 152 wells are being monitored by KCWA personnel, thus providing accurate ground truth data for this remote sensing application.

In the coming months GRSU will attempt to verify the accuracies of interpreted delineations of perched water areas based on field checking and the report published by the KCWA discussed above.

3.50 FUTURE WORK

GRSU research during this reporting period has concentrated on the water demand aspects of the integrated study. Proposed future work will generally follow this same emphasis with a continued major portion of our research directed towards the KCWA hydrology model. Expansion and partial completion of our four model-related research topics is anticipated in the coming fiscal year. These study areas, as detailed in this report, are:

1) Croplands Mapping

2) Crop Identification

3) Salinity

4) Perched Water

The determination of parameters that are critical to agriculturally oriented water demand models is essentially complete (see Work Item 1, Figure 3-2). Remote sensing techniques have been evaluated for most of the major model inputs that originally appeared amenable to such methods (work Item 4). Specific procedures are still being refined in this phase of our research. Parallel to this, conventional methods are being investigated (Work Item 5) to facilitate cost-effective comparisons with remote sensing techniques (Work Item 6).

The analysis of economic impacts resulting from changes in water demand information (Work Item 2) and the effects of changes in the estimation of critical parameters (Work Item 3) have been difficult to determine. Basically, this results from difficulties involved in generating a conventionally gathered data base, separate from a remote sensing augmented data base. Once the two data bases are generated, the independent operation of the model for each separate data set should provide results that can be directly correlated with each data source.

As operation of the model is costly, this approach will require detailed preparation which, though already underway, is not expected to be completed during the next reporting period. Only when such an analysis is complete can overall estimates of the potential impact of using remote sensing techniques in water demand problems (Work Item 7) be made with confidence.

In addition to GRSU water demand studies several special studies are being proposed. The first three are directly related to water resource management (though not specifically water demand) and hence would aid the overall integrated study. The remainder are basically the result of agencies becoming aware of the potential usefulness of remote sensing techniques. A brief description of each proposal follows.

3.60 SPECIAL STUDIES

3.61 Croplands Mapping and Crop Identification Techniques in Coastal Environments

This study is being proposed in conjunction with the Santa Barbara County Water Agency and the University of California Agricultural Extension Office of Santa Barbara. The purpose of the project would be to determine the applicability of procedures developed by the GRSU for use in an arid environment, namely Kern County, and in a coastal environment, namely Santa Barbara County. Special attention would be given to (a) effects of greater cloud cover upon ERTS imagery availability and how this affects crop identification accuracies; (b) the lack of systematically square or rectangular shaped fields that result from flat terrain and a grid pattern of development (township and range); and (c) smaller field sizes in general. The location of the UCSB campus in Santa Barbara County should facilitate economic ground truth collection and provide interpreter familiarity with the region.

3.62 Detection of Waterlogged Soils

This study is proposed in conjunction with the Soil Conservation Service of the United States Department of Agriculture to evaluate the use of remote sensing techniques to detect and delineate waterlogged soils on the East Side of the San Joaquin Valley, mainly in citrus orchards. The study would aid the GRSU research into perched water detection and if successful would be especially useful to the SCS in their upcoming analysis of the San Joaquin Delta region.

3.63 Groundbasin Permeability Study

This special study is proposed in conjunction with the Santa Barbara County Office of Environmental Quality. The purpose is to determine the usefulness of remote sensing techniques for measuring the relative proportion of permeable vs. impermeable surfaces overlaying groundwater basin recharge areas. GRSU personnel have recently been involved in a survey that utilized low altitude photography (scale 1:10,000) and the manual delineation of permeable and impermeable surfaces. Such data should provide accurate groundtruth for use in analyzing remote sensing techniques based on highflight color infrared photography and electronic image analysis procedures.

3.64 Oil Field Sump and Road Mapping

This project is proposed in conjunction with the Division of Oil and Gas of the California State Resources Agency. Recent legislation has required the covering of all open oil field sumps and the enforcement of construction safety regulations. The GRSU has previously been involved with the Division of Oil and Gas in a mapping project where all discernible sumps were mapped from 1:60,000 color infrared highflight photography onto 7 1/2 minute quadrangles. These sheets were then distributed to personnel of the Division of Oil and Gas, and of the Department of Fish and Game so that each sump could be ground checked and its condition noted. (One lesson learned from ground checking was that a large percentage of time spent in the field could have been eliminated by the availability of more recent maps. It was also found that oil sump detection could be improved by the use of more nearly optimum film/filter combinations as well as larger scale imagery.) The region involved in this study would be the five coastal counties from Monterey on the north to Orange County to the south. A revision of Kern County's original sump inventory has also been proposed by Oil and Gas personnel.

3.65 Forest Fire/Fuel Study

This special study is proposed in conjunction with the CRSR and discussed more fully in their section of this report.

CHAPTER 4

USE OF REMOTE SENSING TO DETERMINE THE WATER DEMANDS OF THE UPPER SANTA ANA RIVER DRAINAGE BASIN

<u>Co-Investigator</u>: Leonard W. Bowden, Riverside Campus

<u>Contributors</u>: C. Johnson, J. Drake, G. Thomas, A. Van Curen, D. Nichols, J. Jones

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4.000 INTRODUCTION

The use of high altitude remotely sensed imagery to determine long-term water demand is proving to be most effective. The California State Department of Water Resources (DWR) has, for many years, forecasted long-term water demand by an empirical model that utilizes net land use as the driving parameter.

4.010 Objective

The current investigation has been to obtain the most accurate up-to-date land use by the least expensive methods to determine water demand. Remote Sensing from low flying aircraft has long provided a means of determining land use. Preliminary findings from our present studies show that a single high-altitude (NASA U-2) image can replace many low altitude images and yield far less distortion while permitting much faster data reduction to determine water demands in the Upper Santa Ana Drainage Basin.

4.020 Location and physical factors

The upper Santa Ana River Drainage Basin lies east of Los Angeles (Figure 4.1) and is separated from the coastal Los Angeles Basin by the northern extent of the Santa Ana Mountains and by the Chino-San Jose Hills which rise to the west of the Elsinore Fault zone. The only river outlet of the basin is the Santa Ana River which flows through the gap separating the Santa Ana Mountains from the Chino Hills. The Elsinore Fault cuts across the upstream entrance of Santa Ana Canyon with the west side of the fault block rising nearly to the surface where it forms a barrier to underground water flow. Thus all underground water is stored or flows to the surface. At this site the Corp of Engineers has built the Prado Flood Control Dam which permits only regulated surface water to continue downstream to Orange County. At the southern end of the upper Santa Ana River Basin, between the Elsinore trough on the west and the San Jacinto Fault on the east, lies the Perris fault which effectively blocks the drainage of any surface water to the south. The north and east sides of the basin are divided

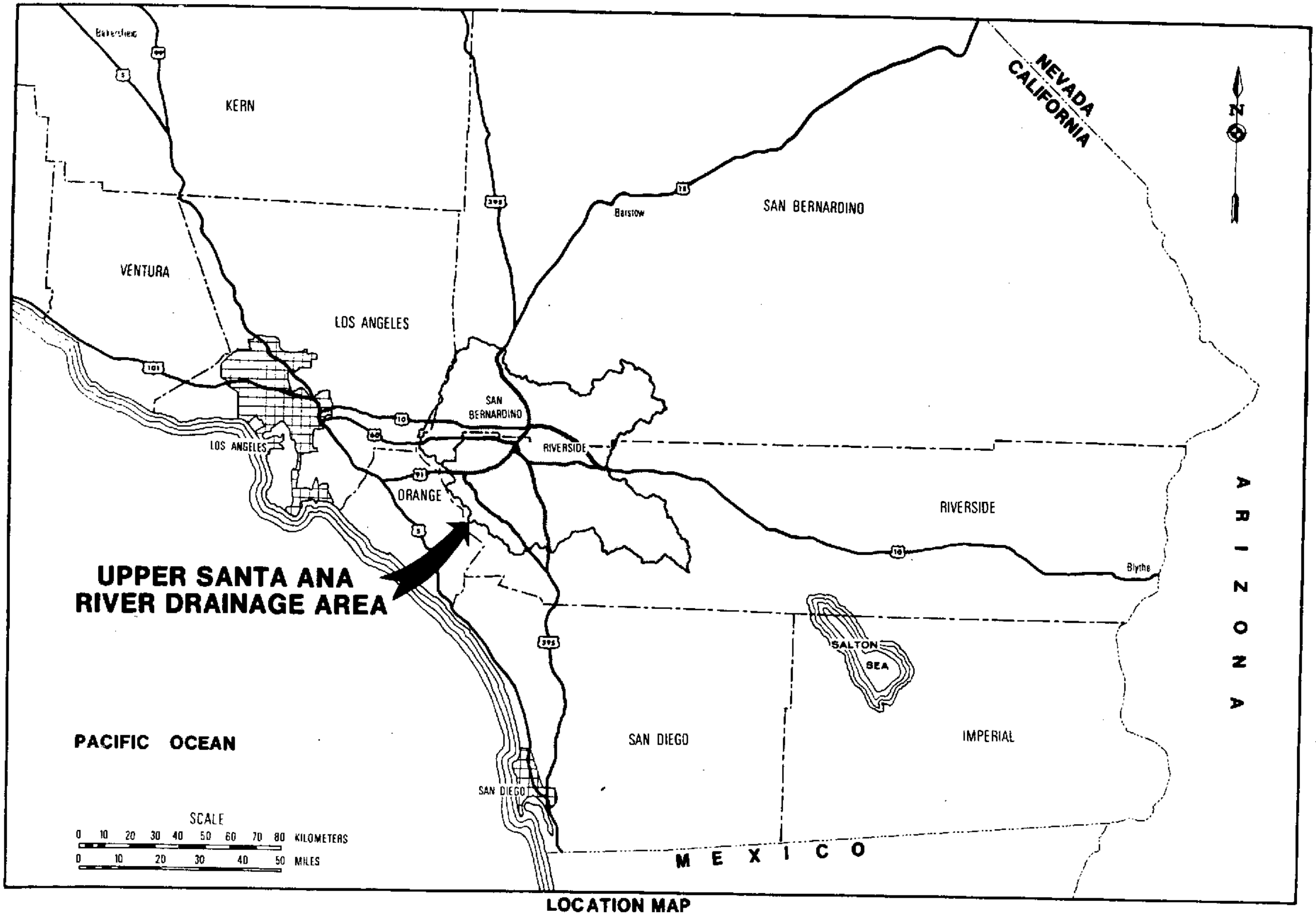

Figure 4.1 - Location Map of Upper Santa Ana River Drainage Basin

into the San Gabriel, San Bernardino, San Jacinto, and Santa Rosa Mountain water-sheds. The mean annual rainfall increases from 28 cm (11 inches) in the southwest portion of the basin to over 38 cm (15 inches) along the foothills in the northeast area. The effective precipitation in this semi-arid basin of 17°C (63°F) mean annual temperature is only 7.6 cm (3 inches), however.

4.030 Water Rights and Historical Demand

A series of litigations over the past 25 years between lower (Orange County) and upper basin (Riverside and San Bernardino Counties) users has resulted in a limit in the quantity of surface runoff water that may be impounded by the upper basin users. Consequently, upper basin users are not permitted to use all of the 32,824 hectare-meters (266,000 acre-feet) that is generally available annually. The water demand in the Upper Santa Ana River Drainage Basin has caused an overdraft since the early 1940's. Imported water from the Colorado River was first delivered in 1943, with the quantity being imported increasing each year. Yet, the basin has continued to be overdrafted by increased urban demands and a decreasing supply from local surface and underground basins resulting from aforementioned litigations. The first deliveries of Feather River Water from the California State Water project have arrived, but even this new source of water may prove to be insufficient. Since the original contract for California Project Water was made, the U.S. Supreme Court has placed a restriction on the amount of water the State of California may draw from the Colorado River. In drought years in the Colorado River Basin this may cause a shortage of importable water.

Another problem which will undoubtedly be resolved only with further litigation is the quality of water passing through Prado Dam on its way to Orange County. All effluent water from upriver sewage treatment plants is discharged into the Santa Ana River after secondary treatment. There exist many settling ponds and septic fields filtering water into the underground basin. The water from both of these polluted sources (surface drainage and the underground water) eventually flow to the Prado Dam area. In addition to the sewage effluent discharging into the Prado Dam catchment basin there is surface runoff that comes from the nearby dairies in Chino Valley. The surface runoff from the dairies pollutes the Prado Basin water with potentially harmful nitrates (especially dangerous, maybe lethal, to babies and the elderly). Orange County officials are objecting to receiving the polluted water and are taking steps to bring suit(again) against the upper basin polluters. The State Water Quality Control Board is increasing the treatment requirements on sewage disposal and more importantly is prohibiting any surface runoff from the Chino Basin dairies. Treatment is supposed to be accomplished by settling basins on the dairy properties and by placement of dikes in the path of natural runoff waters. The Water Quality Control Board has no effective means for monitoring compliance by the dairies and consequently is asking if remote sensing techniques can provide effective monitoring of the control efforts.

Our research problem is thus increased from one of finding a cost-effective means of determining accurate up-dated net-land use inventories for water demand models to one of providing a cost effective means of monitoring improvement of the water quality within the Upper Santa Ana River Drainage Basin.

4.100 ANALYSIS OF IMAGERY FOR LAND USE CLASSIFICATION

Four seasonal high altitude (NASA U-2) missions have been flown of the basin (December 10, 1973, March 14, 1974, June 3, 1974, and October 16, 1974). The first three flights employed the RC-10 camera system with the 153 mm (6 inches) lens and color infrared film (CIR). A 70 mm Vinton Camera package provided the secondary sensor system. The October flight was made up of two RC-10 cameras with CIR film. One of these cameras used the regular 153 mm (6 inches) lens and the other used a 610 mm (24 inches) focal length lens. Unfortunately, the longer lens camera system failed in the last mission, which will be reflown.

The 1:130,000 scale CIR imagery is providing an average ground resolution of about 6 meters (20 feet). This is proving sufficient to interpret land use to better than the second level of classification which is adequate to fulfill the need to determine water use categories. With a few hours of special interpretation training, all dairies can be identified from the imagery to include differentiation between corrals, the milkshed, the residence houses, and definition of the pasture boundaries.

Our research effort has contributed to a further understanding and definition of land use classification systems from high altitude and satellite imagery. The land use definition required for calculating water demand differs from that needed by most planners. Planners desire more detailed urban identification while water resources agencies are more concerned with unit area definition. The ideal classification system would provide sufficient definition in both urban and rural environments for all users. Therefore, the studies performed under this grant have been designed to develop a system thatwould provide the most accurate water demand estimate, but at the same time could be used in a machine assisted geographic information system capable of being utilized by other type users without modification. Table 4.1 lists the UCR land use classification adapted to the study with the equivalent State Department of Water Resources land and water use classification shown in the adjacent column.

One of the more significant adjustments in land use interpretation from high altitude aircraft/satellite imagery is in the Living Area (Residential) category. Housing density is a more apparent residential feature than buildings. Consequently, the concept of classifying living areas into low, medium, and high density classifications is introduced. The low density

TABLE 4.1

LAND AND WATER USE CLASSIFICATIONS

UCR CLASSIFICATIONS		DWR EQUIVALENT CLASSIFICATIONS	
Code	Title	Code	Title
1	LIVING AREA		RESIDENTIAL (URBAN & RECREATIONAL)
11	Medium Density Urban (Single)	UR	Urban Residential
12	High Density (Multiple Units)	UC 2/RR	Motels, Urban & Resort
		UC 4	Urban Commercial (Apts & Barracks)
14	High Density (Mobile Homes)	UR	Urban Residential
15	High Density (Transient Lodge)	UC 4	Urban Commercial
13	Low Density (Urban Estates)	UR	Urban Residential
16	Low Density (Rural Dwelling)		
17	Low Density (Recreation Unit)	RR	Recreation Residential
2-3	INDUSTRIAL (Manufacturing)		URBAN INDUSTRIAL
21-27	Light Industry	UI 1	Manufacturing
28-34	Heavy Industry	UI 61-12	Sawmills, Oil, Paper, Meat, Steel, Food
4	TRANSPORT & UTILITIES		
41	Railways & Rail Terminals	UI 3	Storage & Distribution
42	Motor Transport Facilities		
43	Aircraft Facilities		
44	Marine Craft Facilities		
45	Highways and Roads	UV 4	Urban Vacant, Paved
46	Automobile Parking	UV 4	Urban Vacant, Paved
47	Communications	UI 3	Storage & Distribution
48	Utilities (water, gas, elec., sewer)	UI 3	Storage & Distribution
5	COMMERCIAL (Trade)		URBAN COMMERCIAL
51	Wholesale Trade	UI 3	Storage & Distribution
52-58	Retail Trade	UC 1	Misc. Establishments
6	SERVICES		
61-66	Commercial & Professional	UC 1	Misc. Establishments
67	Government		

TABLE 4.1 (continued)

UCR CLASSIFICATIONS Code	Title	DWR EQUIVALENT CLASSIFICATIONS Code	Title
6	SERVICES (continued)		
68	Education	UC 6	Schools
69	Social	UC 5	Institutions
7	CULTURAL, ENTERTAINMENT, REC		
71	Cultural	UC 7	Auditoriums, Theaters, Churches
72	Public Assemblies	UC 7	Auditoriums, Theaters, Churches
73	Amusements	UC 7	Buildings & Stands w/race tracks, etc.
74	Recreational Activities	UC 7	Football Stadiums, sports parks
75	Resorts & Camps	RT	Camp & Trailer Sites, Recreational
76	Parks and Golf Courses	P	Parks, Recreation
8	RESOURCES		
81	Agriculture	A	Agriculture
81.4	Dairies	A	
82	Agriculture Related	S	Semi-Agriculture
83	Forestry Activities		
84	Fishing		
85	Mining	UI 2	Extractive Industries
9	UNDEVELOPED		URBAN VACANT/NATIVE
91	Land	UV-1	Unpaved, Urban Vacant
92	Forest	NV	Native Vegetation
93	Water (incl. Dry Channels)	NR	Riparian Vegetation
		NW	Water Surface

includes urban residential lots of 0.13 hectares (1/3 acre) or greater, rural residential on lots of 0.2 hectares (1/2 acre) or larger, and resort houses (mountain cabins, or other type second home recreation house). Medium density housing is comprised of the area generally classified as separated single family dwellings on lots of less than 0.13 hectares (1/3 acre). High density living areas can often be detected as apartments of 3 or more household units, hotels, motels, and other buildings devoted to providing shelter for multiple residents.

Industrial areas are detectable as either heavy or light. Light industries are usually of lesser acreage and found in a particular portion of urban areas according to local zoning ordinances. Some "ground truth" is usually required if differentiation between light industry and commercial wholesale trade is required. The heavy industries (oil, steel, food processing) are detectable by their larger acreage and urban fringe location.

The transportation classification, because of linear features or large overall size, can be identified to the third and even fourth level of classification although only necessary to the second level for this study. Likewise utilities (power substations, water plants, sewer plants, and gas facilities) are detectable to the third level from high-altitude imagery.

Commercial wholesale and retail trade is generally limited in detection to the first level of identification. Depending on location in the urban area, wholesale trade is confused with either retail trade or light industry. Second level detection of commercial trade buildings is extremely difficult unless the trade possesses some unique feature of more than 6 ground meters (20 feet) resolution.

The service classification is detectable by the distinctive features of government, educational, religious, and hospital buildings. The exceptions are business and professional services. Unless business services are uniquely located, it is difficult to distinguish them from retail trade.

Amusements and recreational activities can often be classified to the third level because of the large land area involved. Cultural buildings and public assemblies demand approximately the same water use and can be consolidated for investigation. Recreational parks, golf courses and resorts require a similar quantity of water due to the large expanse of grass areas. They too have been consolidated, although coded separately.

Resources in the Upper Santa River Drainage basin are classified into three second level categories: Agriculture, Forestry activities, and Mining. For the first phase of study, agriculture is only being classified to the second level. The high altitude aircraft imagery taken on sequential dates provides adequate data to identify agricultural crops to the fifth level if necessary. Because of the specific investigation mentioned earlier, all dairiesare being identified separately from general agriculture.

Undeveloped land is being coded to second level classifications of open land, forest, and water. Dry water channels are classified under undeveloped water even though many of the dry channels only carry runoff flood waters or underground percolation.

The four-date, high altitude aircraft CIR imagery has been adequate to classify all of the land use in the Santa Ana River Drainage Basin to the second level, a level adequate for a water demand model using land use as the driving parameter. (Driving parameter is defined as the one factor in a model that if incorrect or changed in character will cause the greatest error or change in the final results produced by the model.)

4.200 CURRENT STUDIES

The development of a Water Demand Model for the Upper Santa Ana River Drainage Basin has led to several related studies. Because land use is the driving parameter it is necessary to identify the land use of the basin. Estimating water use by land use area requires that all land use of the same classification be reduced to equivalent net areas. That is, all non-permeable areas contained within a specific land use are deducted from the gross area. Determining the accuracy of the DWR's current Net Reduction Land Use Factor thus becomes one prime study. A second study, specifically requested by the DWR, is to determine how long irrigated agricultural fields lie fallow. Agricultural water demand estimates made by the DWR are made with only a fair guess as to the duration of the fallow season. Because agriculture represents 33% of the land use in the basin, the accuracy with which the length of the fallow season is known can make a considerable difference in the accuracy of the overall water demand estimate. Still another study concerns the quality of recycled water within the basin. A large concentration of dairies (displaced from Orange County) exists in the Chino Valley area of the basin. Disposal of both the solid waste and waste water (including 47 gallons daily wash down water per cow) containing highly concentrated nitrates is of concern. The Santa Ana regional office of the California Water Quality Control Board has requested that we include in our project a feasibility study on use of high altitude aircraft imagery to monitor the control of waste material and water from the dairy industry.

4.210 Machine Assisted Santa Ana Basin Land Use Mapping

The development and maintenance of a water demand model requires both current and accurate data for the driving parameter. The State Department of Water Resources has determined that the most reliable parameter is land use. Changes in long-term living habits are expressed visually in a change of land use. These changes are most detectable through aerial photography and thus provide a unique opportunity for NASA test platforms to display their ability to provide data for solving long-term water resource problems.

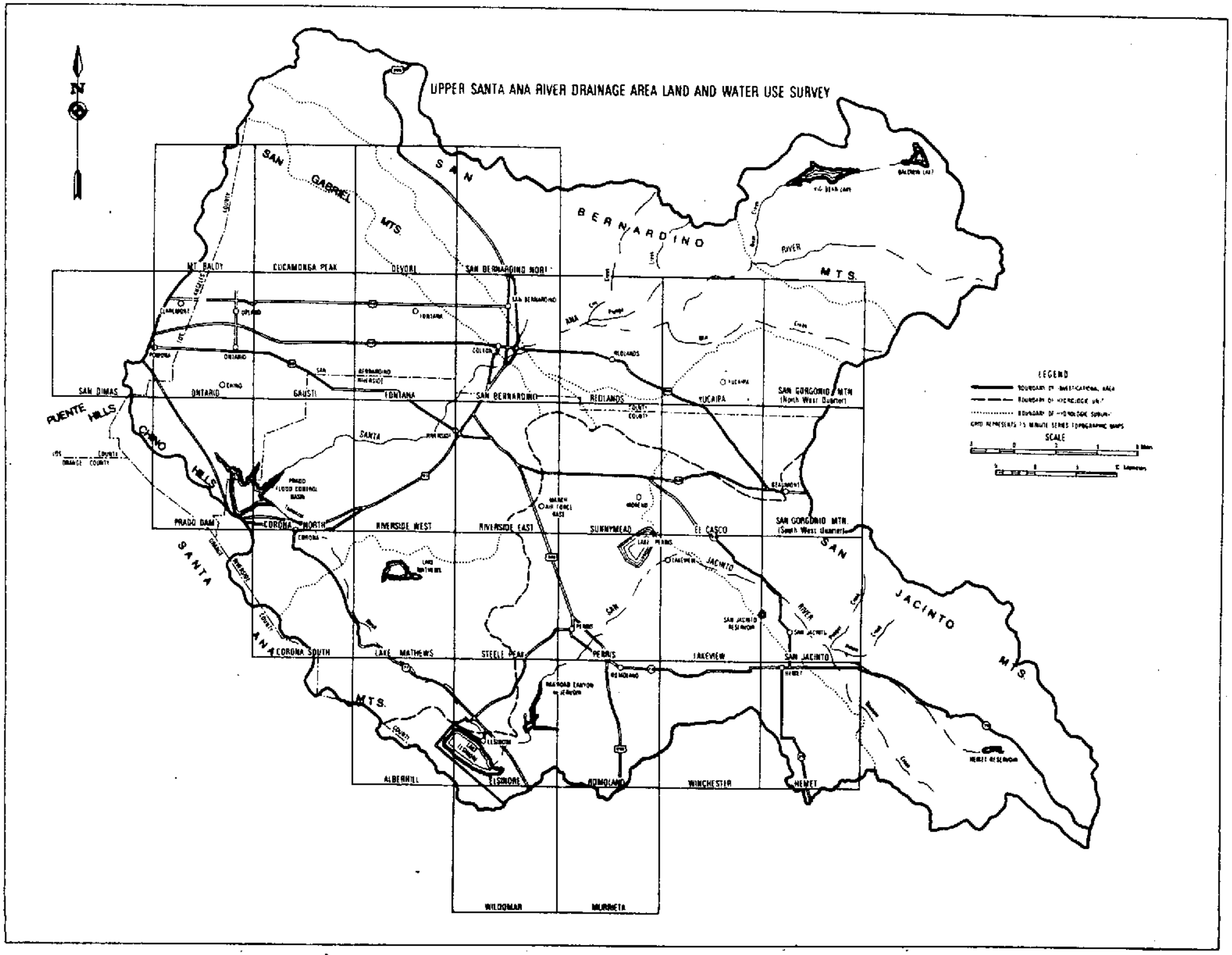

Figure 4.2 Grid Overlay of Upper Santa Ana River Drainage Basin for Land Use Interpretation

4.211 Philosophy of Approach

Current staffing and equipment at the Department of Water Resources (DWR) permit the inventory of a region only once every decade. With the fast changing land use from rural to urban in many areas of California the DWR often is forced to make long-term water demand forecasts with outdated and perhaps inaccurate data. A system is needed that will provide accurate and easily updated land use information. Any system developed must be economical and attainable within the low budget of the various district offices. A statewide computer system is available to the various offices if they can prepare the data within the capabilities of the local district. The present state of data reduction within district offices is exemplified by the fact that acreage calculations are being accomplished by a careful cutting and weighing of special prints of land use maps. Hence, exotic systems that employ procedures of discriminant analysis to identify land use cannot be feasibly transferred to state use at this time. A system of machine-assisted land use inventory is pushing the financial limits of the local office, but can be transferred if a cost-benefit can be proved. With cooperation from the Los Angeles District office of the DWR the following outlined machine assisted land use system is being developed utilizing high altitude aircraft (U-2) imagery for data.

4.212 Planimetric Boundary Transfer

The Upper Santa Ana River Drainage Basin comprises 585,382 hectares (1,446,510 acres). To manage the interpretation of such a large region, it has been divided into more than 30 grid units of approximately 15,985 hectares (39,5000 acres) each. Figure 4.2 shows the grid overlay imposed on the Basin. As noted the grids are comprised of U.S.G.S. 7-1/2' topographic quad sheets at a scale of 1:24,000. Areas not covered by the grid overlay comprise mostly undeveloped forest lands. The use of quad sheets provides a planimetric base map to which the interpreted land use can be fitted for accurate planimetry.

To provide for the accurate transfer of data from the 1:130,000 scale imagery to the 1:24,000 scale base, an enlarging process has been instituted. The RC-10 metric camera on the U-2 platform flown at an altitude of 65,000 feet provides an almost distortion-free image, especially within the area close to the nadir. To insure that transfer is planimetrically correct, a mylar overlay with control features (roads, rivers, etc.) outlined on the overlay is used to receive the projected image on a K & E Kargl enlarging/reducing projector. Boundaries of the various detectable land uses are then drawn on the map overlay. It has been found that, with accurate land use boundaries drawn on the overlay, it is best to view the image through a magnifying lens to interpret the land use type. The Kargl enlarger, when projecting through the matte finished mylar, degrades the resolution to an unacceptable level. This method of boundary transfer from image to map has proved far superior to other manual methods previously employed and has maintained the required boundary accuracies for calculating acreages of land use. However, a more economical machine process needs to be developed for this phase of data reduction.

4.213 Digital Encoding of Polygon Data

The reduction of map data to digital form for computer processing has been time consuming and error prone. The original program obtained to produce shaded chorpleth maps required that each vertex (any change of direction of a boundary) had to be hand numbered. Many of the quad sheets have well over 2,000 vertices which required up to 40 man-hours to hand number. Another manual task was to encode the vertices that corresponded to each polygon, which was another 40 man-hour task. Each of these manual tasks has been eliminated by program development performed under the present NASA grant. The reasoning for the manual encoding was sound because it was a method to eliminate duplicate vertices which occur every time there are two adjacent polygons. The duplicate vertices problem has been eliminated in a computer edit program that searches the vertices tables encoded by the X-Y coordinate digitizer. Each polygon is now encoded by the X-Y coordinate digitizer. Each polygon is now encoded on the digitizer with all data (polygon number, vertices location, and land use type) punched automatically from the digitizer console. The digitizer measures the vertices in both X and Y direction from an arbitrarily selected origin with an accuracy of .25 mm (.001 in). The new procedure, in addition to eliminating 80 man hours per map, has reduced the number of coding errors caused by mistakes in numbering or in reading the formerly pre-encoded numbers. A sample of a completed four color shaded land use map of the Riverside Area is shown in Figure 4.3. The figure is a four pen simultaneously plotted computer color map using the UCR CHORMAP routine. It is one of the first chorpleth type land use maps to be produced in this manner.

4.214 Statistical Compilation of Land Use Acreage

While the production of a map is necessary to display the results and provide the planners with a better idea of where future actions should be directed, the most important result of the land use mapping for water demand studies is in the compilation of acreage statistics. Once a polygon has had its vertices identified and encoded into machine code, it becomes a simple, almost instantaneous, calculation to determine the acreage of the polygon. Summaries by land use type, hydrologic sub-unit or any other defined sub-division are obtainable in less than one minute of computer time on an IBM 360-50 system. A tabulation of the acreage summaries for the fully completed maps is listed in Table 4.2.

Thirty maps comprise the grid overlay of the Santa Ana River Basin. All thirty maps have been interpreted and exist on mylar overlays. Fourteen

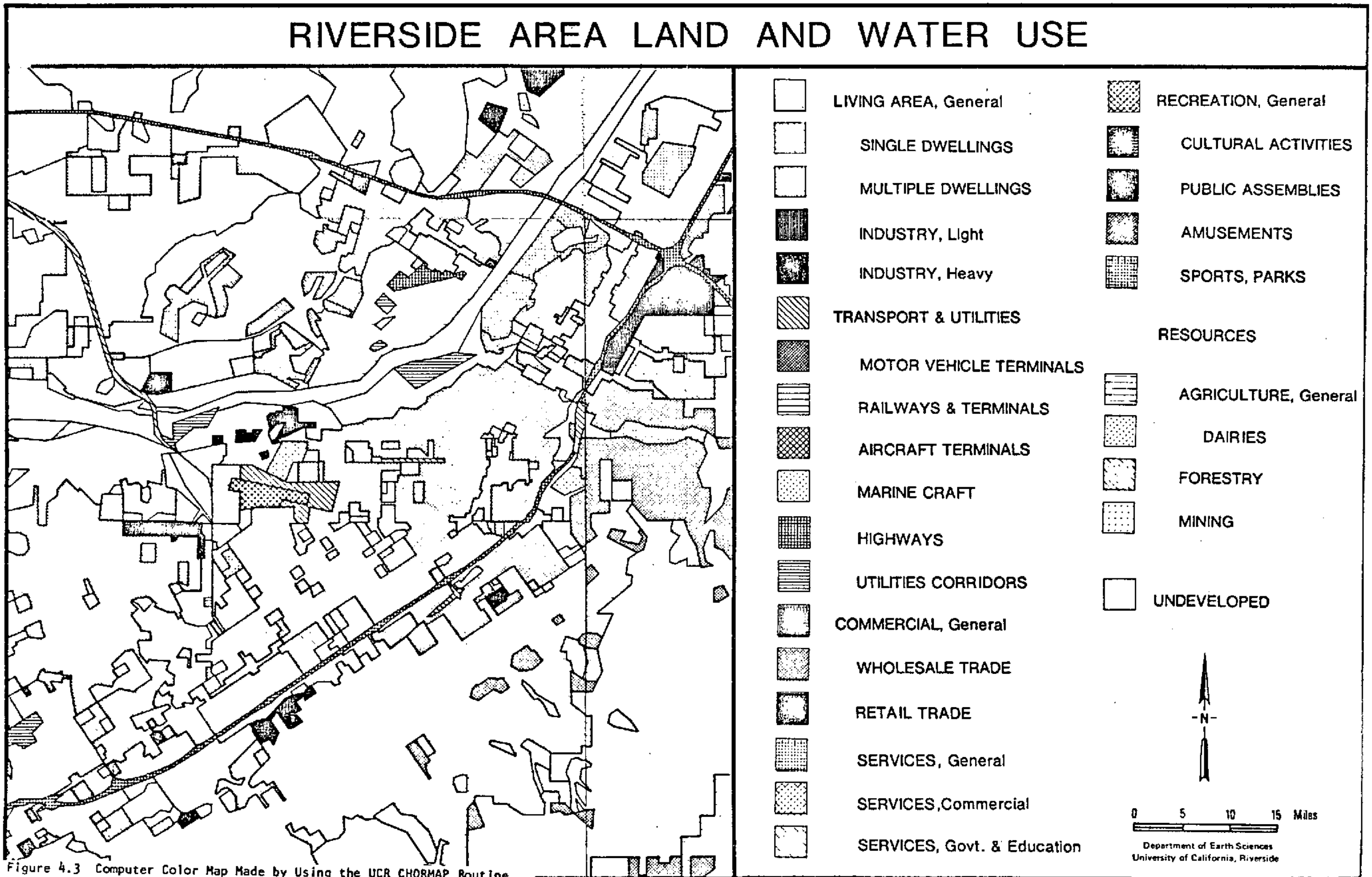

Figure 4.3 Computer Color Map Made by Using the UCR CHORMAP Routine as Described in the Text

of the maps have been completely processed, a four pen color map has been produced, and a base scale plot program is on file for each of the 14 maps. A fifteenth map has reached the stage where area compilations have been produced. The total acreage of the 15 maps as shown in Table 4.2 is 194,762 hectares (481,262 acres) which represents 33.3% of the total area.

Upon completion of the total land use mapping, it will then be possible to implement the water demand model for the entire basin. However, accuracy of the model will require updating the land use data on an annual basis as well as using appropriate reduction factors to determine net water use areas from gross land use data.

4.220 Factors for Reducing Gross Land Use to Net Water Service Areas

The California Department of Water Resources (DWR) utilizes a water consumption value based upon the Net Water Use Area. That is, it reduces gross land use areas to permeable soil areas and building areas whose occupants consume water either in occupation or living. The continual change and regional variations in land use make it necessary to continually update the reduction factors for each region separately. The purpose of the following study was to develop a method of deriving net reduction factors using remote sensing techniques. It was discovered that the net reduction factors could be updated 125 times faster by remote sensing than by conventional ground survey methods. An accuracy check indicated that remote sensing techniques provide values which are within 5% of actual ground measurements. The inherent error of the overall water consumption per water use area makes the 5% variance insignificant, compared to the savings in time.

By DWR definition, the water service area is a gross area containing many non-water use areas which would be both difficult and extremely time consuming to differentiate during the initial survey. The non-water use areas include: sidewalks; public highways and roads; farm access roads; vacant lots; tank farms; oilfields; quarries; gravel pits; storage yards; railroad rights-of-way; miscellaneous impervious areas and miscellaneous non-irrigated farm areas.

In the past, the DWR has employed two means of deriving the reduction factors. For agricultural areas appropriate percentage factors were determined from detailed surveys of representative sample plots. In urban regions, the net areas were derived through estimating the percentage of non-water use lands; the making of a more traditional detailed survey is time consuming and therefore costly. The variation within most of the general land use types indicates the need for an extended number of surveys in order to obtain a representative reduction factor.

Table 4.2

PARTIAL LAND USE AREA OF THE UPPER SANTA ANA RIVER
DRAINAGE BASIN, 1974

CLASSIFICATION	Hectares	Acres
LIVING AREA		
Urban, Single dwelling	24,106	59,566
Urban, Multiple dwelling	711	1,756
Rural, Mixed dwellings	579	1,430
INDUSTRIAL		
Light	1,813	4,479
Heavy	815	2,013
TRANSPORTATION & UTILITIES		
Transportation	2,906	7,181
Utilities	1,465	3,620
COMMERCIAL OR TRADE		
Wholesale	68	168
Retail	1,993	4,926
SERVICES		
Business & Professional	230	568
Government	2,980	7,363
Educational	1,425	3,521
Social	43	106
CULTURAL, AMUSEMENT & RECREATION		
Cultural & Public Assembly	293	723
Recreational, Resort & Parks	2,542	6,282
RESOURCES		
Agricultural	65,552	161,982
Forestry	8	20
Mining	643	1,590
UNDEVELOPED		
Land	54,488	134,642
Forest	25,018	61,821
Water (including Dry Channels)	7,084	17,505
TOTALS	194,762	481,262

Total Basin Acreage: 585,382 Hectares
1,446,510 Acres

Percent Complete Sept. 30, 1974: 33.3%

4.221 Sample Selection and Area Computation

Prior to sample selection and analysis, time was taken to study the land use classification system for which reduction factors were to be derived. In this case it was the eight class, first level system used by the DWR in the Upper Santa Ana region. The study provided information on the variation within each land use class that needed to be considered for sampling when the overview of the study area was made.

The method of sample selection was another preliminary consideration. To use statistical sampling methods and arrive at an acceptable reduction factor the population and distribution of all significant variations would have had to be determined. Because the information was not available it was decided that representative samples would be selected according to their ability to combine with other samples and give a true representation of all land use within a land use type.

The actual process of sample selection began with a general overview of land use in the drainage basin using CIR imagery from NASA mission 164 (1:60,000) and NASA-Ames mission 72-112 (1:132,000). The use of this relatively small scale imagery permitted a comprehensive complete image of the study area to be obtained. After the general distribution of land use and the types of variation that needed to be sampled had been noted, representative sample plots were located on larger scale imagery according to mechanical limitations of analysis and the availability of imagery. Smaller scale imagery was suitable for block use types such as shopping malls and agricultural areas. Larger scale imagery was needed for use types having fine detail such as the residential and educational types. Large-scale imagery used included: 14 July 68 (1:8,000), 13 July 70 (1:12,000), 25 May 73 (1:20,000), 24 May 68 (1:60,000).

The imagery containing each plot was placed on the Kargl Reflecting Projector and enlarged. The boundary of each plot and the water use area within it were traced onto mylar, a process which produced a schematic of area polygons on which non-water use could be analyzed.

The process of schematic analysis involved placing the schematic on the digitizing table and recording (x,y) values for each vertex to an accuracy of one-thousandth (.001) of an inch. Once the vertices for each polygon had been compiled, its area was computed on a programmable calculator. The sum of the water use polygons was subtracted from the total area of the sample to obtain the ratio of non-water use area to total area. The ratio was then used to calculate a percentage reduction factor for the sample. The arithmetic mean of the percentages for all the samples within the use type was the factor used to reduce the gross water service area to net water service area.

4.222 Analysis of Results

Usually the most effective way to analyze the strengths and weaknesses of a new problem solving technique is to compare it with previous methods. In order to be acceptable, a new approach must offer significant advantages of efficiency and/or accuracy yet have no significant disadvantages which would outweigh these advantages. Emphasis here is given primarily to comparing the results of the UCR method with those of the DWR and analyzing the variables to determine what makes the difference. The methods and results of the DWR are used only as a medium for analyzing the UCR method.

The problem solving format outlined in the preceding section was employed in selecting thirty-one sample plots in the Upper Santa Ana Basin. The study area and the location of these plots are shown in Figures 4.4 and 4.5. These samples were considered to be characteristic of the land use variation and thus should provide representative reduction factors. These reduction factors are compared with those used by the DWR in Table 4.3. The discrepancy between the reduction factors immediately raises questions as to possible causes.

Possible causes for the discrepancy are found in three general areas: 1) land use change, 2) the sample base problem, 3) method error. Each of these possibilities is examined.

4.222.1 Land Use Change

A basic assumption about land use is that it is a function of man's needs. As these needs change through time they produce changes in land use. The overt signs of these changes are seen in both convergent and divergent trends in human activity, such as an increase in the concentration of roads, houses, etc., and the abandonment of the central business district (CBD) in favor of shopping malls. More roads, wider streets and larger parking lots all increase the percent of non-water use area. The effects of these changes as they relate to non-water use areas are illustrated by comparing a CBD with a shopping mall as in Figures 4.6 and 4.7. The percentages of non-water use area for the CBD and the mall are 49 and 67 respectively. Such a shifting land use pattern makes it necessary to update reduction factors with each new water use survey. The fact that these land use changes can most effectively be monitored and evaluated by remote sensing techniques has been demonstrated by several NASA projects carried out by the Geography program at the University of California, Riverside.

4.222.2 The Sample Base Problem

The goal of sampling is to arrive at a representative reduction factor without having to evaluate the entire study area for non-water use. A representative sample base consists of the number of samples that are required to produce a reduction factor that will be representative of all the variations within the general land use type. It is necessary, until detailed surveys of each variation are available, to rely on the skills

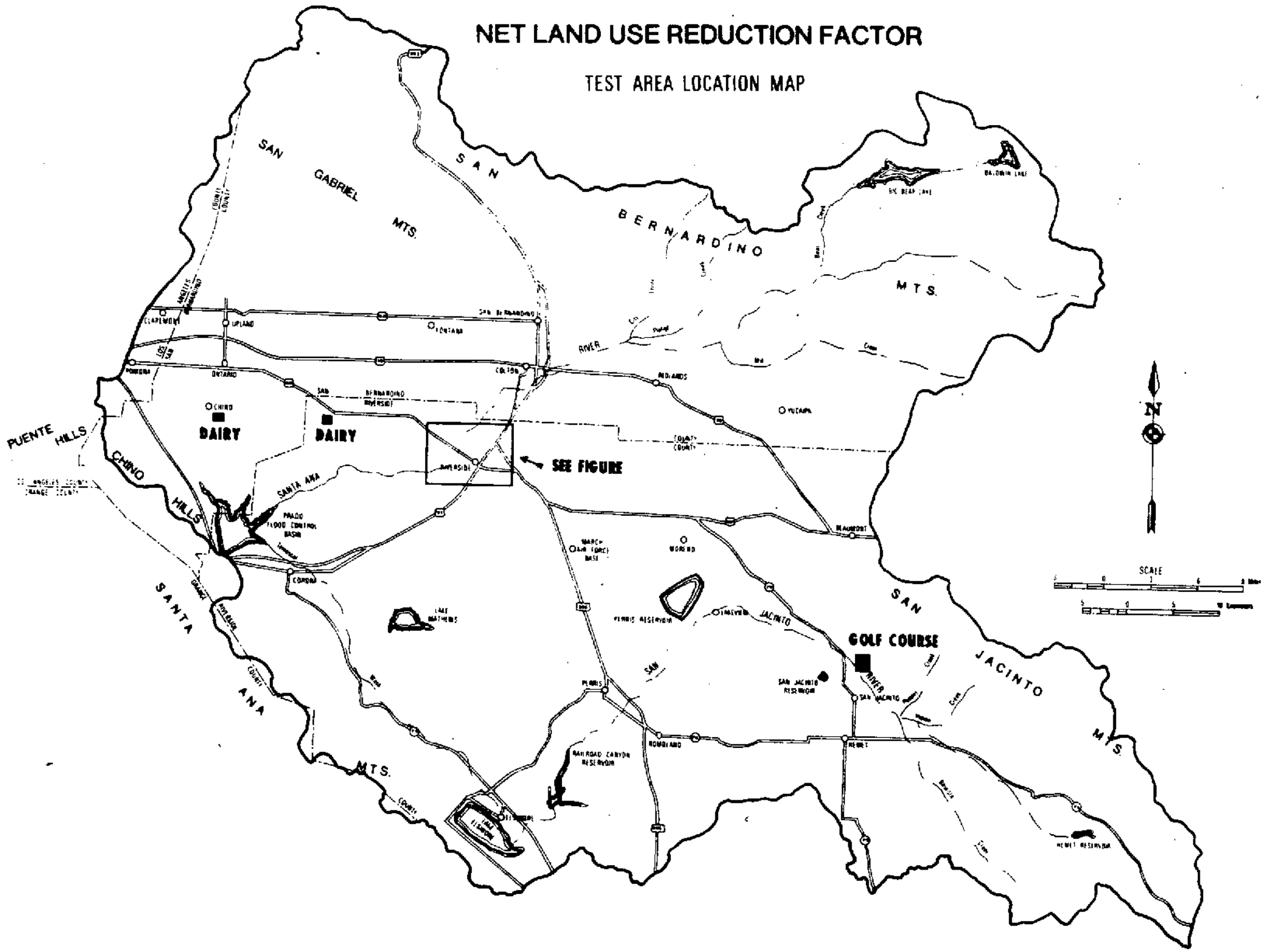

Figure 4.4 Area Location of Sample Test Sites for Determining Net Reduction Factor Used to Derive Net Water Use Area From Gross Land Use

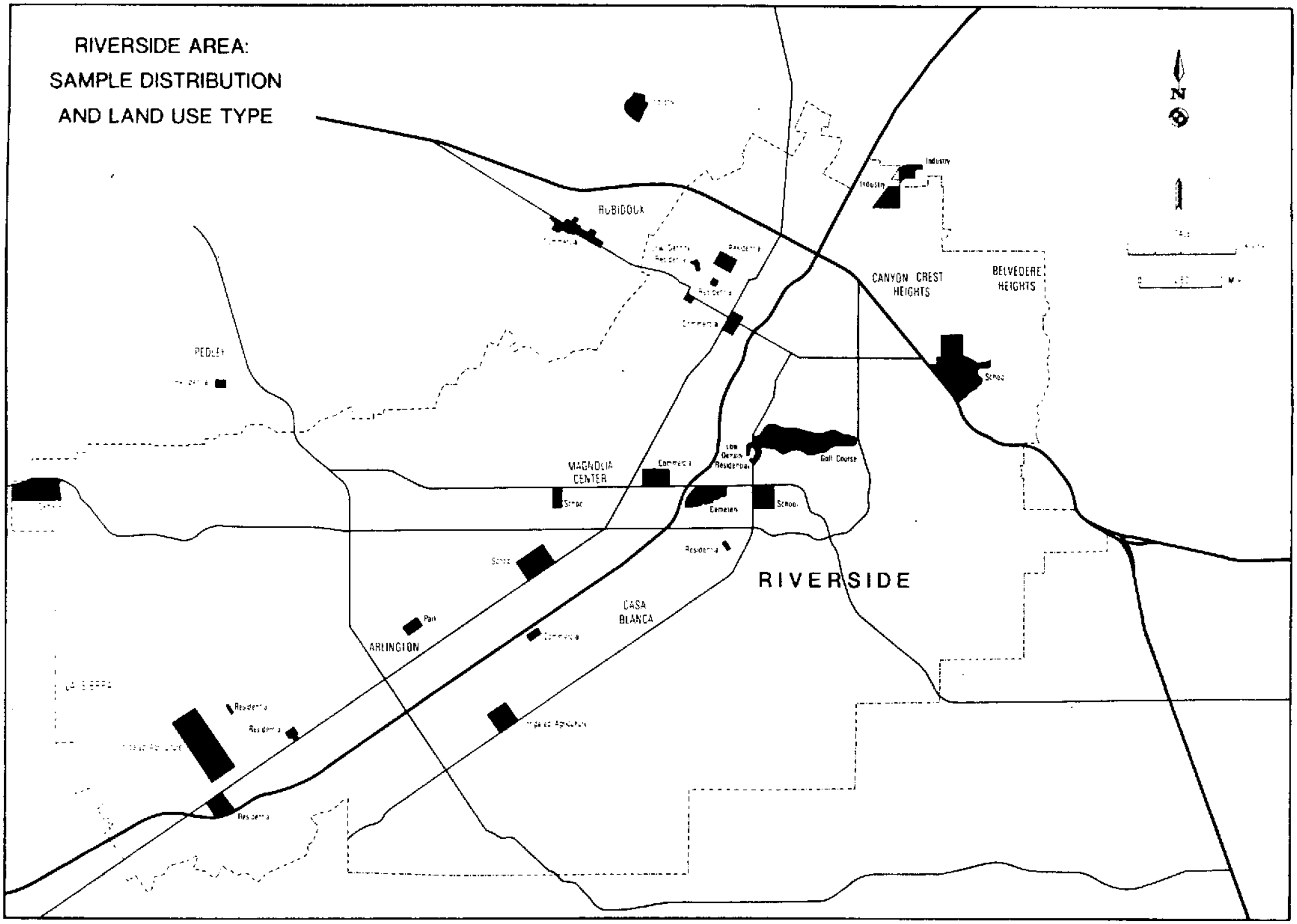

Figure 4.5 Location of Sample Test Sites for Calculating Net Reduction Factor to Derive Net Water Use Area From Gross Land Use

of the investigator to establish a representative sample base. The investigator is limited as to the number of samples he can analyze by the resources that are available to him. It is important that the method of analysis used by the investigator not restrict the number of samples to less than a necessary representative base.

The possibility of a less than representative sample base producing variation in the percentage reduction factor is well illustrated in a comparison of the thirty-one samples analyzed by the UCR method. Within most of the general land classes the difference between the individual variations is sufficient to give a wide range of percentages of non-water use area. The significance of each variation as it is added to the sample base is shown by calculating a cumulative mean reduction factor. While some samples have relatively no effect on the cumulative mean, each sample represents a significant variation of land use and, as an addition to the denominator in the mean calculation, each is significant to the final product. The representative character of the reduction factor is insured only when all significant variations are represented.

The problem can be illustrated in the figures for non-water use area for parks, cemeteries, and golf courses. Non-water use area ranges from 21-23 percent for parks and cemeteries and from 4 to 7 percent for golf courses. If, for example, a golf course comprises 77 percent of the area in this general land use type, a 15 percent reduction factor is not representative. There are three samples of parks and cemeteries, each of which has a much larger reduction factor than the two samples of golf course. In a straight mean calculation using these percentages, the golf course samples are properly de-emphasized. The problem can be eliminated in the future when detailed surveys are available which provide area figures for each significant variation. One solution is to calculate weighted reduction factors according to the amount of area comprising each variation. The weighted reduction factor is calculated by computing the arithmetic mean of each subgroup, multiplying it by the percent which the subgroup represents of the gross area of that particular land use type, and adding these products to get the reduction factor. ($22.2 + 22.8 + 21.2 = 66.2/3 = 22.07$, $22.07 \times 0.23\% = 5.1\%$; $6.7 + 4.3 = 11/2 = 5.5$, $5.5 \times 0.77 = 4.2$; $5.1 + 4.2 = 9.3$, the weighted reduction factor).

4.222.3 Methods Error

The use of an analysis method is based on the assumption that the method will produce results of acceptable accuracy. The most critical question that can be asked when differences appear in the results is that of the possibility of inherent error in one of the analysis methods. The UCR method is based on the schematic, which to a degree is a generalized form of reality. A study of the different areas where error might enter

Table 4.3

REDUCTION FACTORS: METHOD COMPARISON

DWR VERSUS UCR

LAND USE TYPE	Percent of Land Deducted from Gross Area		
	DWR	UCR*	% difference
Residential	22	29	32
Residential (low density)	10	24	140
Commercial	20	63	215
School	15	36	140
Industrial, Mfg.	25	50	100
Park, Cemetery, Golf Course	15	15	0
Farmstead, Livestock Ranch, Dairy	10	8	20
Irrigated Agriculture	5	9	80

* Measurements accurate to within ± 5% of value shown.

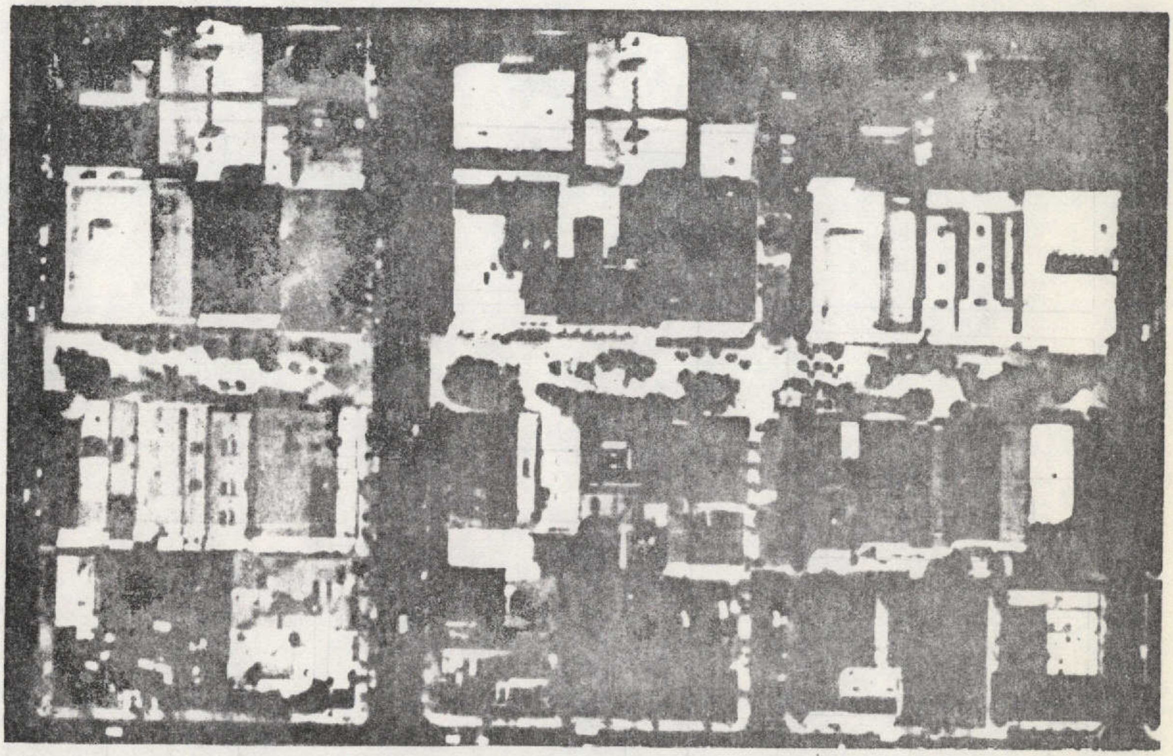

Figure 4.6a Photograph of portion of Riverside Central Business District showing 49% of the area in impervious sidewalks, streets, and parking lots.

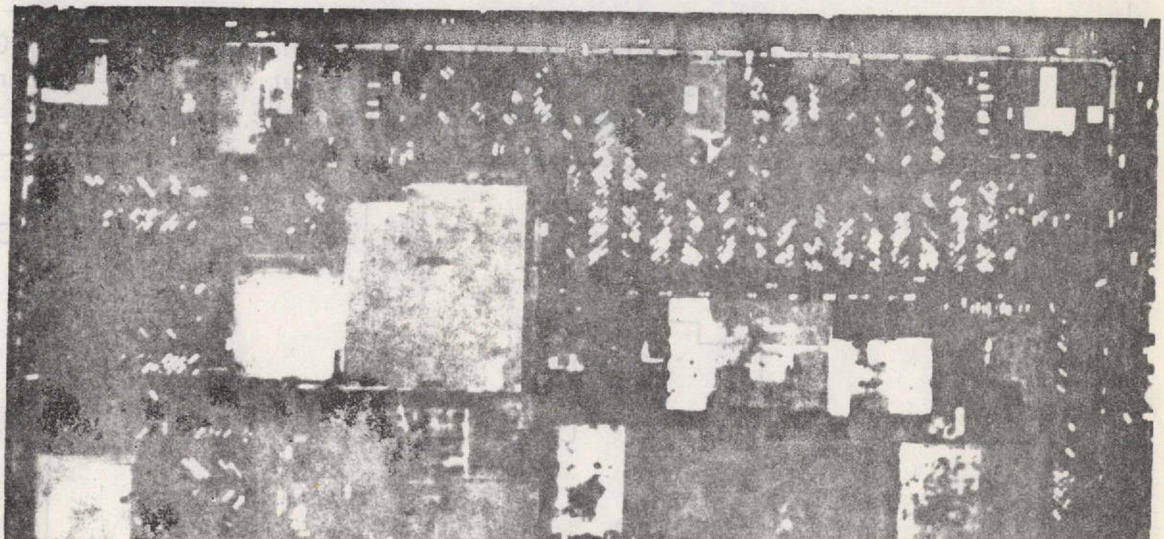

Figure 4.6b Photograph of Riverside Plaza regional shopping center showing 67% of the area in impervious parking lots.

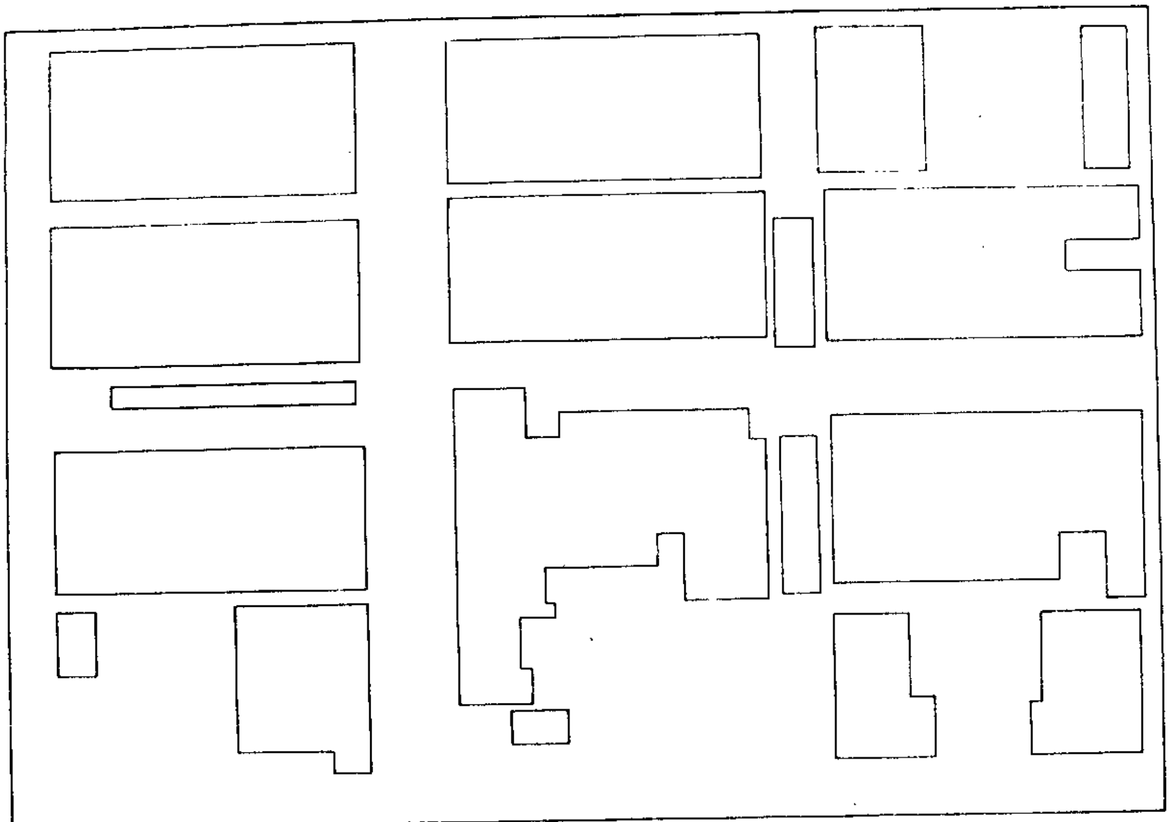

Figure 4.7a Schematic drawing of Riverside Central Business District (CBD) outlining impervious areas used to determine the Net Reduction Factor for calculating the Net Water Use Area from the Gross Land Use area.

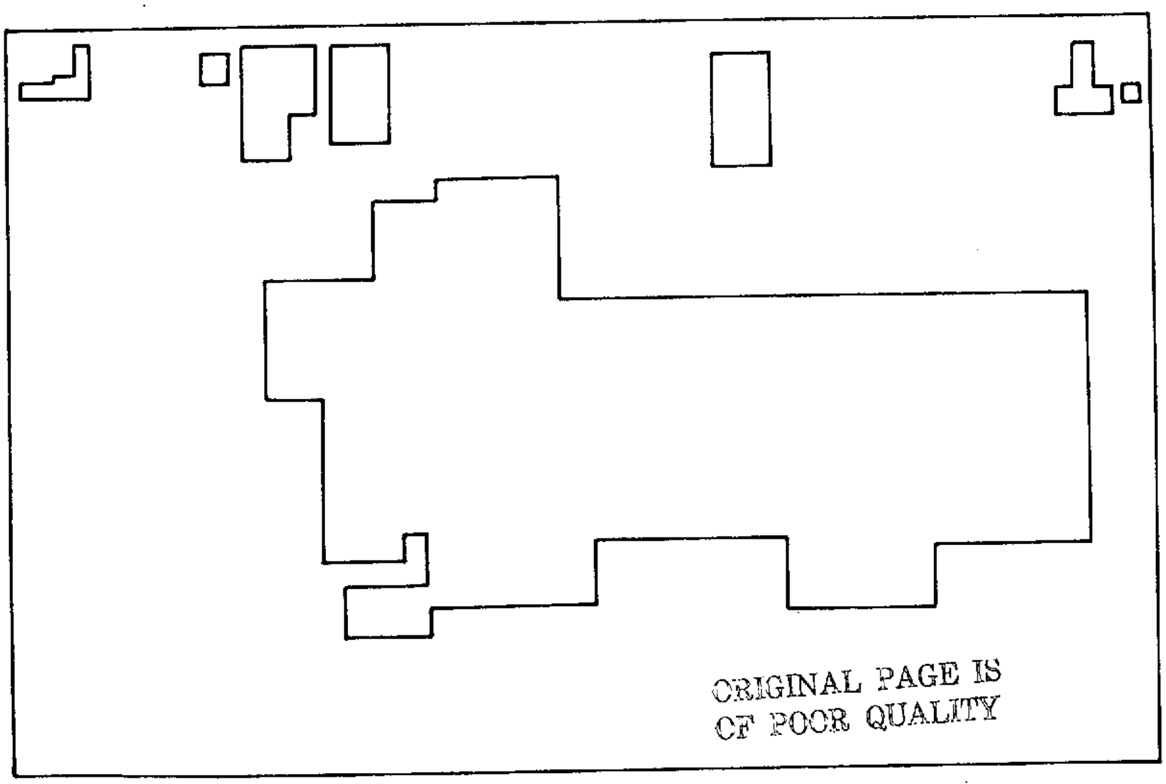

Figure 4.7b Schematic drawing of the Riverside Plaza regional shopping center contrasting the different in non-water use parking areas to the above CBD area of downtown Riverside.

the process of schematic analysis include: A) Scale of the imagery, B) human error, C) sample size, D) area measurements.

4.222.3.1 Scale of the Imagery

Certain physical characteristics of different land use types combine with imagery resolution and drafting skills to place an upper limit on the scale of imagery that can be used to produce the schematic. In this study there appeared to be no problem in producing a schematic from imagery with a scale of 1:60,000 when the land use sampled was of a block nature such as a shopping mall. Residential land use, however, with long narrow linear areas of water use required a larger scale of imagery. The primary problem was with the width of the tracing line. Imagery appeared to be acceptable as long as the resolution was high enough to permit interpretation and legible tracing. The degree of generalization increased to an extent as the scale of the imagery was reduced. Greater generalization is illustrated by a decreasing number of vertices. To determine what effect increased generalization might have, three schematics were drawn using different scales of imagery for the same sample area. A comparison of the results indicates a minimal difference in the reduction factor as shown in the following table:

THE MARGINAL EFFECT OF GENERALIZATION
PRODUCED FROM THREE DIFFERENT SCALES OF IMAGERY

Sample: shopping mall	Imagery scale	Number of vertices	Percent non-water use area	Percent deviation from mean
C02A	1:12,000	56	67.7	1.04
C02B	1:24,000	52	66.7	0.45
C02C	1:60,000	46	66.7	0.45

4.222.3.2 Human Error

The accuracy of the schematic depends on the skills of the investigator in interpreting the imagery and in drafting the schematic. Because these are skills which are open to human error they provide a possible unacceptable source of error in the analysis method. The possible significance of human inconsistency in applying skills was evaluated by checking the possibility of producing consistent results. A human consistency check was carried out by drawing three schematics of the sample plot at three different times from the same imagery. The results of the consistency check appear in the following table.

THE HUMAN ERROR FACTOR AND ITS IMPORTANCE TO ACCURATE REDUCTION FACTORS

Sample: residential	Reduction factor	Deviation from the mean	Percent deviation from the mean
A02A	31.1	1.0	3.32
A02B	28.6	1.5	4.98
A02C	30.6	0.5	1.66
Mean	30.1	Range 2.5	

The percent deviation from the mean was greatest for the second sample, taken several months after the first. The result enforces the hypothesis that human error exists in the reduction factors. The significance of the error is represented by the 2.5 range in the reduction factors.

4.222.3.3 Sample Size

The sample size problem in land use sampling is analogous to the sample base problem. Even if the statistical population of the land use was known the geographic factors of concentration and dispersion would obtain problems in determining what the individual size of each sample should be. The fact that a single variation of land use is being sampled tends to lead the investigator to sample uniformly "pure" patterns and exclude irregularities. Often the irregularities comprise the non-water use area (vacant lots, railroad rights-of-way, non-irrigated farm areas, etc.) that the investigator should be monitoring. The investigator does not know how typical these areas are, so he does not know how much to include in the sample. The problem cannot be ignored because if these areas are included, as they should be, the percentage reduction factor will increase. For illustration, two residential samples A02 and A06 are used. A02 is a pure type residential city block with a reduction factor of 30.1 percent. Sample A06 includes both block A02 and additional residential blocks and has a reduction factor of 34.4 percent. The difference is not large but when it is considered that residential land use makes up approximately half the urban land use it could have a significant effect on water use estimates. Thus, the larger the sample, the better it will represent actual land use. The UCR method is designed to facilitate large sample analysis. Table 4.4 lists the size of the samples used to illustrate the UCR method. The thirty-one samples surveyed comprise a total of approximately 643 hectares (1588 acres).

4.222.3.4 Area Measurements

The reduction factor is calculated from a ratio of non-water use area to gross water service area. The accuracy of the reduction factors depends on the accuracy of the area figures taken from the schematic. To determine the accuracy of area figures taken from schematics, a comparison was made between these figures and figures taken from other sources (viz., an architectural plot plan, a field survey, a topographic map, and zoning maps).

4.223 Efficiency of the UCR Method

The second prime consideration in evaluating a research method is its efficiency. How does the new method compare with the old in its ability to get the job done? A time check on the UCR method demonstrated that it took an average of 1.25 minutes to draw, digitize and calculate the percentage associated with each vertex on the schematic. There was an average of 57 vertices for each city block of residential land use in the samples analyzed. Thus, approximately 72 minutes was needed in order to derive the reduction factor for an average block. To obtain a comparable figure for the traditional survey method the Department of Public Works was contacted. They suggest that it would take a three or four man survey crew three or four days to make the necessary survey of the average block and a cartographer three or more days to draft a map from the survey crew's field notes and to calculate the areas with a planimeter. The total comes to 97 - 152 man hours. Comparing this figure with that of the UCR method, the UCR method is 81 to 125 times faster. The Department of Public Works also mentioned two other problems associated with the traditional survey: 1) the problem of gaining permission to carry out the survey on private land, and 2) the accuracy of the planimeter to give accurate figures in small area calculations.

4.224 Gross Water Demand Test

How significant is the difference between the Net Reduction Factor as determined by the UCR method and that used by the DWR? The generally higher reduction factors obtained by the UCR method translate into lower water use figures. However, do these variances occur in land uses that are significantly small for the Santa Ana Basin, or do they occur in land use types which make up a large percentage of the land use of the basin?

A sample test area was selected from the completed land use mapping project. The Riverside West 7-1/2' quad sheet was selected (Figure 4.3) as a representative urban-rural sample containing 15,992 hectares (39,515 acres). Table 4.4 reveals that a total water demand for this area would produce a difference of 476 hectare-meters (3.854 acre feet) between the two systems. That amount represents a difference of 6.9%. Allowing for possible errors in computation of the Net Reduction Factor and using 370 hectare-meters

SAMPLE ESTIMATED WATER USE
DWR vs UCR

CLASSIFICATION	GROSS AREA	WATER USE EST. ACRE-FEET	DWR ACRE-FEET	UCR ACRE-FEET
Living Area	11,462	1.6	14,304	13,020
Industry	441	4.0	1,324	884
Commercial	1,014	1.3	1,054	487
Recreation	884	3.7	2,779	2,779
Culture	25	1.3	26	22
Transportation, Communication, Utility	1,248	.5	624	624
Services: Education, Government	1,085	1.1	1,014	763
Other	325	1.3	338	156
Resource (agriculture)	11,354	2.7	29,122	27,896
Undeveloped	11,677	.6	7,006	7,006
TOTAL	39,515		57,591	53,637
			6.9% difference	

WEST RIVERSIDE 7½' MAP

Table 4.4

(3,000 acre feet) as the average difference per each of the 30 grid areas (Figure 4.2) dividing the basin, the gross water demand difference for the basin would still total 11,106 hectare-meters (90,000 acre feet)! With water rates ranging from $10 to $40 per acre foot this difference is considerable when calculated annually.

4.225 Conclusion

The primary advantage of the UCR method is the time efficiency it provides. A more representative reduction factor for each land use class is insured, in a shorter period of time, to rough use of the more numerous and larger samples that this time efficiency offers. The margin of error that may occur with area measurements on the schematic is offset by a larger sample that is more likely to be representative of the non-water use and by the greater number of variations sampled. The total process yields a more accurate reduction factor than has previously been available. The generally higher reduction factors are supported by research done by Niedercorn and Hearle who reported that 19.9 percent of the land area in 48 large American cities was used for streets and highways and that an additional 20.7 percent was vacant. Though not directly comparable to the present study, these figures do indicate what might be expected. Accurate up-to-date reduction factors will insure more representative water use figures.

4.230 <u>Special Investigations of Agricultural Land Use</u>

Three special investigations concerning agriculture have been programmed for this study. However, all three require a minimum of four seasonal overflights. With receipt of the fourth flight imagery in October, it will now be possible to proceed with these investigations.

4.231 Remote Sensing System to Monitor Abandonment of Vineyards

The grape growing region of the Upper Santa Ana River Basin is concentrated between the cities of Ontario and San Bernardino on the Cucamonga Fan (Figure 4.2). The vineyard area has undergone a change from rural to urban land use in the past decade as exemplified by the increase in the Kaiser Steel plant slag piles, the Ontario motor speedway, expansion of the Ontario International Airport, conversion to industrial buildings, and even encroachment of housing developments.

To provide an early indication of conversion of vineyard lands, it is desirable to establish a monitoring system to detect such conversion. It is believed that the U-2 imagery is particularly suited for this task. The shifting trend is first indicated by abandoned vineyards which have probably become non-profitable operations due to high taxes, high labor costs and decreased demand for certain types of wine grape. Active vineyards are readily detected from imagery by the clarity of appearance of access roads, differences in seasonal moisture due to irrigation practices in the summer months, the appearance of ground cover (to prevent blowing sand) and weeds, and the general texture of the full growing vines. Already it has been determined from the March imagery that it is impossible to distinguish active vineyards from abandoned vineyards in the wet spring months. The other three seasonal flights will be studied to determine the best season for detecting the abandoned vineyards. Grapes require .26 hectare-meters (2.1 acre-feet) of water per season, so with large abandonments it could affect the total demand considerably.

4.232 Other Agricultural Investigations

Two other agricultural investigations will be discussed under the future studies section.

4.240 Monitoring the Waste Disposal of the Chino Valley Dairies

The area of the lower Chino and Riverside sub-basins of the Upper Santa Ana River Drainage Basin (lying between the city of Ontario to the north and Corona on the south, Figure 4.2) encompasses an intense areal concentration of dry-lot dairies. The dairies are a distinctive land use easily recognized on the NASA high altitude U-2 imagery. Dairy practices in the region are fairly uniform; thus monitoring of this land use should lead to accurate predictions of water consumption, waste production, and polluting effects on surface and sub-surface water quality. It is the pollution effects that have become most important in the Chino-Riverside sub-basins and have led the State Water Quality Control Board to request assistance in developing a system to monitor the control of dairy pollution.

4.241 Image Interpretation

The 426 dairies in the Chino area have been identified from U-2 imagery. Preliminary maps have been prepared and are in the process of being encoded into computer format. Initial training required the use of 1:24,000 scale CIR imagery to assist in identifying the various components of the entire dairy. The milking barn located near the residence with its circular drive (for milk trucks) and reflective front lawns, usually is the most distinctive feature (Figure 4.8). The dark brown corral area, with adjacent poled hay barns, became the more distinctive feature in these studies when interpretation was transferred to the 1:130,000 scale U-2 imagery. The remaining pasture area to the rear of the farm encompasses the major open area.

4.242 Ancillary Data

Collection of data on regional hydrology, geology, water quality, and dairy practices has been completed. In addition, the Water Quality Control Board is furnishing information supplied by the dairymen on their individual operations to include: number and classification of livestock, water use, waste production, and waste disposal. Information on each dairy has been machine encoded and preliminary statistics on waste disposal compiled, but not yet evaluated. Dairy operations information will be collated with dairy location data and will be incorporated in the map display.

4.243 Dairy Waste as a Source of Water Pollution

Most dairies in the Chino sub-basin have 150 to 400 cows. A substantial number of very large dairies have up to 700 head of cows. The total cow population at the end of 1973 was 176,077 located on 426 dairies. 135,501 of these cows were in milk production. Table 4.5 outlines the dairy population and concurrent waste production for the Chino sub-basin.

Wash water and other wastes produced by the dairy operation yield a daily outflow containing an average of 1162 ppm of total dissolved solids (TDS). Rainwater from corral areas can have a similar high pollutant content. An experimental rain simulation of 7.6 mm (0.3 inches) of runoff yielded water which had a pH of 8.9; 7% TDS, 17.5 mg/l ammonia (NH_4^+), and 4.5 mg/l nitrates (NO_3^-).

Such alarming statistics have led the Santa Ana Regional Water Quality Control Board to prohibit any surface runoff from dairies in the Chino Basin, except runoff waters caused by 20-year floods. To prevent runoff, the Board has required the dairyman to construct settling ponds and/or dikes on the downslope of their farms. It is the ponds or dikes that become detectable from the CIR imagery. Wet soils and standing water are easily detectable from U-2 imagery. It appears that a monitoring can be established by remote sensing.

4.300 FUTURE STUDIES

The Riverside campus proposes to study two different areas upon renewal of the grant with total effort divided as follows:

Study 1:

Continuing Study of the Water Demands of the Upper Santa Ana River Drainage Basin.

Study 2:

Remote Sensing Studies of the Environment of the Southern California Coastal Region.

4.310 Water Demand Studies

Three sub-studies will lead to the completion of the ongoing study of the Long Term Water Demands of the Upper Santa Ana River Drainage Basin.

4.311 Water Demand Model

Encoding of the remaining maps of the basin will be completed by the end of the current contract year. Initial testing of the model and comparison of results can then be made with the Department of Water Resources. At that time, the cost-benefits can be more precisely computed and evaluation of the system can be made. The development of housekeeping tasks for the model will be accomplished in the forthcoming year with updating techniques being the prime work.

4.312 Refinement of Agricultural Parameters

Perhaps the most important drivers of the water demand model are those involving agriculture. Three projects need completion.

4.312.1 Vineyard Abandonment Monitoring

If this study is not completed prior to the end of the current year, it will be necessary for us to complete the development of surrogates in the following year, that will permit early detection of vineyard abandonment as outlined in previous sections. This study has been delayed awaiting receipt of four seasons of imagery.

4.312.2 Identification of Permanent Citrus Crops

Another crop that requires year around irrigation and thus has a stabilized water demand is citrus. Like the vineyards, the citrus groves have been subject to gross displacement. It was first thought that much of the citrus activity would move to the Central Valley of California, but this has not been the case. Riverside County now has more acreage in citrus than it had at the height of the citrus era (1930-40). Citrus co-operatives and corporations have chosen to move to the fringe areas and remain in the more climatically suited Riverside-San Bernardino area. The availability of new sources of water, although more costly, has encouraged this decision. A system of monitoring by remote sensing needs to be established to detect this trend of relocation of citrus as an aid to better water and crop management.

4.312.3 Determination of Period of Fallow Season of Irrigated Fields

It has been previously stated that the DWR desires to improve its estimate of water demand of irrigated fields. However, that Department has instantaneous data collected at periods as much as ten years apart on the number of fallow fields. The current method of estimating is to list all fields that are fallow at the instant of the decadal inventory as "non-water use." Irrigated fields in production at the time of inventory are counted as demanding the full amount of water for the full annual term. Hopefully, the variations between the producing fields and the fallow fields will cancel any errors that exist.

It is hoped that, through studies of the four seasonal flight images, an average period of the fallow season can be established so that we can adjust the water demand estimated for irrigated crops to a more realistic value.

4.313 Chino Sub-basin Dairy Water Quality Control

The most immediate problem in monitoring water quality in the Chino Sub-basin is to determine the scale of imagery required to detect the presence of ponds and/or dikes on each dairy farm. The ponds and dikes, as indicated in a previous section, are constructed in order to contain the runoff waters from each dairy operation. Besides flying a sensor package containing longer focal length cameras for high resolution, we also intend to request at least one flight of the infrared thermal scanner. It is believed that a thermal flight will aid in determining water content of the soils on each of the dairies and thus may indicate the effectiveness of waste disposal.

Completion and updating of the data collection, both imagery and ancillary, will permit the development of numerical estimates of the hydrologic impact of dairying in its present form, and lead to the development of predictive techniques to assess the effects of changes in dairy practice, distributions and intensity. The models of dairy impact can be used to produce, through computer graphics, maps of the various aspects of the dairy water use problem (e.g., projected ground water draw-down attributable to an additional dairy in the basin).

Once the correlative models have been developed, they will be tested to determine how well imagery interpretation can be used to monitor dairy land use. "Postdiction" will be attempted in which the dairy parameters of an earlier date will be applied to the models and the results compared against records of well depth, water quality, and supply for that date. In addition, a cross-regional study will be made to determine how well the Chino data can be used to predict water use, waste production and other factors in the San Jacinto Area (Southeast region of the Santa Ana Basin).

It is believed that a study of the paleogeography of the Santa Ana Basin through the use of ERTS and U-2 imagery will be helpful in predicting modern subsurface flow and recharge conditions. It is the subsurface sediments (which now provide a medium for ground water flow) that were laid down by surface waters and hence mark the routes and boundaries of ancient drainages. Groundwater flows, as a response to hydrostatic conditions and subsurface flow routes, frequently coincide with buried ancient surface drainage routes. Therefore, the ancient surface hydrologic system will provide a basis for an understanding of the modern geohydrologic system. The importance of understanding the subsurface flow is to determine the rate of possible underground pollution (i.e. high nitrates) flowing to the Prado Dam area. The character and geometry of the Santa Ana Drainage Basin has undergone extensive changes

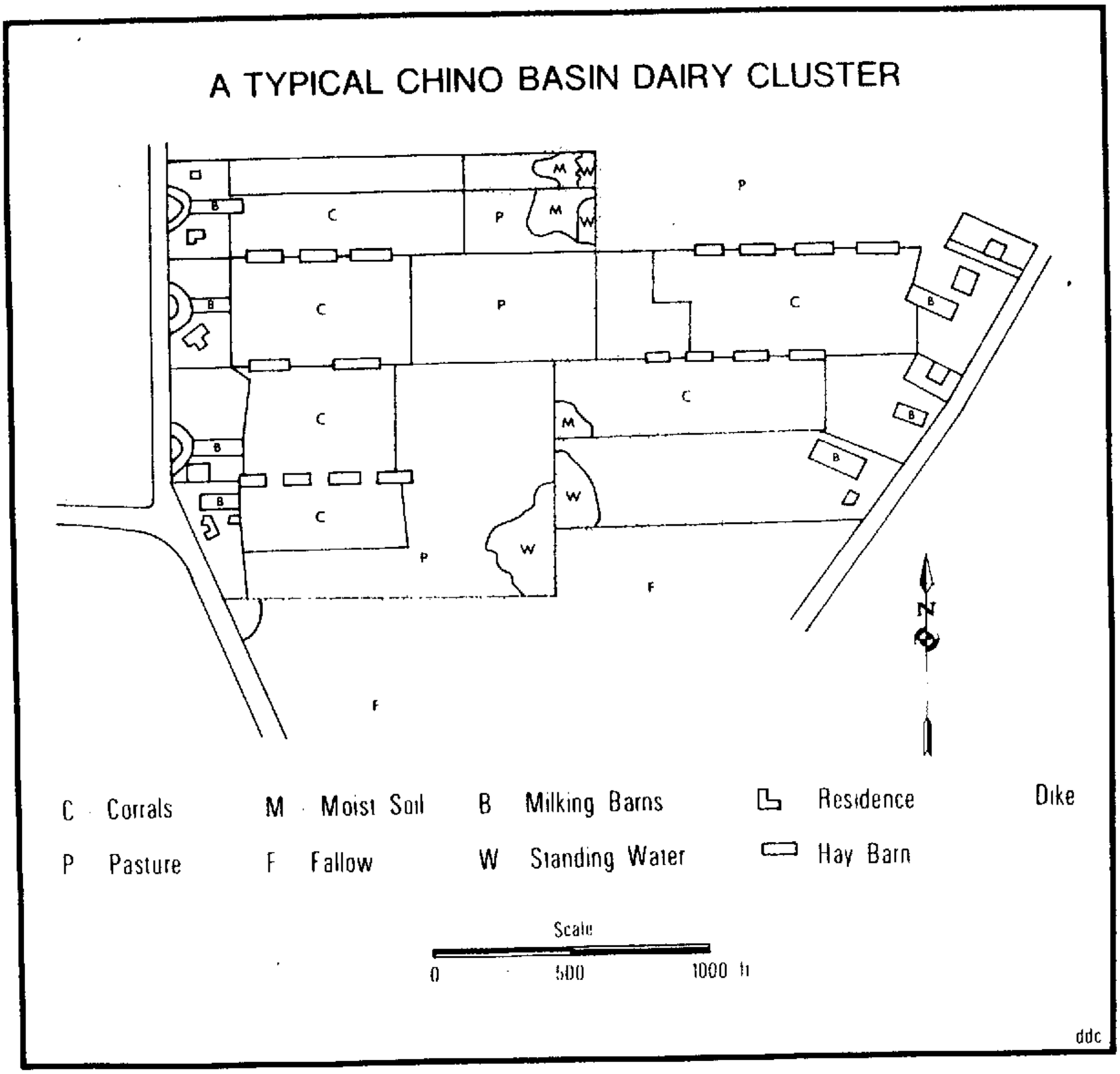
A TYPICAL CHINO BASIN DAIRY CLUSTER
C Corrals
M Moist Soil
B Milking Barns
Residence
Dike
P Pasture
F Fallow
W Standing Water
Hay Barn
Scale
0
500
1000 ft
ddc

Figure 4.8

Table 4.5

CHINO SUB-BASIN DAIRY POLLUTION STATISTICS

(426 Dairies - 1973)

	COWS (Equivalent)	ACRES	DISPOSAL ACRES	WASTE PRODUCTION TOTAL (Gallons)		NITRATES (lbs)	
				Daily	Annual	Daily	Annual
Regional Totals	176,077	18,217	11,838	8.28×10^6	3.02×10^9	311,656	1.14×10^8
Average Dairy	413	42.76	27.79	19,411	7.09×10^6	731	266,819
One Cow (Equivalent)		0.104	0.067	47	17,155	177	646
One Acre	9.67		0.650	454.5	165,893	17.12	6249
Avg Disposal Acre	14.87			698.9	255,095	26.32	9607

during the last 2-3 million years. The Transverse Ranges (San Gabriels and San Bernardino Mountains), constituting the largest portion of watershed of the Santa Ana Basin, have been uplifted during this time. In addition, deformation of the Southern Coastal Ranges, which constitute the basin's southwestern boundary, has continued at a fairly constant rate, and tilting of the Perris block between the San Jacinto and Elsinore faults has taken place.

It is proposed to reconstruct generally the ancient (pliopleistocene and pleistocene) drainage of the Santa Ana Basin through reconnaisance mapping methods utilizing satellite and high altitude aircraft imagery.

4.320 Remote Sensing Studies of the Southern California Coastal Environment

In the questioning of various agencies concerned with the programs of the Southern California Coastal Region, it has become evident that each agency has a concern about some particular facet of the environment. The environmental problem that has lead to the establishment of the Air Quality Control Boards is visibly evident in Riverside most everyday. The previous section has described at length the problems of the Water Quality Control Boards. A coastal commission has been established to insure that our future generations may enjoy our coastal beaches. Control boards are attempting to restrict the construction of power plants, refineries, deep sea ports for super tankers, off-shore oil drillings, etc. Another very difficult problem lies in the selection of the method or methods used to move large densities of population from the nodal points of living areas to the nodal points of commerce and industry. In fact, the establishment of these nodes themselves is considered to be of prime importance. All of these later mentioned efforts to control various aspects of living are to protect the environment. What can remote sensing do to solve these environmental problems? We propose to find out, as indicated below:

4.321 Development of a Coastal Geographic Information System

A representative of the Southern California Association of Governments (SCAG) concerned with the transportation problem stated that there is an overwhelming amount of data with a multitude of time bases. What is needed is an organization of the data in a common time frame. Conventional High Altitude Imagery can provide base data around which a Coastal Geographic Information System can be established.

It is proposed that the Riverside Campus make a feasibility study this next year for a Coastal Geographic Information System utilizing U-2 CIR imagery as a base for the data.

4.322 Studies Utilizing SO 397 Film

The recent experiments with the Kodak SO 397 water penetration film as described in the November 1974 issue of Photogrammetric Engineering indicates there are great possibilities for studying the coastal environment.

It is proposed that the Riverside Campus study the uses of the water penetration film in the immediate coastal environments to include: coastal landforms; beach erosion and depositions; marine vegetation (kelp) inventory and growth or decline; monitoring of harbor and possibly offshore water pollution; and other target of opportunities.

4.323 Environmental Studies Utilizing Thermal Infrared Imagery

The acquisition of a thermal infrared scanner has added a new dimension in sensors available on a continuing basis to environmental studies in California. The power plant operation problems, the refinery problems, and the automobile freeway problems (all environmental pollution concerns) are responsive in a very different way from when imaged by a thermal scanner. The thermal effects of these heat emitters may lead to a better understanding of their effects on the environment.

It is proposed that the Riverside Campus study the effects of heat emission from various sources of hydrocarbon emissions to determine the effects on the environment.

4.324 Coastal Lagoon and Marsh Study

The ria-coast of southern California from Newport to San Diego, is marked by uplifted beach terraces, cut by sharply-incised valleys which have been filled with sediment as a consequence of the Holocene (post-glacial) eustatic rise in sea level. Where these rivers meet the ocean, the cliffed shoreline opens into a broad flat, usually fronted by a sandy beach with a lagoon behind it. Varying rates of discharge from the streams cause some of the beaches to be breached, others to fully impound the streams flow.

These marsh-lagoon areas, highly active biological environments, are seriously affected by coastal land use. Sedimentation, pollution, and beach erosion can be stimulated by changes in neighboring land use, while they can be permanently changed by direct development, such as dredging, filling, channelling and other "reclamation" activities.

Structural features of coastal marshes and lagoons are clearly visible on CIR imagery even at typical U-2 scales. Remote sensing of these areas will make possible an inventory of this valuable tideland environment, and evaluation of the present level of disruption due to man's activities. Higher resolution imagery (i.e., at image scales between 1:10,000 and 1:30,000) should be investigated for properties of vegetation distinction as well as providing a basis for more detailed geomorphic analysis. A high level of information extraction might also be possible using photo-enhancement techniques such as density-slicing or custom-tailored filter packs.

4.325 The Surf-Zone: Beach Sand Movement and Changing Beach Morphology

Intensive development of the southern California coastline has had a profound effect on the "sediment budgets" of the beaches. Groins, jetties, seawalls, marinas, harbors, and flood control projects all influence local beach morphology and the movement of beach sand.

Many beach forms, especially rhythmic features such as cusps, are clearly visible in remotely sensed images. These forms, especially when viewed with moderate water penetration to show sub-surface turbidity, can tell much about near-shore coastal currents and allow the interpreter to map sediment movement along natural coastlines and around man-made barriers.

Knowledge of sediment movement is valuable for the planning and management of safe marinas and harbors, and for the planning of recreational beach uses. In addition, remote sensing offers the most practical way to monitor seasonal changes in the beach sediment system and to identify areas that are exceptionally vulnerable to storm-wave erosion, a major cause of damage to beach front property.

Chronological Plan for the Performance of Water Demand Studies

Work Item	Investigator	Period of Performance Present Funding Year M J J A S O N D J F M A	 Next Funding Year M J J A S O N D J F M A
1. Determine critical parameters in water demand models	Riverside(1)	——————→	
2. Analyze economic impact resulting from changes in water demand information	Riverside (1)	——	————→
3. Compute economic effects of changes in estimating of critical parameters	Riverside (1)	——	————→
4. Evaluate and test remote sensing techniques	Riverside (1)	———	————————→
5. Determine costs of information-gathering using conventional methods	Riverside (1)	—	————→
6. Compare remote sensing techniques with conventional ones. Draw conclusions regarding cost-effectivness	Riverside (1)	—	———————→
7. Estimate potential impact of using remote sensing techniques in water demand problems.	Riverside (1)	———	————→

CHAPTER 5

SOCIO-ECONOMIC IMPACT OF REMOTE SENSING WATER SUPPLY DATA

Co-Investigator: Ida R. Hoos, Berkeley Campus

CHAPTER 5

TABLE OF CONTENTS

Social Sciences Group

Semi-Annual Progress Report, December, 1974

5.00 Current Activities

The primary focus of our ongoing research remains the management of California's water resources, crucial in the past development of the State, vital in the present, and ever more critical in the future as the world's needs for food become translated into direct demands on the State's agricultural productive capacity. The objectives of the research are linked closely with those of the other projects conducted under the Remote Sensing Integrated Project. Essentially, they are as follows: to observe the institutions and mechanisms through which water policy decisions are made and implemented; to ascertain the information requirements on which policy is based and operations designed; to identify and establish rapport with persons responsible for making and carrying out decisions; to explore the ways in which remote sensing and related advanced technology might be utilized in the management of water resources. This calls for a broad-gauged approach, reaching from very explicit operating procedures to future policy matters.

With respect to the more explicit, our work during this period has involved participation in an RSRP conducted analytical study of remote sensing as an input in the process of snow survey and, hence, water supply forecasting by the Department of Water Resources. This work, focusing on the economic aspects of applied remote sensing, has been carried on as part of the activity of the Social Science Group.* The present cost-effectiveness study relates to one specific aspect of water management. It will, however, lead to the development of techniques that will have considerably wider applicability in resource management. With the recognition that resource management never takes place in a social vacuum comes the necessity to understand the total decision-making process. Along with the economic, there are the social, political, and legal factors that bear on policy.

In an era when science and technology are regarded as the fulcrum for progress toward solution of many of the world's problems, these interrelated dimensions have critical importance. Moreover, in an era when technology assessment is mandatory, they cannot be ignored. The U.S. Army Corps of Engineers Board of Engineers for Rivers and Harbors invites

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*The work in progress is reported in Chapter 6 of this report. Involvement in such work is and will continue to be an intrinsic part of the functions of the Social Sciences Group in its ongoing efforts (1) to provide NASA decision makers with useful research results and (2) to assess remote sensing technology in its wider implications.

sociologists to assess the social impacts of public works;* the U.S. Army Engineer Institute for Water Resources** calls on the social science community for advice and guidance in the use of social indicators, data banks, and the like.

The Environmental Protection Act of 1969 and the Rivers and Harbors and Flood Control Act of 1970 have given official blessing to these efforts, hailed as "the new approach." The Environmental Protection Agency supports research that is specific in its social orientation in its Environmental Laboratory for the Social Sciences. For NASA, the multi-dimensional approach and the built-in assessment are not new; NASA's commitment to and concern for the total spectrum of costs and benefits of technical advance have placed it in the vanguard of government agencies.

In the on-going Integrated Project, NASA's primary interest is in determining the usefulness of remote sensing techniques for studying various aspects of California's earth resources complex, the ultimate objective being to ascertain how this advanced technology can provide Data that will contribute to the more efficient management of the resources. We in the Social Sciences Group concern ourselves with the decisions that must be made, the decision-makers, the way in which decisions are made, and the possible impacts of remote-sensing-derived information. In an era when public decision-making is undergoing scrutiny for its sensitivity to public needs and when environmental protection has become a matter for official concern, timely, synoptic data are prime requisites for use as a planning tool. With California water our main focus, we are ascertaining how well remote-sensing techniques can fulfill this need.

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*E. Jackson Baur, "Assessing the Social Benefits of Public Works Projects," Report submitted to the Board of Engineers for Rivers and Harbors, U.S. Army Corps of Engineers, July, 1973.

**Annabelle B. Motz, "Social Science Data Banks and the Institute for Water Resources," U.S. Army Engineer Institute for Water Resources, I.W.R. Pamphlet No. 1, July, 1974.

Consistent with the format of the preceding Progress Report (dated 1 May 1974) and reflecting the suggestions made by Dr. Peter A. Castruccio,* in his capacity as NASA consultant, this report will be divided into three major sections: quantity, quality, and long-range social considerations. It may be recalled that in the course of the foregoing report, much space was allocated to an explication of who manages California's water and how this is done. This now serves as a useful backdrop against which to examine the various aspects and prospects of California water with respect to our three above-designated categories.

5.10 Quality

With the California State Water Project as our primary focus, the developments during the past fiscal year stand out as crucial for setting in sharp perspective (a) the multifarious and complex considerations that lean on water decisions and (b) the rapidly changing social environment and how it perforce impinges on these decisions. The first development of note was completion of what may be called the initial phases of the Project. These included facilities necessary for service to all agencies which had contracted for water deliveries before 1980, -- 20 dams and accompanying lakes, 18 pumping and generating plants, and 527 miles of aqueduct. Figure 1 shows the timing and location of the various facilities, which are of a multi-purpose nature. Intended not only to transport and store water, they contribute variously to the generation of electric power, to flood control, recreation, and fish and wildlife enhancement. Figure 1. Initial Project Facilities shows the chronological development and location of project facilities. (p.4)

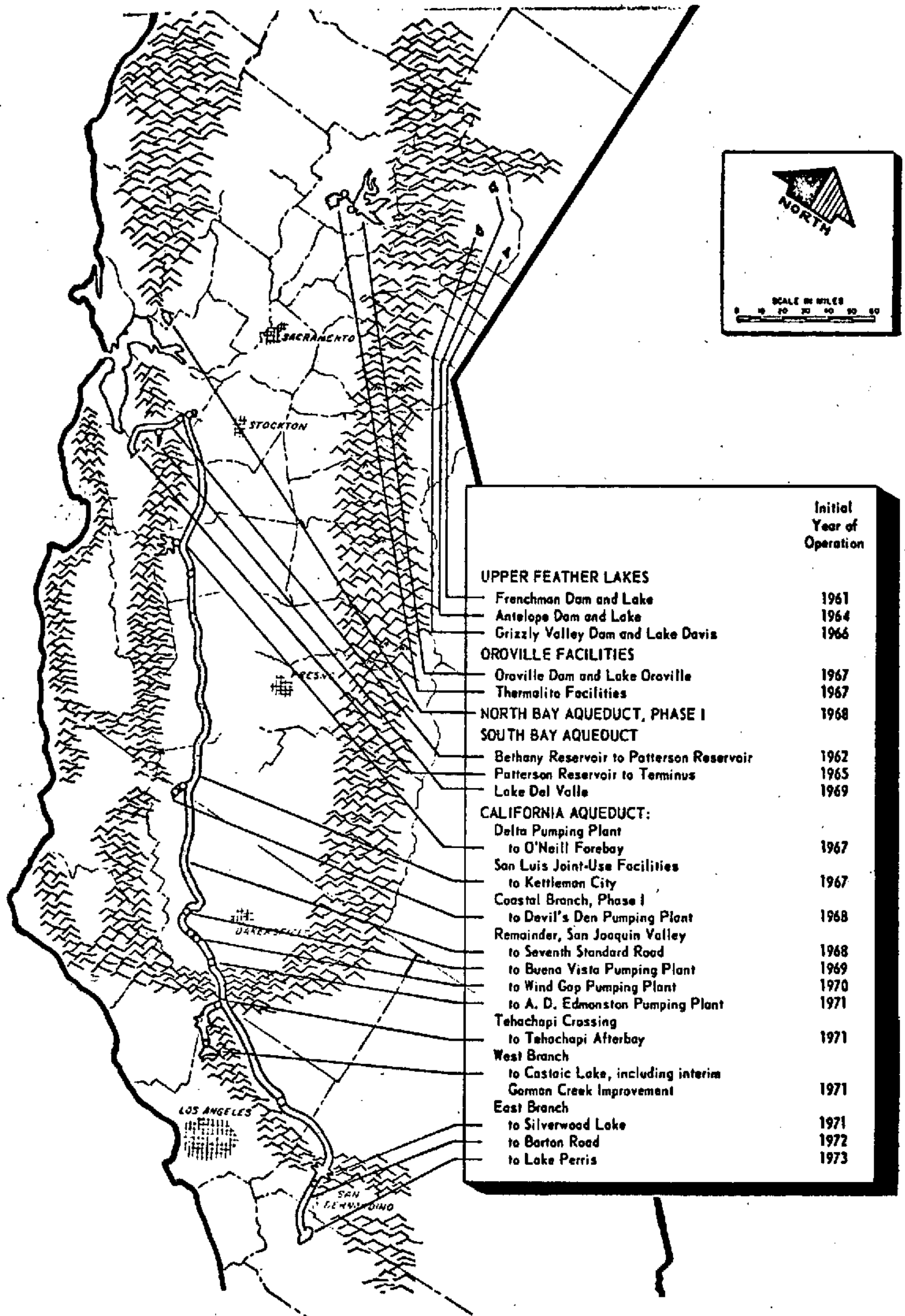
The completed construction accounts for about two-thirds of the funds allocated to the entire State Water Project and accomplishes water delivery commitments until about 1980. To satisfy projected needs and commitments after that time, further construction will be required. It is estimated that during the coming decade about $700 million will be devoted to further construction.

Table 1. Water Deliveries in 1973 ** gives a detailed analysis of the contracting agencies, their service orientation, and the amounts of water they received in 1973. The figures represent the result of operations somewhat more adequately than they depict regional conditions. While water conditions for the state as a whole were at least normal for the year 1973, there were local variations, with below normal precipitation in the area of the Oregon border and above normal runoff from the Sierras in the lower San Joaquin Valley. Thanks to the availability of local water supplies, the project

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

** p. 5.

FIGURE 1. INITIAL PROJECT FACILITIES



Source: State of California, The Resources Agency, Department of Water Resources, The California State Water Project in 1974, Bulletin No. 732-74, June, 1974, p. 13.

TABLE 1. WATER DELIVERIES IN 1973

(In acre-feet)

Line No.	Contracting Agency and Type of Service	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total	1973 Contract Entitlement	1973 Entitlement Not Delivered	Net Cumulative Entitlement Not Delivered thru 1972	Net Cumulative Entitlement Not Delivered thru 1973	Net Entitlement Credits Under "Wet Weather" Provisions As of January 1, 1974: Deferred Delivery	Net Entitlement Credits Under "Wet Weather" Provisions As of January 1, 1974: Future Reductions	Line No.
	FEATHER RIVER SERVICE AREA																				
	County of Butte:																				
1.	Entitlement Water	0	12	0	1	3	3	0	4	0	3	4	11	33	600	547	1,622	2,360	-	-	1.
	Last Chance Creek Water District:																				
2.	Regulated Delivery of Local Supply	0	0	0	837	4,669	1,777	3,381	3,072	313	3	0	0	13,971	-	-	-	-	-	-	2.
	Plumas County Flood Control & Water Cons. District:																				
3.	Entitlement Water	48	43	44	47	43	54	76	86	78	54	44	44	679	500	0	1,083	812	-	-	3.
4.	AREA TOTAL	48	55	44	885	4,740	1,836	3,385	3,162	390	59	48	55	13,703	1,100	547	2,715	3,081	-	-	4.
	NORTH BAY SERVICE AREA																				
	Napa County Flood Control & Water Conservation District:																				
5.	Regulated Delivery of Local Supply	664	585	456	647	60	4	13	15	173	119	284	632	3,792	-	-	-	-	-	-	5.
	SOUTH BAY SERVICE AREA																				
	Alameda County Flood Control & Water Cons. Dist., Zone 7:																				
6.	Entitlement Water	165	0	18	317	1,127	396	354	199	37	413	49	0	2,975	13,600	10,625	11,177	21,802	20,506	0	6.
7.	Regulated Delivery of Local Supply	282	185	275	436	186	1,657	2,119	1,931	1,680	825	304	186	10,066							7.
8.	Agency Total	447	185	293	653	1,313	2,053	2,473	2,130	1,717	1,238	353	186	13,041							8.
	Alameda County Water District:																				
9.	Entitlement Water	0	0	0	0	0	0	90	1,700	502	52	160	0	2,521	18,000	16,279	42,100	30,388	43,260	0	9.
10.	Regulated Delivery of Local Supply	0	0	0	0	0	0	1,427	1,647	1,473	842	0	0	5,379							10.
11.	Agency Total	0	0	0	0	0	0	1,517	3,345	1,975	894	163	0	7,900							11.
	Santa Clara Valley Water District:																				
12.	Entitlement Water	4,500	3,122	2,752	5,067	9,855	10,300	10,600	10,600	10,300	8,100	6,720	5,984	88,000	88,000	0	30,714	30,714	5,389	0	12.
13.	Surplus Water	582	0	0	0	105	398	455	490	214	837	0	0	3,081							13.
14.	Agency Total	5,082	3,122	2,752	5,067	10,060	10,698	11,055	11,090	10,514	8,937	6,720	5,984	91,081							14.
15.	AREA TOTAL	5,529	3,307	3,045	5,720	11,373	12,751	15,045	16,565	14,206	11,060	7,242	6,170	112,072	120,400	26,904	92,080	118,904	69,164	0	15.
	SAN JOAQUIN VALLEY SERVICE AREA																				
	J. G. Boswell Company:																				
16.	Repayment of Preconsolidation Water	0	234	315	278	464	990	1,091	924	42	0	0	0	4,354	-	-	-	-	86,587[a]	-	16.
	Buena Vista Water Storage District:																				
17.	Repayment of Preconsolidation Water	0	0	199	670	0	1,943	1,989	1,144	0	0	0	0	5,945	-	-	-	-	74,564[a]	-	17.
	County of Kings:																				
18.	Entitlement Water	166	0	0	165	0	168	170	170	170	165	165	165	1,500	1,500	0	0	0	0	0	18.
	Devil's Den Water District:																				
19.	Entitlement Water	783	622	696	429	765	1,236	1,131	1,392	822	348	236	640	8,700	8,700	0	0	0	-	-	19.
20.	Surplus Water	322	238	158	0	0	443	1,555	1,186	110	72	0	730	4,822							20.
21.	Agency Total	1,105	700	854	429	765	1,679	2,686	2,578	632	420	236	1,370	13,522							21.
	Dudley Ridge Water District:																				
22.	Entitlement Water	800	17	193	2,288	3,100	3,500	3,600	3,773	1,400	2,700	577	52	22,000	22,000	0	0	0	-	-	22.
23.	Surplus Water	57	0	0	0	31	1,578	3,884	2,356	2,974	98	0	2,271	13,249							23.
24.	Agency Total	857	17	193	2,288	3,131	5,078	7,484	6,129	4,374	2,798	577	2,323	35,249							24.
	Empire West Side Irrigation District																				
25.	Entitlement Water	67	0	0	410	500	540	540	540	0	17	188	188	3,000	3,000	0	0	0	0	0	25.
26.	Surplus Water	0	0	0	0	161	806	853	494	0	0	0	500	2,814							26.
27	Agency Total	67	0	0	410	661	1,346	1,393	1,034	0	17	168	688	5,814							27.
	Hacienda Water District:																				
28.	Entitlement Water	0	0	0	0	120	140	0	220	520	520	520	860	2,900	2,900	0	0	0	0	0	28
29.	Surplus Water	0	0	0	0	0	0	0	0	80	2,099	1,000	2,471	5,600							29.
30.	Agency Total	0	0	0	0	120	140	0	220	600	2,619	1,520	3,281	8,500							30.
	Kern County Water Agency:																				
31.	Entitlement Water	6,455	12,096	13,144	23,718	35,558	54,870	62,825	62,513	28,644	11,282	3,953	3,440	310,500	310,500	0	0	0	-	-	31.
32.	Surplus Water	5,303	8,851	9,705	7,112	20,093	33,623	41,950	28,244	6,731	6,642	14,758	14,232	194,743							32.
33.	Agency Total	11,758	20,947	22,849	30,830	55,651	88,493	104,775	90,757	36,075	17,924	18,712	17,672	505,243							33.
	Oak Flat Water District:																				
34.	Entitlement Water	0	0	0	550	550	550	550	706	184	12	0	0	3,100	3,100	0	0	0	0	2,000	34.
35.	Surplus Water	0	0	0	114	150	113	601	149	0	0	0	0	1,127							35.
36.	Agency Total	0	0	0	664	700	663	1,151	855	184	12	0	0	4,227							36.
	Tulare Lake Basin Water Storage District:																				
37.	Entitlement Water	1,600	0	0	200	0	113	7,000	7,000	7,000	7,000	5,687	5,052	40,652	40,652	0	0	0	0	14,853	37.
38.	Surplus Water	3,509	0	0	3,403	141	0	6,863	19,490	6,675	9,545	10,841	8,433	70,900							38.
39.	Agency Total	5,109	0	0	3,603	141	113	13,863	26,490	13,675	16,545	16,528	13,485	111,552							39.
40.	AREA TOTAL	19,081	21,978	24,410	39,337	61,653	96,610	134,602	130,299	46,553	40,500	37,926	38,003	685,910	392,152	0	0	0	0	77,310	40.
	SOUTHERN CALIFORNIA SERVICE AREA																				
	Antelope Valley-East Kern Water Agency:																				
41.	Entitlement Water	0	0	0	0	0	0	0	28	0	0	0	0	28	23,000	24,980	19,947	44,927	-	-	41.
42.	Castaic Lake Water Agency	0	0	0	0	0	0	0	0	0	0	0	0	0	3,700	5,700	1,236	4,936	-	-	42.
	Coachella Valley County Water District:																				
43.	Entitlement Water	0	0	0	0	0	0	1,550	724	718	0	0	2,030	5,000	5,000	0	5,200	5,200	-	-	43.
	Crestline-Lake Arrowhead Water Agency:																				
44.	Entitlement Water	43	18	25	0	0	46	67	64	54	62	13	41	461	870	409	62	471	-	-	44.
	Desert Water Agency:																				
45.	Entitlement Water	0	0	0	0	0	0	2,295	1,086	1,130	0	0	4,489	9,000	9,000	0	8,000	8,000	-	-	45.
	Littlerock Creek Irrigation District:																				
46.	Entitlement Water	0	0	0	0	0	19	78	105	65	32	0	0	298	298	0	0	0	-	-	46.
47.	Surplus Water	0	0	0	0	0	0	0	8	0	72	0	0	80							47.
48.	Agency Total	0	0	0	0	0	16	78	113	65	104	0	0	378							48.
49.	Mojave Water Agency	0	0	0	0	0	0	0	0	0	0	0	0	0	10,700	10,700	8,345	19,045	-	-	49.
50.	Palmdale Water District	0	0	0	0	0	0	0	0	0	0	0	0	0	2,040	2,000	1,620	4,560	-	-	50.
	San Bernardino Valley Municipal Water District:																				
51.	Entitlement Water	2,761	860	677	970	3,338	1,482	4,352	4,873	1,145	3,410	4,295	4,242	32,476	48,000	15,574	402	15,876	-	-	51.
52.	San Gabriel Valley Municipal Water District	0	0	0	0	0	0	0	0	0	0	0	0	0	11,500	11,500	172	11,622	-	-	52.
	The Metropolitan Water District of Southern California:																				
53	Entitlement Water	14,035	8,375	9,985	14,281	20,228	19,013	17,722	15,537	3,197	12,274	11,739	11,697	159,083	354,600	194,717	82,836	277,551	-	-	53.
54.	AREA TOTAL	16,839	9,262	10,685	15,251	23,566	20,571	26,044	22,217	8,314	15,859	16,047	21,305	207,060	472,400	264,520	127,760	382,380	-	-	54.
	ALL AGENCIES:																				
55.	Entitlement Water	31,422	25,074	27,534	48,343	76,312	93,440	113,988	111,118	49,647	44,452	34,359	30,751	684,480	986,252	291,071	232,481	510,273	69,164	0	55.
56.	Surplus Water	9,773	9,089	9,861	10,629	20,681	34,061	56,161	52,417	18,204	19,363	26,600	28,535	296,416							56.
57.	Total-Project Water	41,195	34,163	37,395	58,973	95,993	127,501	168,149	163,535	67,851	63,817	60,959	68,346	988,876							57.
58.	Regulated Delivery of Local Supply	936	779	931	1,920	4,824	3,458	6,060	5,655	3,548	1,700	888	418	32,200						-	58.
59.	Repayment of Preconsolidation Water	0	254	514	948	464	2,933	3,080	2,068	42	0	0	0	10,303					169,151	-	59.
60	TOTAL WATER	42,131	35,187	38,840	61,840	101,301	133,772	179,089	171,258	71,541	67,807	61,547	69,164	1,033,387	986,252	291,071	222,481	510,273	238,315	77,310	60.

a) Repayment of Preconsolidation water.

Source: State of California, The Resources Agency, Department of Water Resources, <u>The California State Water Project in 1974</u>, Bulletin No. 732-74, p. 28-29.

water deliveries to the agricultural areas in the Southern San Joaquin Valley dropped from 867,317 acre feet in 1972 to 695,910 feet in 1973, i.e., from almost 79 percent of all project water to two-thirds. Similarly, the South San Francisco Bay area required less water from the Project. At the same time, the deliveries to southern California almost tripled in the year past. Table 2 Annual Water Requirements* lists historical data and projections on requirements.

Furthering the California Water Project's objectives with relation to hydroelectric power generation, the record for 1973 showed a 72 percent increase over 1972 production, the total approximating some 3,298 million kilowatt hours. Moreover, there was a marked increase in recreation days, a new high of 2,502,000 accounted for by improved fishing access sites on the California Aqueduct as well as construction of added sections of the California Aqueduct Bikeway.

In Figure 2 Water Operations, 1973, we find a graphic representation of the past year's activities, with clearer demarcation as to geographical divisions and the particular characteristics of each.

As we indicated at the beginning of the Section called Quantity, the California State Water Project has at this point reached a significant point in its development. The next important phase is construction of the Peripheral Canal, an extremely controversial matter which provides an area for the collision of adversary and advocacy forces and reveals most tellingly the broad range of desiderata that enter into the management of California's water. Because of the enormous importance of the Peripheral Canal, we shall devote a special section in this report to analysis of the issues and their implications, with special attention directed to the growing and changing information needs they generate.

It might be noted, in this connection, that while the Peripheral Canal has generated considerable controversy, and while the issues cover a broad range from the hydrological and ecological to the economic, political, and social, there is unanimity on one point, viz., the urgent need for reliable, up-to-the-minute information, possibly of the kind to be derived from remote sensing.

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* p. 7.

TABLE 2. ANNUAL WATER REQUIREMENTS

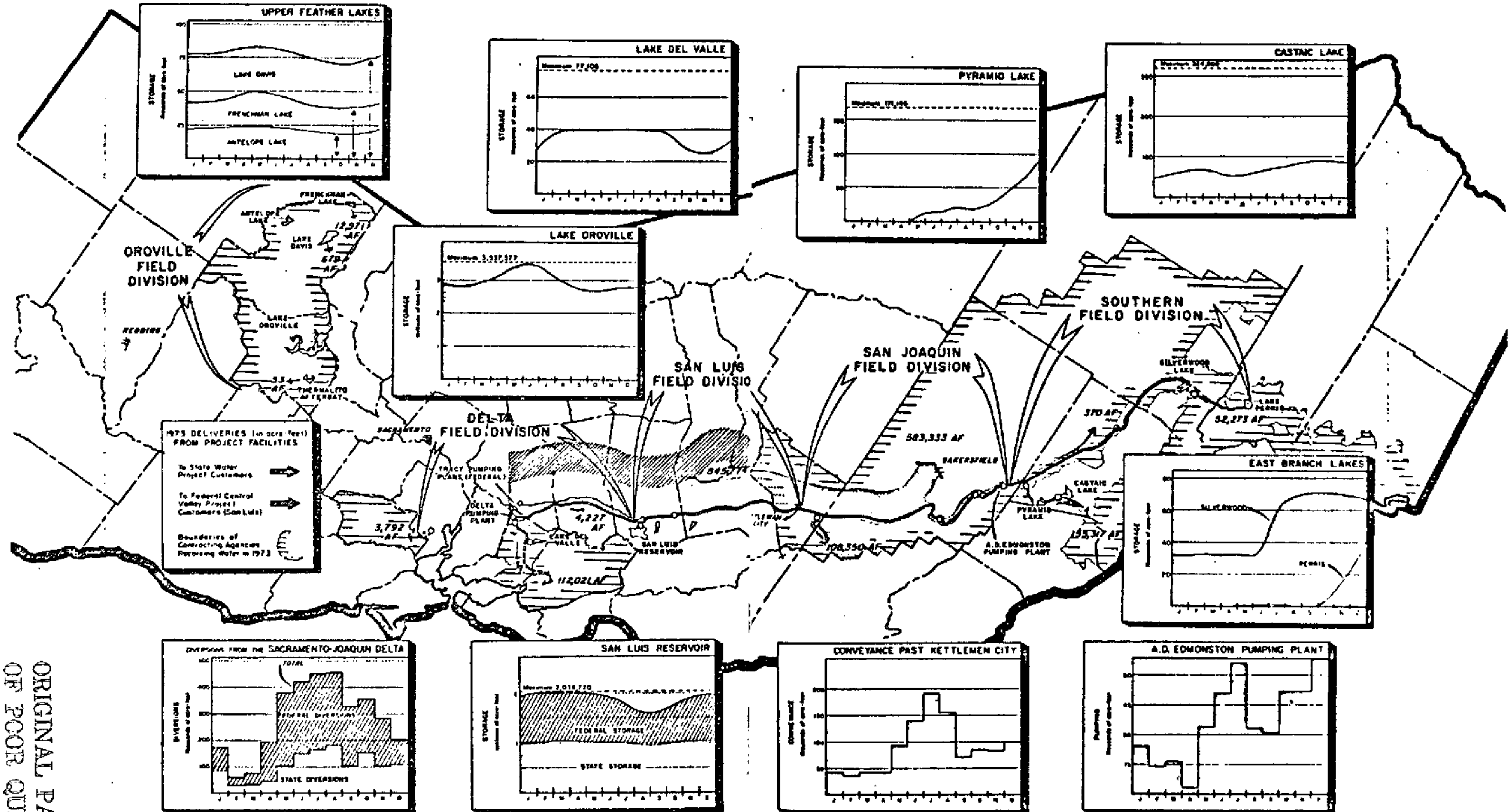
(in acre-feet)

	Annual Entitlements Under Long-term Water Supply Contracts							Estimated Annual Water Demands							
								Deliveries to Contracting Agencies							
Calendar Year	Feather River Area	North Bay Area	South Bay Area	San Joaquin Valley Area	Central Coastal Area	Southern California Area	Total	Entitlement Water	Surplus and Nonproject Water[a]	Total	Initial Fill	Operational Losses and Storage Changes	Recreation Water	Total	Calendar Year
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	
1962	0	0	0	0	0	0	0	0	18,289	18,289	9	272	0	18,570	1962
1963	0	0	0	0	0	0	0	0	22,456	22,456	71	185	0	22,712	1963
1964	0	0	0	0	0	0	0	0	32,507	32,507	171	152	0	32,830	1964
1965	0	0	0	0	0	0	0	0	44,105	44,105	93	729	0	44,927	1965
1966	0	0	0	0	0	0	0	0	67,928	67,928	0	1,746	0	69,674	1966
1967	0	0	11,538	0	0	0	11,538	11,538	53,605	65,143	8,328	4,212	0	77,683	1967
1968	550	0	109,900	81,050	0	0	191,500	171,709	136,311	308,020	498,926	117,906	0	924,852	1968
1969	620	0	98,700	168,075	0	0	267,395	193,020	91,226	284,246	510,614	72,196	0	867,056	1969
1970	700	0	114,200	207,700	0	0	322,600	233,993	171,104	405,097	23,947	2,435	0	431,479	1970
1971	890	0	116,200	258,500	0	0	375,590	357,340	340,138	697,478	7,853	5,812	8	711,151	1971
1972	970	0	118,300	420,766	0	201,723	741,759	611,801	490,602	1,102,403	100,274	53,062	6,489	1,262,228	1972
1973	1,100	0	120,400	392,352	0	472,400	986,252	694,460	338,927	1,033,387	204,638	54,955	1,081	1,294,061	1973
Subtotal for 12 years 1962-1973	4,830	0	689,238	1,528,443	0	674,123	2,896,634	2,273,861	1,807,198	4,081,059	1,354,924	313,662	7,578	5,757,223	12 years, 1962-1973
1974	1,230	0	122,400	434,800	0	588,220	1,146,650	959,335	569,736	1,529,071	264,165	165,330	6,800	1,965,366	1974
1975	1,610	0	124,500	480,900	0	704,250	1,311,260	1,218,975	651,839	1,870,814	150,865	97,124	7,000	2,125,803	1975
2 years, 1974-1975	2,840	0	246,900	915,700	0	1,292,470	2,457,910	2,178,310	1,221,575	3,399,885	415,030	262,454	13,800	4,091,169	2 years, 1974-1975
1976	1,990	0	126,500	535,600	0	824,780	1,488,870	1,457,615	716,806	2,174,421	9,492	14,071	7,200	2,205,184	1976
1977	2,420	0	128,600	594,100	0	942,201	1,667,321	1,692,725	679,556	2,372,281	4,360	209,963	11,400	2,598,004	1977
1978	2,850	0	130,700	651,600	0	1,060,722	1,845,872	1,776,735	704,621	2,481,356	4,360	-49,775	11,600	2,447,541	1978
1979	3,280	0	132,700	707,700	0	1,177,873	2,021,553	1,864,075	692,841	2,556,916	0	106,751	11,790	2,675,457	1979
1980	4,710	19,250	134,800	765,000	2,200	1,304,914	2,230,874	1,993,450	672,439	2,665,889	3	511,359	44,305	3,221,556	1980
1981	10,390	21,750	137,000	828,500	3,300	1,425,865	2,426,805	2,113,770	635,539	2,749,309	0	180,720	44,415	2,974,444	1981
1982	12,270	24,400	139,200	889,200	6,600	1,546,806	2,618,476	2,242,490	695,539	2,938,029	0	277,255	44,525	3,259,809	1982
1983	14,200	27,050	141,400	955,500	9,900	1,668,557	2,816,607	2,364,653	551,403	2,916,056	0	36,384	44,645	2,997,085	1983
1984	16,130	29,600	143,600	1,017,900	14,900	1,790,398	3,012,528	2,481,206	501,326	2,982,532	0	103,763	44,755	3,131,050	1984
1985	19,060	32,750	145,800	1,079,100	24,800	1,912,549	3,214,059	2,597,825	454,739	3,052,564	0	266,890	44,875	3,364,329	1985
10 years, 1976-1985	87,300	154,800	1,360,300	8,024,200	61,700	13,654,665	23,342,965	20,584,544	6,304,809	26,889,353	18,215	1,657,381	309,510	28,874,459	10 years, 1976-1985
10 years, 1986-1995	340,420	587,500	1,650,200	13,032,300	688,000	23,869,646	40,168,066	34,541,445	0	34,541,445	0	1,709,692	453,650	36,704,787	10 years, 1986-1995
10 years, 1996-2005	386,460	670,000	1,878,000	13,550,000	827,000	24,975,000	42,286,460	39,853,735	0	39,853,735	0	1,828,767	455,000	42,137,502	10 years, 1996-2005
10 years, 2006-2015	393,170	670,000	1,880,000	13,550,000	827,000	24,975,000	42,295,170	41,900,070	0	41,900,070	0	1,820,047	455,000	44,175,117	10 years, 2006-2015
10 years, 2016-2025	398,000	670,000	1,880,000	13,550,000	827,000	24,975,000	42,300,000	42,227,260	0	42,227,260	0	1,854,142	455,000	44,536,402	10 years, 2016-2025
10 years, 2026-2035	398,000	670,000	1,880,000	13,550,000	827,000	24,975,000	42,300,000	42,300,000	0	42,300,000	0	1,866,340	455,000	44,621,340	10 years, 2026-2035

a) Amounts shown for 1962 thru 1973 include regulated delivery of local supply (393,395 acre-feet), surplus water (1,343,354 acre-feet), and repayment of preconsolidation water (70,449 acre-feet). Amounts shown for 1974 thru 1985 are based on studies as to the availability and cost of surplus water.

Source: State of California, The Resources Agency, Department of Water Resources, The California State Water Project in 1974. Bulletin No. 732-74, June, 1974, pp. 24-25.

FIGURE 2. WATER OPERATIONS, 1973



Source: State of California, The Resources Agency, Delpartment of Water Resources, The California State Water Project in 1974, Bulletin No. 732-74, June, 1974, pp. 42-43.

Table 3 Summary of 1973 Project Operations presents chronologically and in tabular form a summary of project activities for the past 12 years. The figures and trends become all the more significant when viewed, as we shall see later in this report, from the standpoint of their policy implications and as a base for projections for the future.

TABLE 3. SUMMARY OF PROJECT OPERATIONS IN 1973

Year	Water Delivered (acre-feet)[a]			Recreation Supported (recreation days)[b]	Electrical Energy Generated (megawatt-hours)
	Municipal and Industrial Use	Agri-cultural Use	Total		
1962	4,594	13,695	18,289	30,000	--
1963	6,686	15,770	22,456	105,000	--
1964	11,293	21,214	32,507	331,600	--
1965	17,642	26,463	44,105	499,800	--
1966	27,529	40,399	67,928	482,700	--
1967	28,736	36,407	65,143	455,200	--
1968	52,686	255,334	308,020	931,300	628,000
1969	40,123	244,123	284,246	1,554,800	2,614,000
1970	61,915	343,182	405,097	1,804,800	2,679,000
1971	103,550	593,928	697,478	2,085,900	3,302,000
1972	207,702	894,701	1,102,403	1,971,200	1,922,000
1973	309,144	724,243	1,033,387	2,502,000	3,298,000
Total[c]	871,600	3,209,459	4,081,059	12,754,300	14,443,000

a) An acre-foot of water (325,851 gallons) will cover one acre of land to a depth of one foot.
b) A recreation day is the visit of one person to a recreation area for any part of one day.
c) In addition, dams of the State Water Project have prevented millions of dollars worth of flood damage, the most notable to date being an estimated $30,000,000 by operation of partially completed Oroville Dam during the storm of December 1964 and January 1965.

Source: State of California, The Resources Agency, Department of Water Resources, The California State Water Project in 1974. Bulletin No. 732-74, June, 1974, p. 40

As we shall see later, when we examine the projected demands for water in 1990 and 2020, the pattern of demand may change considerably, depending on which future one posits. And the factors which cause the divergencies in projection are almost totally related to the social climate. Hence, the need to examine water management in its full social context. It becomes readily apparent in viewing the past, present, and future that supply of and demand for water cannot be estimated by simple measures. Whatever decisions are made in the twentieth century are bound to have implications for the style and quality of life in the twenty-first. In the course of our studies, we try to find better ways to assess our technology and learn how to apply our sophisticated methods toward fashioning a better future.

5.20 Water Quality

The distinction between water quality and water quantity has never been clean and clear. And as the pressures for more usable water become greater, the interrelationships become even more complex. In descriptive terms, it has been said that the quality of water is influenced by usage, natural pollution, drainage of urban and agricultural lands, waste-solid disposal practices, recreational activities, and certain political implementations.[1] These items only suggest the multiplicity of dimensions of water quality considerations and barely hint at their magnitude.

With respect to the quality of California water, there exists a strong functional relationship between the Department of Water Resources and the State Water Resources Control Board. As was pointed out in our previous report (dated 31 May, 1974), the Dickey Water Pollution Act of 1949 and amendments in nine subsequent sessions of the State legislature through 1965 contain the enabling legislation for what has been a vital role in the maintenance of quality standards. The State Water Quality Resources Board, in its central and regional activities, formulates and adopts water quality policies. Under the Porter-Cologne Water Quality Control Act, effective January 1, 1970, the powers of the State and nine Regional Boards were strengthened to the point where they represent one of the most effective regulatory

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1 Ernest F. Gloyna, "Major Research Problems in Water Quality," in Allen V. Kneese and Stephen C. Smith, editors, Water Research, published for Resources for the Future, Inc. by the Johns Hopkins Press, 1966, p. 481.

agencies in the State government. The following table (Table 4. Major Water Quality Problems in California by Region) provides a synoptic view of the types of problems, distributed regionally, which engage the official attention of the Board. This table appeared in our foregoing report as part of our explanation of the interlocking responsibilities of the various agencies and bodies involved in the management of water. It is reproduced here as useful reference point from which to review in some detail the specific activities of the Board.

Since the enactment of the Porter-Cologne Water Quality Control Act, these activities have broadened in scope and effect. Figure 3 Administrative Enforcement Procedures of California Regional Water Quality Control Boards shows how enforcement actions take place. As of February, 1974, the nine regional boards had over 250 such actions pending. Of them, 157 were in the Cease and Desist category, which frequently served as adequate warning to a polluter. Cease and desist orders are issued by the regional boards after reviewing testimony by staff, the discharger, and the public. The offender may be ordered to clean up immediately or within a specified time. If he fails to comply, he will receive a cleanup order, also issued in some cases of Water Code violation. In situations where additional connections to a waste-water collection system would cause a pollution problem, regional boards can declare a ban. Where violation continues despite cease and desist orders, cases are referred to the Attorney General for action. Penalties of up to $10,000 per day are levied once the case reaches the court. The following table (Table 5. Summary of Enforcement Actions in Progress, February, 1974.) presents a succinct account of this aspect of the boards' activities. Worth noting in terms of our particular interest is the Los Angeles Regional Water Quality Control Board's favorable settlements of oil spill cases against five firms, among them Gulf Oil and Exxon Company, U.S.A. As remote sensing techniques become more refined, they will provide extremely valuable input in the process of maintaining control over water pollution. In fact, our initial contacts indicate considerable interest on the part of officials in pursuing an investigation of the applicability of data derived from remote sensing imagery.

Waste-water management, constructed so as to meet federal law requirements for secondary treatment by 1990, involves planning for sewage treatment plants, interceptor servers, outfalls and disposal systems and collection systems which add up to some $6 billion. Since funds, even with passage of certain bond issues, are less than that figure, priorities must be established. This is far from simple, since many communities have discovered, in a no vote at the ballot box, an effective way to limit growth. Water bonds and other public works will, it may be anticipated, become a useful means by which the public can exert control on development.

TABLE 4. MAJOR WATER QUALITY PROBLEMS IN CALIFORNIA BY 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 L
(4) Most drainage basins	Siltation and turbidity	Erosion.
San Francisco Bay		
(5) San Francisco Bay	Depressed oxygen levels	Discharge of MGI waste water.
	Elevated coliform bacteria	Discharge of MGI waste water.
	Fish kills	Accidental oil spills and deliberat toxic waste discharge.
	Nuisance, algal growths	Discharge of several kinds of waste:
	Bacterial pollution	Sewer overflows.
(6) Russian River	Turbidity	Improper land use and imported wate from Eel River.
	Algal blooms	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.

Source:

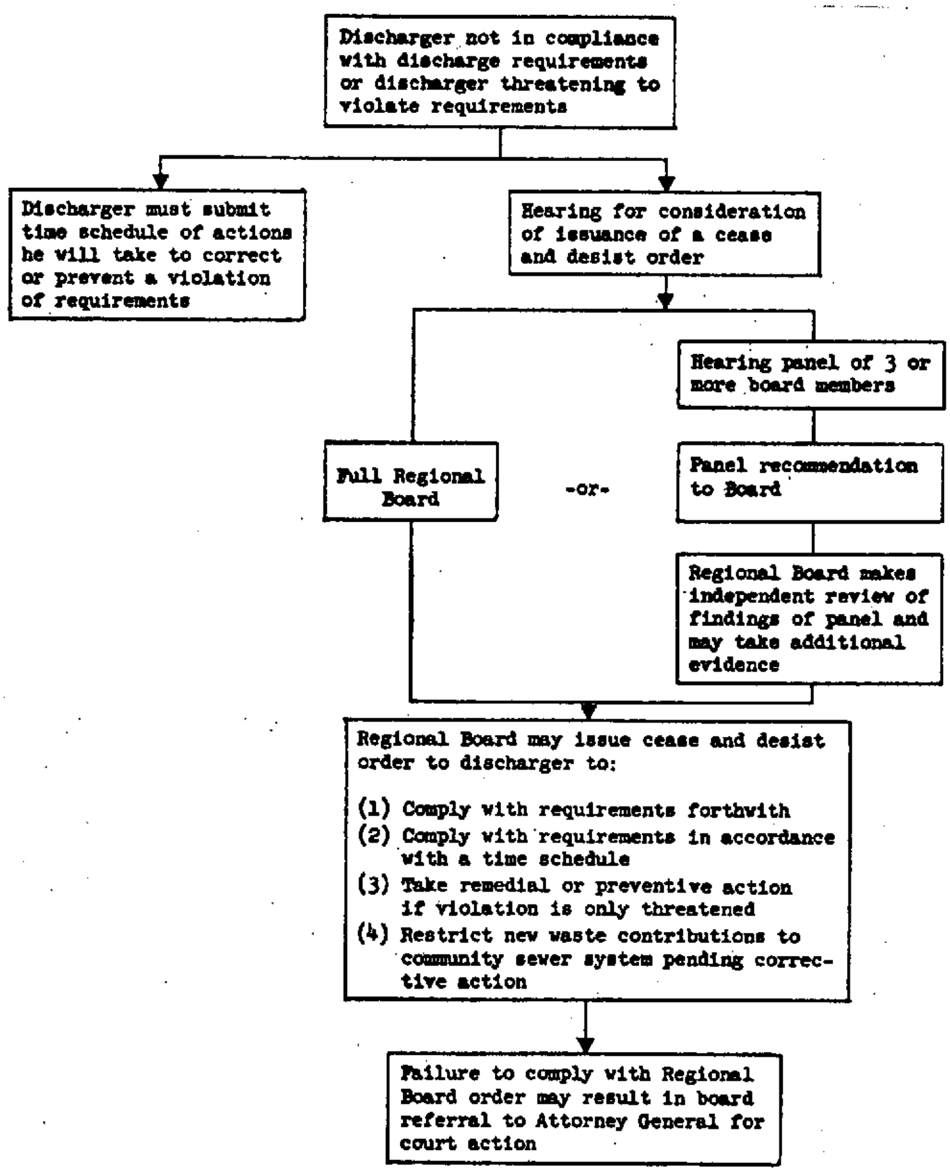
Subregion/Area	Problem	Cause
South Coastal		
(11) Near shore areas	High coliform bacteria concentrations	Floating material of waste water origin.
(12) Coastal lagoons-estuaries	Excessive algal growth, oxygen depression and odors	Runoff carries enriching nutrients from urban and irrigated lands and wastes 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 pumpin and waste discharge during low flow:
(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 natura flow from San Joaquin River and its tributaries.
(19) Tuolumne River	"	"
(20) San Joaquin River	"	"

Subregion/Area	Problem	Cause
San Joaquin		
(21) Lower San Joaquin River	High salt content	Saline water from abandoned gas we
(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 conter water from Colorado River.
(29) Salton Sea	Eutrophic and increasing salinity	Agricultural waste discharges.
(30) Salton Sea	Fish kills	Decreasing oxygen from decompositi of algal blooms and waste dischar from Mexicali into New River.

Source: Pacific Southwest Inter-Agency Committee.

FIGURE 3

ADMINISTRATIVE ENFORCEMENT PROCEDURES OF CALIFORNIA REGIONAL WATER QUALITY CONTROL BOARDS*



*Source: Ronald B. Robie and Norman B. Hume, "Practice Under California's New Porter-Cologne Water Quality Control Act," Bar Bulletin (Los Angeles County Bar Association), March, 1970, p. 15.

TABLE 5

SUMMARY OF ENFORCEMENT ACTIONS IN PROGRESS, FEBRUARY, 1974*

Region	Cleanup Orders	Court Actions	Cease and Desist Orders	Connection Bans
North Coast	15	2	4	1
San Francisco Bay	9	8	67	13
Central Coast	4	3	5	1
Los Angeles	1	3	5	1
Central Valley	8	5	39	1
Lahontan	8	5	18	1
Colorado River	1	0	4	1
Santa Ana	2	1	4	0
San Diego	2	0	11	2
Total	50	27	157	21

*Source: State Water Resources Control Board, News and Views, Vol V, No. 3, February, 1974, p. 3.

Exemplifying further the Board's activities is a case involving the North Coast Region, where a permanent injunction was issued against logging operations by a contractor who had failed to comply with the Regional Board's clean-up and statement order. Through surveillance teams from the Department of Fish and Game, the Regional Board learned that slash material, including tree-tops, branches, and organic substances, were being deposited in a stream which supplied domestic water and also lay adjacent to spawning areas for steelhead, salmon, and trout. These were having a degrading effect. As a result of the lawsuit requested by the North Coast Regional Board and initiated by the Office of the Attorney General in the Mendocino County Superior Court, the defendants were required to obtain the services of a professional civil engineer for cleanup operations and of specialists in geology and biology to stabilize logged slopes and protect spawning grounds from products of erosion. The work schedule imposed in the defendants called for construction of water bars on logging roads, and the reseeding of landings, skid trails, and denuded areas beside the stream.

As an indication of another potential tie-in with the work of the Remote Sensing Integrated Project is the State Water Quality Control Board's particular interest in forestry practices. Under recent legislation, logging operations must include a plan prepared by a professional forester who has assessed the likely effects and recommended mitigating measures. The State Board's two-volume report, "A Method of Regulating Timber Harvest and Road Construction Activity for Water Quality Protection in Northern California,"* provides valuable guidelines by proposing a method for "assessing, regulating, and controlling the impact on water quality by logging road building, and similar land disturbing practices."[2] Included is a field inspection methodology for ascertaining potential water quality damage. Examined also are the effects of logging in aquatic ecosystems; the types, methanics, and effects of erosion; and causes and control. For the period from June, 1973 to February, 1974, the monitoring and enforcement activities with relation to polluting logging practices were as shown in Table 6, Monitoring and Enforcing Actions Relating to Logging June, 1973 to February, 1974.

Timber management and implementation of forestry policies might benefit directly from the use of space satellite-derived imagery.

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* California State Water Resources Control Board, Research Publication No. 50, 1973.

[2] Described in News and Views, op. cit., February, 1974, p. 7.

TABLE 6.

MONITORING AND ENFORCING ACTIONS RELATING TO LOGGING
JUNE, 1973 -- FEBRUARY, 1974*

- review of 1,050 Notices of Timber Operations filed with the Division of Forestry
- review of approximately 200 Timber Sale Prospecti filed by the U.S. Forest Service with the regional board
- investigation of approximately 700 stream bed alteration permits from Dept.of Fish and Game
- examination of approximately 70 potential sites for logging activities
- initiation of six enforcement actions.

Acknowledging its responsibility under the Porter-Cologne legislation and taking seriously its mandate to provide effective leadership to a coordinated state wide water quality control program, the State Water Resources Control Board has sponsored the development of comprehensive plans which "define the beneficial uses of each California water segment, set water quality objectives to protect those uses, and outline waste water treatment, water use, and other management tools needed to preserve and enhance water quality."[3] Probably emerging from this effort came one of the Board's most significant publications, cited in our 31 May, 1974 Progress Report. In "Research Needs for Water Resources Control in California,"[4] we find a definition of the problems associated with water quality, articulation of attendant research needs, and policy guidelines for establishing priorities, as well as finding and evaluating proposals. The Board assigned "highest priority to the development of methodology and data for the State Board and the nine regional water quality control boards in their planning and control functions."[5]

Because of its importance as a continuing reference point, we reproduce again for inclusion in this context the section on water quality data from the Research Needs report.[6]

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*Source: News and Views, Vol. V., No. 3, February, 1974, p. 7.

[3] News and Views, February, 1974, op. cit., p. 1.

[4] California State Water Resources Control Board Publication No. 48, April 1973.

[5] Ibid., p. iii.

[6] California State Water Resources Control Board, "Research Needs for Water Resources Control in California," Publication No. 48 April, 1973, pp. 19-20.

B. Information Needed to Assess and Control Quality of the Water Resources of California[7]

5.21 Water Quality Data

Reliable information is needed for decision-making to control and manage effectively the water resources of the State. It is necessary to determine or predict possible environmental effects of control actions. At this time, there is little data available which allows a quantitative, statewide assessment of improvements in water quality achieved by State and Regional Boards' actions during the 22 years of their operation. Except for a few water bodies, a quantitative measure of results is not possible due to the lack of monitoring data. The absence of historical, baseline data is particularly critical. To evaluate the effectiveness and results of the state-federal construction grant program, water quality data is essential. It is important that collected data be summarized, analyzed and evaluated, and presented to the regulatory agency in a convenient, usable form.

In addition to the "basic data" requirements, information pertaining to individual discharges needs to be collected and processed in an analytical form suitable for the study of water quality trends, mass emissions, sources of pollution and compliance checking.

The State Board's responsibilities in the administration of water rights also create a need for inventories of water quantity and water use through the State. An application for the appropriation of water requires that records of water rights for all downstream users be checked and notices of diversion be sent out where diversion will affect others.

Recognizing the urgent need for water quality data, the Porter-Cologne Water Quality Control Act has charged the Board with the responsibility to prepare and implement a statewide water quality information storage and retrieval program. A functional system of data collection, storage and retrieval is basic to effective water quality planning, monitoring, enforcement and management. A system needs to be developed and implemented that will: (1) standardize data reporting statewide; (2) pinpoint the location and timing of sampling for statistically sound sampling action by regulatory agencies; (3) establish a water quality and environmental baseline and historical trend; and (4) be

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[7] *Ibid.*, pp. 19-20.

applicable to the physical, chemical and biological water quality factors associated with ground and surface waters.

5.22 Comprehensive Monitoring of Water Quality

Concomitant with the development of a data management system is the need to design a comprehensive but standardized statewide monitoring program for surface waters and groundwaters, and special problem constituents such as pesticides and heavy metals. Such a system will greatly enhance the effectiveness of all water quality management efforts, provide a basis for assessment of effectiveness of water quality control programs and for forecasting pollution problems, and result in considerable savings in data management manpower needs over the long run.

Equipment and instruments are available to test for most of the significant pollutants in waste discharges and in the receiving waters; however, field equipment is seriously lacking for the on-line measurement of most wastewater constituents. The reliability of some of the available instruments for continuous monitoring under field condition has not been demonstrated satisfactorily. Interference, corrosion and suspended material in wastewater monitoring require specific attention.

Also germane to our research are the matters included in the report under the category, "Institutional Considerations," which spell out recommended research in the following areas:[8]

a) Improvement of methodology under which State and Regional Boards operate. This research is to include a study of function and operation of the boards together with an evaluation of their effectiveness, particularly in the water quality-water rights relationship.

b) Evaluation of appropriate institutional arrangements for apportioning costs and financing of a selected control system to control groundwater quality degradation from irrigation wastewater in the San Joaquin River and Tulare Lake Basins. There is also a need to investigate cost allocation philosophies and institutional mechanisms for distribution of project costs in order to support and implement a regional plan.

c) Improvement of transfer of applicable technology and information from the University of California to other state

[8] *Ibid.*, p. 48.

agencies. Development of a central clearing facility, or information center for all water quality related research activities, needs to be considered.

d) Evaluation of the effectiveness of environmental impact statements required by the National Environmental Policy Act of 1969 and the 1970 California Environmental Quality Act in protecting beneficial uses of California's water resources.

e) Study of appropriate agencies and organizational structures to encourage wastewater reclamation and reuse.

f) Study of appropriate drainage districts for control of agricultural wastes.

Especially noteworthy here is item (c), which calls for better communications with and use of the University of California's technical capability in water quality related research activities. In this regard, the Board explicitly recognized the importance of socio-economic considerations. For this reason, the assessment, in the short and long run and in all possible dimensions, of public works becomes absolutely essential. Almost invariably, long-range water quality protection involves a broad spectrum of projections, careful analysis of alternate courses of action and awareness of costs. Under the Porter-Cologne Act, the Board, a quasi-judicial regulatory agency plays a key role in protecting and enhancing California's waters. How the Board views the future is embodied to some extent in its Recommended Water Management Plan,[9] further mention of which will be made later in this report, in the section on Long Range Social Considerations. At present, an urgent item on the Board's agenda is the Peripheral Canal, since Decision 1379 (to be discussed further on) calls for specific protective action. It is to the Peripheral Canal that we next turn our attention.

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[9] Bay-Valley Consultants, Recommended Water Quality Management Plan, July, 1974.

5.30 The Peripheral Canal Project

As was noted earlier in this report, construction of the Peripheral Canal is the next important step in the construction of the State Water Project. That this has long been a highly controversial matter from almost every point of view -- political, social, economic, aesthetic, hydrologic, ecological, and environmental -- is generally recognized and there has been debate over it for years. Completion of the Project up to this point and the appearance of the environmental impact statement,[10] prepared by consultants for the Department of Water Resources and released by that agency, have precipitated a heightened public awareness of the pro's and con's, with the advocacy and the adversary positions clearly drawn.

Controversy over the management of resources, especially those in which allocation for their desired uses and limitation of undesirable impacts is crucial, must be expected. The costs and benefits of any course of action taken to bring about improvement are not directly measurable in commensurate units, nor do they serve equally all interest groups. This is not to say that the controversies should be ignored because they are likely to cause institutional nervousness on the part of researchers and their sponsoring agencies. Quite the contrary, the very incidence of controversy may be an indicator of the importance of the issues involved and makes it mandatory that (1) the full range of parameters be identified so that modeling will include behavioral variables and socio-economic complexes, and (2) that, whenever possible, factual information be fully utilized in order to reduce uncertainties, which provide cause for partisan debate. In the case of the Peripheral Canal, the simplistic view of costs and benefits available from the customary management model is totally inadequate. Involved here are diverse and conflicting objectives, with pending jurisdictional battle between the federal government and the state of California acting as a constraint. Since the future of the Peripheral Canal and, indeed , the California Water Plan may ultimately be determined by the outcome of the litigations, the decision-making model must perforce encompass the legal input. Ultimately, the controversy over the Peripheral Canal will bring into focus the very issue that Dr. Castruccio* identified in his earlier guidelines for research, *viz.*, the relationship in resource management between federal and state government.

The Foreword of the Environmental Impact Report presents the Department of Water Resources' viewpoint on the Peripheral Canal, seen as "an integral feature" of the "authorized" State Water Project, and "needed by 1980, to convey water across the Sacramento-San Joaquin Delta to the aqueducts of the State Water Project and Central Valley Project without undue reduction in supply or deterioration in quality, to correct certain adverse environmental conditions in the Delta, and to facilitate water

[10] State of California, The Water Resources Agency, Department of Water Resources, *Environmental Impact Report, Peripheral Canal Project,* August, 1974.

* *Op. cit.*

management in the Delta." (emphasis added.) The objective of the canal is "to convey good quality water from the Sacramento River to the existing State Water Project and Central Valley Project pumping plants for export and to release facilities to distribute water from the canal to Delta channels to maintain water quality within prescribed criteria and to improve the Delta aquatic environment and the resources and economics it supports."[11]

Historically, precedent for this diversion is found in the federal Central Valley Project, which, in 1940, began to use Delta channels as conduits for conveying water to areas of shortage. Due to expansion of the Central Valley Project and development of the State Water Project, diversions have increased to the present (1973) level of 3.5 million acre-feet annually. (The projection to 2020 calls for an increase to an annual 8 million acre-feet.)

Forensically, the observation is made in the environmental impact statement that even at present rates of diversion, some sections of the Delta are already experiencing altered flow patterns and water quality degradation. "Without intelligent water management, the situation will deteriorate as export diversions increase."[12] Hydrologically, justification is drawn from studies purporting to indicate that the Peripheral Canal must be operational by 1980 to protect the water supply and water quality functions of the State Water Project during years when precipitation is below normal. Fiscally, implementation seems possible by conveyance needs of the State Water Project and the Central Valley Project until 1985, and even for the second stage, the construction of a pumping plant to meet conveyance needs after 1985, if federal financial participation is not forthcoming by 1975.

As substantiation, the environmental report offers the following statement: "The concept of a hydraulically isolated Peripheral Canal around the Delta to improve the quality of export supplies and provide for the environmental needs of the Delta culminates years of study and numerous proposals by many agencies. The plan was officially adopted as a feature of the SWP by the Department of Water Resources in 1966. In 1969, the U.S. Bureau of Reclamation issued a feasibility report recommending the Peripheral Canal as an additional unit of the CVP to serve the joint needs of the federal and state projects."[13]

Table 7 (Physical and Operational Features of the Peripheral Canal) presents in concise form the details of the proposed operation. Beginning at the Sacramento River near Hood, it will extend southeastward along the eastern side of the Delta, cross the San Joaquin River west of Stockton, and end at Clifton Court Forebay of the State Water Project. The objectives of the Canal are set forth as follows:

(1) to provide a conveyance for the export of water without undue reduction in supply or degradation in quality; (emphasis added)

(2) to change the point of export diversion from near Clifton Court Forebay to the vicinity of Hood via the Sacramento River, thereby isolating export water and eliminating the adverse effects on Delta channels;

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[11] Ibid., p. 1. [12] Ibid. [13] Ibid.

TABLE 7

PHYSICAL AND OPERATIONAL FEATURES OF THE PERIPHERAL CANAL

Facility	Description	Operation
Peripheral Canal	43-mile-long leveed earth channel.	Export by gravity flow during Stage I; by pumping during Stage II.
Canal Intake	23,300 cfs design capacity including 1,500 cfs for proposed Hood-Clay connection, decreasing to 18,300 cfs at Clifton Court Forebay.	Intakes water from Sacramento River into Canal. Gravity flow less than design and dependent on river stage.
Intake Facilities	Trashrack, sediment basin, flood gates, and fish protection facility.	Screens fish and debris, minimizes sediment entering canal, and controls diversions.
Siphons	Four siphons placed under major sloughs and rivers crossed by canal.	Conveys canal water under major rivers and sloughs so as not to impede floodflow capacities of existing channels, navigation, and fish migration.
Fish Protective Facility	Perforated plates at entrance to intake facilities or rotating drums downstream of entrance. (Type to be determined from studies.)	Screens juvenile fish from export water and keeps them in or returns them to Sacramento River.
Delta Release Facilities	12 water release points along canal with total capacity of 6,300 cfs.	Releases to Delta channels to replace severed water supplies, meet consumptive needs, control water quality, and maintain positive flows in channels. Releases minimal during Stage I and increasing during Stage II.
Drainage and Irrigation Facilities	Substitute or modified channels to replace minor irrigation and drainage systems severed by canal.	Will continue current functions.
Morrison Creek Flood Control	Drainage enters Peripheral Canal forebay between floodgates and Stage II pumping plant over a weir structure.	Floodflows from Morrison Creek Drainage diverted into enlarged section of canal. Flows released through release facilities or exported.
Middle River Facilities	Pumping plant and control structure on Middle River. Location dependent on alternative selected. (See Southeastern Delta Water Control Facility.)	Provides releases for water quality control and and controls floodflows taken into Peripheral Canal.
Fourteen Mile Slough Facilities	Combination water quality control channel and boat access channel. Provides boat access to Lincoln Village Marina from San Joaquin River.	Increased releases and elimination of effluent disposal to improve water quality. Boaters will be provided a more direct route to San Joaquin River.
Utilities	Replacements for those in canal right-of-way.	Will continue current operation.
Bridges	12 crossings to current standards.	Will carry 10 roads and 2 railroads over the canal.
Roads	Alternate public access road and service road on Peripheral Canal levee embankments.	Public access road for vehicular traffic and off shoulder public parking. Service road will double as a recreational trail.
Recreational Facilities	Recreation trails, auto-aquatic parks, fishing areas, nature study areas, picnic and camping areas, beaches, boat-in development, and swimming lagoons.	Operated by Department of Parks and Recreation or local agencies
Wildlife Areas	4 major preserve and habitat areas. Also along canal berms and outside of canal embankments.	State Department If Fish and Game will operate, regulating use and access to specified areas.
Control for Delta Cross Channel	Gates would be automated by remote control. Boat lock and bypass canal would be contructed to compensate for increased duration of closure.	Would permit gates to be open, either fully or partially, on varying schedule to meet environmental requirements in Mokelumne River not met by canal releases.
Peripheral Canal Pumping Plant	3 miles south of intake. Capacity of 21,800 cfs at 10-foot lift. Could pass floodwater from Morrison Creek by gravity flow.	Will provide additional capacity to convey joint SWP and CVP export flows. (Stage II facility.)
Southeastern Delta Water Control Facility	3 alternate plans under consideration for water quality improvement and water control facilities for southeastern Delta	Two plans will use Middle River release facilities to distribute flows to Old and San Joaquin Rivers. Third will release water from Delta-Mendota Canal to San Joaquin River. (Stage II facilities.)
Georgiana Slough Facilities	Series of rock weirs.	Will prevent excess transfer from Sacramento River to Mokelumne River caused by tidal action. (Stage II facility.)

Source: State of California, The Resources Agency, Department of Water Resources, Environmental Impact Report Peripheral Canal, August, 1974, p. 15.

(3) to provide controlled releases of water into the Delta at 12 locations where the Canal intersects Delta channels to facilitate year-round water quality management in the Delta and assure positive downstream flows in all main fish migration channels;

(4) to accept floodflows from Morrison Creek Basin and Middle River into the Canal to reduce the pressure of the flow on the natural channels downstream;

(5) to incorporate suitable recreation and fish and wildlife facilities and operational considerations so as to retain fish and wildlife resources at present levels and to increase these resources to the degree compatible with other project purposes; (emphasis added).

(6) to design the Canal so as to add a new recreation use, build new recreation facilities, and improve public access to this area of the Delta.

It is important to note that the source of most of the materials presented above is the Draft Environmental Report on the Peripheral Canal Project, the study having been performed under contract by the consulting firm of Jones and Stokes Associates, Inc. for the Department of Water Resources. The items underscored for special attention reflect intent and not demonstrated capability. Consequently, they are far from indisputable. As will become clearer when we report on the public hearings, these are some of the very issues about which serious controversy still rages. Moreover, it is essential that we reiterate that the position reflected in the environmental impact statement is that of the DWR and that inherent in it is the proposition that the California Water Project, as conceived 25 years ago, is still as good and valid as it appeared then to be, that the conditions and philosophy about population distribution, land use, and growth are still appropriate, and that, therefore, the construction of the Canal is, in fact, the logical and necessary next step. What must be taken into account at this particular time, however, is that the main focus of our scrutiny is on the environmental impact statement rather than the Peripheral Canal itself. This distinction is rather difficult to maintain, for the two are virtually inextricable in the presentations and discussions, and the line up of proponents and opponents almost identical as to both, i.e., the adequacy of the environment impact study and the propriety of proceeding with construction of the Canal.

Carrying out its mandate to assess the likely environmental impacts, the study team considered both short- and long-term effects in a number of specified areas, since, not unexpectedly, it was assumed that there would be regional differences. The first mentioned of these was the local vicinity, the area encompassing the Canal and the physical facilities along the Canal, with recognition made of the short-term impacts due to construction and the longer range effects of the actual physical presence of the Canal. The report rated as "environmental pluses" the "extensive recreation, fish and wildlife areas, and improved access to the Delta" stemming from the existence of the Canal. Acknowledged as negative results were the destruction of existing wildlife habitation, of agricultural acreage, and of parts of marsh and riparian lands. The second area was delineated as the Delta, Suisun Marsh, and San Francisco Bay and was conceived on the whole to be affected mainly by the operation of the Canal. It was envisioned that adverse environmental conditions were probably likely to occur only during one-third of the 45 years used in operation studies, had such years occurred. While implying that the design of protective facilities and mitigation features, plus an "environmentally sound" plan of operation, would assure that adverse impacts would be kept to a minimum, the authors of the report conceded that, in the complex ecological systems bound to be affected, much is still unknown about the potential results of disruptions. Only through actual operation of the Canal could such assessment be made. What might happen, and the unanimous agreement that there will be need for constant surveillance and monitoring, will be discussed later. Not unexpectedly, impacts on the export service areas were all seen as beneficial, since the Peripheral Canal is calculated for the enhancement of the "economy, environment, and social well-being of several million people."

The environmental impact assessment acknowledged the possibility of some adverse effects. For example, out of the 6,570 acres of land inside the total right-of-way, 5,820 acres, or 93 percent were devoted to agricultural production in 1973. Construction of the Canal would result in the reduction in acreage of some 14 crops, or a total crop production of about 37,000 tons. Cropping patterns and estimated loss appear in the following table (Table 8. Annual Loss of Agricultural Production Within the Peripheral Canal Right-of-Way by Reach and County).

Based on 1973 records, greatest annual tonnage loss would be experienced in sugar beets (12,100 tons), tomatoes (7,400 tons), corn (4,048 tons), pasture (2,869 tons), alfalfa (2,828 tons), pears (2,480 tons), and asparagus (2,392 tons). Concurrent with the crop loss, there would occur a loss to the counties of land with a market value of $7.2 million, with assessed tax valuation of $1.8 million. (See Table 9 , 1973 Estimated Loss of Tax Base Within The Peripheral Canal...).

The above two categories of losses led off the chapter in the Environmental Impact Report Peripheral Canal Project (Chapter VI) on adverse environmental effects which cannot be avoided. There were others. Construction of the Canal would, it was estimated, affect some 6,600 acres of agricultural land and native vegetation that at present are the habitat for about 191 species of birds, 36 species of

TABEE 8

ANNUAL LOSS OF AGRICULTURAL PRODUCTION WITHIN THE PERIPHERAL CANAL RIGHT-OF-WAY a/ BY REACH AND COUNTY (In Tons)

LAND USE	REACH					COUNTY			
	Hood to Beaver Slough	Beaver Slough to Disap-pointment Slough	Disap-pointment Slough to AT&SF Railroad	AT&SF Railroad to Clifton Court b/	Total	Sacra-mento	San Joaquin	Contra Costa b/	Total
AGRICULTURE									
Small Grains	220	188	360	116	884	110	774	0	884
Rice	269	0	0	0	269	269	0	0	269
Alfalfa	427	1,442	574	385	2,828	427	2,401	0	2,828
Pasture	342	2,527	0	0	2,869	334	2,535	0	2,869
Sudan Grass	14	0	0	0	14	14	0	0	14
Asparagus	38	59	1,062	1,233	2,392	4	2,388	0	2,392
Squash & Cucumbers	22	0	0	0	22	22	0	0	22
Tomatoes	3,360	384	1,800	1,896	7,440	1,272	6,168	0	7,440
Safflower	143	93	138	151	525	114	411	0	525
Sugar Beets	0	3,750	1,600	6,750	12,100	0	9,975	2,125	12,100
Corn	2,736	680	232	400	4,048	1,756	1,928	364	4,048
Grain Sorghum	555	205	87	78	925	555	370	0	925
Pears	2,232	0	248	0	2,480	2,232	248	0	2,480
Vineyard	220	0	0	0	220	220	0	0	220
TOTAL	10,578	9,328	6,101	11,009	37,016	7,329	27,198	2,489	37,016

a/ Based on 1973 Land Use Survey. Yields at farm roadside.
b/ Includes loss of agricultural production for the Clifton Court Forebay-Delta Mendota Canal Connection.
Source of Data: Sacramento and San Joaquin Counties Agricultural Extension Service; Sacramento County Agricultural Commissioner; California Department of Food and Agriculture; Tomato Growers Association; Cargill, Inc.

Source: State of California, The Resources Agency, Department of Water Resources, Environmental Impact Report Peripheral Canal Project, August 1974, p. V-2.

TABLE 9

1973 ESTIMATED LOSS OF TAX BASE WITHIN THE PERIPHERAL CANAL RIGHT-OF-WAY BY REACH AND COUNTY
(In Dollars)

LAND USE	REACH					COUNTY			
	Hood to Beaver Slough	Beaver Slough to Disap-pointment Slough	Disap-pointment Slough to AT&SF Railroad	AT&SF Railroad to Clifton Court a/	Total	Sacra-mento	San Joaquin	Contra Costa a/	Total
AGRICULTURE									
Small Grains	20,620	23,500	45,000	14,500	103,620	10,310	93,310	0	103,620
Rice	18,000	0	0	0	18,000	18,000	0	0	18,000
Alfalfa	14,490	61,800	24,600	16,500	117,390	14,490	102,900	0	117,390
Pasture	16,880	166,250	0	0	183,130	16,500	166,630	0	183,130
Sudan Grass	1,690	0	0	0	1,690	1,690	0	0	1,690
Asparagus	8,400	13,200	236,000	274,000	531,600	800	530,800	0	531,600
Squash & Cucumbers	500	0	0	0	500	500	0	0	500
Tomatoes	35,000	4,800	22,500	23,700	86,000	13,250	72,750	0	86,000
Safflower	20,620	18,000	26,500	29,000	94,120	16,500	77,620	0	94,120
Sugar Beets	0	37,500	16,000	67,500	121,000	0	99,750	21,250	121,000
Corn	128,250	42,500	14,500	25,000	210,250	82,310	105,190	22,750	210,250
Grain Sorghum	41,620	20,500	8,750	7,750	78,620	41,620	37,000	0	78,620
Pears	108,000	0	12,000	0	120,000	108,000	12,000	0	120,000
Vineyard	33,000	0	0	0	33,000	33,000	0	0	33,000
Fallow	0	12,250	0	0	12,250	0	12,250	0	12,250
Idle	6,190	50,000	0	0	56,190	6,190	50,000	0	56,190
SUBTOTAL	453,260	450,300	405,850	457,950	1,767,360	363,160	1,360,200	44,000	1,767,360
NONAGRICULTURE									
Native Vegetation	10,620	1,500	0	380	12,500	10,620	1,500	380	12,500
Native Riparian	1,880	9,750	0	0	11,630	1,880	9,750	0	11,630
Water Surface	nominal	nominal	nominal	nominal	nominal	nominal	nominal	nominal	nominal
Levees	nominal	nominal	nominal	nominal	nominal	nominal	nominal	nominal	nominal
Farmstead	1,500	0	2,250	5,250	9,000	1,500	7,500	0	9,000
SUBTOTAL	14,000	11,250	2,250	5,630	33,130	14,000	18,750	380	33,130
TOTAL	467,260	461,550	408,100	463,580	1,800,490	377,160	1,378,950	44,380	1,800,490

a/ Includes loss of tax base for the Clifton Court Forebay-Delta Mendota Canal Connection.

Source: State of California, The Resources Agency, Department of Water Resources, Environmental Impact Report Peripheral Canal Project, August 1974, p. V-4.

mammals, 19 species of reptiles, and 8 species of amphibians. Most severely affected by the destruction of agricultural land would be the pheasants totalling an estimated annual loss of 7,400. Listed as another adverse effect was the anticipated seepage from the Canal, especially during the early years of its operation. The Canal is designed as an unlined earthen channel, since lining it was deemed incompatible with aesthetic appearance, recreational activities, and the plans for fish and wildlife. The seepage would, to an extent that cannot yet be determined, affect the groundwater in the adjacent areas. Also, seven archeological sites would be sacrificed in order that adverse impacts on agricultural lands, property boundaries, wildlife areas, and waterways might be kept at the minimum extent possible. Because the Canal would cross several Delta sloughs and channels, some impairment seemed unavoidable; it would intersect some roads and thus cause extra travel distance and inconvenience to the property owners involved. Predicting what is commonly known as the "freeway effect," the authors of the Report pointed out the possibility of "accelerated and possibly haphazard" development of the land adjacent to the Canal.

In the Sacramento-San Joaquin Delta, Suisun Marsh, and San Francisco Bay Complex, the following were among the unavoidable adverse environmental effects:

Sacramento -- San Joaquin Delta Region

- Loss of anadromous fish at fish protective facility.
- Minor increased water elevations in the Mokelumne River floodplain east of the canal, due to floodflow backwater effects upstream from the Mokelumne River siphon.
- Possible attraction of some Sacramento River salmon to release sites in the southern Delta.
- Some loss of suspended sediment transport by settling out in canal.
- Time delay in navigation through boat locks in Old River and possibly the Delta Cross Channel.

Suisun Marsh

- Increased duration and extent of salinity intrusion with or without Peripheral Canal, with slightly greater increase with the canal.

San Francisco Bay Complex

- Some reduction in the flushing of pollutants from Suisun Bay and slight reduction in San Pablo Bay.

- Reduced Neomysis habitat in dry and critical years.

Seen as irreversible were the following environmental changes and commitments resulting from construction of the Peripheral Canal:

1. Changes in land use along canal alignment.

2. Channel relocations.

3. Distribution of water into intercepted sloughs.

4. Removal of archaelogical areas.

5. Expenditure of irretrievable capital funds, construction materials and labor.

Discussion of irreversible adverse impacts of the proposed Canal culminates in a paragraph which has crucial significance but which has so far been subjected to little serious comment:

> If ongoing studies reveal compelling reasons for discontinuing use of the canal for its intended purposes, <u>such a solution would be possible</u>. Under this condition, <u>only enough water would be diverted</u> at Hood to maintain circulation and to supply water to intersected sloughs. In time, the canal would become similar to existing sloughs. Land would be lost to agriculture, but not fish, wildlife and recreation use. It must be recognized, however, that <u>such</u> a decision would be very difficult to make in view of <u>the</u> \$286 million in irretrievable expenses it would represent.[15] (emphasis added)

The Environmental Impact Report on the Peripheral Canal was formally presented to the California Water Commission at its regular monthly meeting, on September 6, 1974. In making the presentation, Mr. Robin R. Reynolds, District Engineer for the Northern District, Department of Water Resources, pointed out the highlights, already extracted and available in a summary report.[16] He expressed the hope that the Canal would have the physical appearance of a new river, that it would look "natural," with wildlife planning built into it and beach access. Intended to "correct adverse conditions in the Delta and to transfer water," the Canal would, he averred, improve water management and have little adverse impact on the environment, "already altered by man," through private gun clubs and the like. Mr. Reynolds remarked that the environmental report was the culmination of some ten years of study, debate, and litigation and that it included inputs from groups sharply divergent in position vis-a-vis the construction of the proposed canal.

In answer to the query, "If everything should go right for you people, then when will construction begin?" Mr. John Teerink, Director of the Department of Water Resources, replied that after all the comments

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[15] <u>Environmental Impact Report</u>, <u>op</u>. <u>cit</u>., p. 40.

[16] State of California, The Resources Agency, Department of Water Resources, <u>Summary of Draft Environmental Impact Report Peripheral Canal Project</u>, August 1974.

are in (through a series of scheduled public hearings on the environmental report), then comes the schedule of design activity; the decision, he said, is to be made by the Director of Water Resources. Studies have been going on for a decade at a cost of millions of dollars; all kinds of information on biology and ecology have been gathered; an environment advisory committee has served a useful function; there have been court cases and decisions. Everything we have learned points to the Peripheral Canal as the best way to proceed, and it will stand up in Court, he stated.

Before turning our attention to the testimony presented at the public hearings, we should repeat that their main focus was supposed to be the reliability and adequacy of the environmental impact report. In other words, the series of hearings, in Oakland, Sacramento, Stockton, Bakersfield, Los Angeles, and Brentwood, were not, strictly speaking, on the Canal itself, although more often than not, debate was centered on it. Moreover, the tautology was evident throughout, those favoring the construction of the Canal approving the Report, which ultimately endorsed the Canal as the best possible way of achieving a certain set of objectives. These objectives, as well as the Peripheral Canal,as the means of attaining them, promise to become big issues in this, the most crucial step in the California Water Project.

Assessment of the environmental impact statement was polarized, as we observed earlier, toward the same positions, positive or negative, as were opinions on the Canal itself. Among the statements critical of the Report, the one presented by Senator John A. Nejedly was very explicit. He found the Report general and descriptive, not even as specific as were the deliberations in the 1920's. It contained nothing real with respect to the operations of the Canal, statements being so vague as "operating criteria for releases from the Canal will be flexible pending a determination of requirements..." He was concerned over the ill-defined statements of responsibility, for here he saw a potential gap, especially as between state and federal authority such as has prevailed in the problem of salinity control in the Shasta Dam area. Most serious, he considered, was the omission of careful review of alternatives to the Canal. There had been no study of conditions in the State to ascertain whether they were the same as when the California Water Plan was first concerned. He raised, in his remarks and in his printed submission, the important demographic point that patterns of population distribution and migration diverged greatly from the earlier projections and that under the prevailing situation, there is enough water for the people in Southern California. What they lack, he said, is air! He stressed in detail the unfavorable impacts on the economy and ecology of the Delta and the attendant adversities on the whole region affected and called on the State Water Resources Control Board to take a firm stand on maintaining the standards set forth in Decision 1379.[17] The Senator interpreted 1379 to say that the rights of all legal users of water in the Delta are superior to the rights of the export projects to store or divert water for use outside the Delta."[18] Senator Nejedly, in his capacity as chairman of the Natural Resources and Wildlife Committee of the State Legislature, has scheduled hearings for early December, 1974. One can reasonably anticipate that they will provide an opportunity for further discussion on the environmental impact report and the Canal it endorses.

Mr. Nejedly's position was endorsed by Mr. Daniel Boatwright, the Assemblyman from the District which would be most directly affected. He brought a number of petitions from his constituents, strongly opposed to the Canal and asking for consideration of alternative ways of providing water to the South, such, for example, as desalinization of sea water. His main criticism of the environmental impact statement was that it spoke in broad, general terms and not the specifics of water management. It made recommendations to go ahead with construction and assess damage later. And he cited the Owen Valley and the upper Colorado River as a horrible example of this mode of planning.

At the Stockton hearing, on October 7, 1974, the official opposition of the Board of Supervisors of San Joaquin County and the San

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[17] As will be recalled from our discussion under the heading of Water Quality, Decision 1379, July 28, 1971, declared that beneficial uses of water in the delta must be protected in the public interest without regard to whether or not the users of such water in the Delta have prior vested rights.

[18] Senator John A. Nejedly, "Comments on Draft Environmental Impact Report Peripheral Canal Project," October 3, 1974, p. 17.

Joaquin County Flood Control and Water Conservation District was voiced by Dan S. Parises, Chairman of the Board of Supervisors. He reiterated the September, 1969 statement issued by his organizations in opposition to construction of the Peripheral Canal "until such time as firm guarantees and assurances satisfactory to San Joaquin County are given by the United States and the State of California to the effect that an adequate and dependable supply of water of suitable quality will be maintained at all times in the Delta by the State and Federal Governments."[19] His primary concern was that there could be a level of water quality poorer than is required under the terms of Decision 1379 because of a lack of firm statements regarding operation of the Canal. "In the absence of such firm statements, there is no possible way of assessing the impact of the Canal on the Delta and its environment. We note this grave weakness in the Draft because the Canal, once constructed, will enable the Department to make adverse changes in the environment and the economy of the Delta, thus leaving the citizens and public agencies of the county with only the remedy of complex and expensive litigations to protect themselves."[20]

Mr. Parises raised a number of searching questions about the much-touted recreational and wildlife areas that the Peripheral Canal was supposed to provide. Emphasizing that the Board of Supervisors of San Joaquin County had no intention of assuming the heavy financial burden of operating, maintaining, and patrolling these State planned and constructed recreational facilities, he pointed out the potentially adverse environmental impact if recreational and wildlife areas were acquired but then left undeveloped. Moreover, he found no provision for separating these areas from adjacent farmland and urban areas and mentioned the ravages of uncontrolled trespassing. Among other items, loss of prime agricultural land from tax rolls was of great concern, and Mr. Parises considered that the financial burden should be borne by the State and not the County.

The viewpoint of the business community in the Delta was expressed by Mr. Andronico, a Bethel Island marina owner. Saltwater intrusion and ecological damage were among his basic concerns. He questioned the wisdom of providing southern California with more water, and, hence,

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[19] Dan S. Parises, "Statement before the Department of Water Resources on the Draft Environmental Impact Report Peripheral Canal Project," Stockton, California, October 7, 1974.

[20] <u>Ibid.</u>, pp. 4-5.

more people when they already have a surfeit. "Our Delta will suffer; we'll lose fresh water and have nothing but salt. We need fresh water in the Delta for our recreation business -- the life of our community." As to the environmental report's promise of recreation areas as "benefits," Mr. Andronico took strong exception. The State should not compete with private enterprise; attracting more people into the Delta for water sports, fishing, and hunting would cause deterioration of present facilities.

The President of the Bethel Island Chamber of Commerce, Mr. Boyles Gilmore, himself a harbor owner, corroborated this position. He criticized the environmental impact report for being based on the a priori assumption that the Delta had to supply the water contracted; he questioned the unspoken premise that the Department of Water Resources would and should proceed even though the State Water Project would be diverting about 50% inflow into the Canal and about 90% of the Sacramento River by the time it is operational. The plan to do this was made in an era of growth, he said. Now we are in a different socio-economic environment with different views about resource management, different values, and different attitudes toward the benefits and costs of public works.

Flood control was the primary concern of Mr. Walter M. Gleason, speaking in his capacity as President and Trustee of Union Island Reclamation District No. 1. Stating that the Middle River Plan offered by the Department of Water Resources would leave the upstream side of the Peripheral Canal open, so that the water could be lifted up and over by gantry down to the San Joaquin River, he then asked, "But how about floods?" He said, "We've protected our lands from floods through sweat and blood, but there is no concern shown here in the environment impact report." Elementary hydraulics have been ignored; the huge additional flow of water will undermine the levee system and undo work that began in the 1870's, when reclamation of land through building of levees was first begun.

In his role as legal counsel for the Contra Costa Water Agency, and various Delta land-owners and water-right owners, Mr. Gleason had, on a previous occasion[21] made a number of cogent points. Challenging as specious the justification for the Canal as something needed to protect and enhance the ecological and environmental resources of the Bay-Delta Estuarine System, Mr. Gleason said that any

[21] Walter M. Gleason, "The Real Reason for the Promotion of the Peripheral Canal by the California Department of Water Resources and the U.S. Bureau of Reclamation; and Various Vital Legal Problems Created Thereby," Presentation at Commonwealth Club of California -- Section on Water, San Francisco, California, July 26, 1973.

current problems there were directly attributable to the export pumping now going on at the Tracy Pumping Plants and that if the Canal were to become a reality it would irreparably injure the Delta and the rest of the Bay Delta Estuary. "Among other disastrous results, Peripheral would not only cause severe impairment and destruction of many of the priceless ecological and environmental resources in the Bay-Delta Estuarine System but it would also cause great and irreparable injury to the multitude of long-standing riparian and other vested water rights, which are the indispensable foundation of both the economy and ecology of this vast and rich region. Furthermore, Peripheral would enmesh these invaluable water resources and water-rights in grave legal problems."[22] (His italics)

Listed among these were, first, the "defiant" position of the U.S. Government with respect to jurisdiction, such that the federal government claims not to be obligated to comply with the terms set forward in Decision 1379. If the Canal were built without the jurisdictional dispute settled, the Delta could be ruined. The second item was one Mr. Gleason called a "time bomb."[23] This has to do with the federal government's right of seizure, with the only recourse a lawsuit against the U.S. government in the U.S. Court of Claims, Washington, D.C. If the Peripheral Canal becomes a reality with the U.S. Bureau of Reclamation a joint or sole operator, "Seizure" could be accomplished by simply diminishing or stopping water releases from the Canal. The Delta would be in particular danger during future, inevitable, dry cycles. The "hydraulic squeeze" would affect the water right owners in the Delta because of its locations "at the end of the ditch."[24]

The third problem was one that Mr. Gleason felt had to be fully settled by final adjudication before any further move toward construction of the Canal occurs. It deals with the legal obligation of

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22 Ibid., p. 4

23 Ibid., p. 20

24 Ibid., p. 25.

the Federal Central Valley Project and the State Water Project to provide adequate salinity control in and for the Bay Delta Estuary. There has been much litigation over this matter and it is still in the courts. Mr. Gleason insists that until it is settled, the Canal should not be constructed, for "whoever controls Peripheral controls the spigot."[26]

As his fourth point, Mr. Gleason questioned the legality of applying "Excess Land Provisions" of Federal reclamation Law to the agricultural lands along the Bay-Delta Estuarine System.

Of particular interest to us in our continuing study of the institutional interrelationships in the decision-making processes vis-a-vis the management of water was the position of the State Water Resources Control Board on the environmental impact report. This was presented at the October 10, 1974 hearing in Sacramento by Mr. Bill B. Dendy, the Board's executive officer. "The Board's responsibility for determining the public interest requires balanced protection of natural or long-established beneficial water use, as well as consideration of the need for development of the water resources in the State," was his opening remark.[27] He emphasized the need for an accurate and complete environmental impact report on the Peripheral Canal because of the centrality of the Delta's position in key water right decisions. "One of the longest hearings in Board history occurred in 1969 and 1970 concerning reserved jurisdiction in permits and pending applications for diversion from the Delta. Those hearings resulted in Decision 1379,[28] dated July 28, 1971, which established the State Delta Standards for the protection of all Delta uses. Those standards must be maintained."[29]

Addressing the Environmental Impact Report, Mr. Dendy first discussed its Chapter VII, in which safeguards for Delta protection had been mentioned but which had failed to set forth any clear statement of the Department of Water Resources' ability to meet the requirements of such institutional constraints as the Delta Protection Act, the Area of Oregon Law, and Decision 1379. He raised searching questions about some of the Report's assumptions regarding

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[26] Ibid., p. 32.

[27] Bill B. Dendy, "State Water Resources Control Board Comments on the Draft Environmental Impact Report for the Peripheral Canal," presentation at Hearing, Sacramento, Calif., October 10, 1974, p.1.

[28] The Delta Water Rights Decision 1379 in the matter of Application 5625 and 38 Other Applications of United States Bureau of Reclamation and California Department of Water Resources to appropriate from the Sacramento-San Joaquin Delta Water Supply; State Water Resources Control Board, July, 1971.

[29] B. Dendy, op. cit., p. 2.

the operating criteria for the Canal, since they were different from those in D1379. Moreover, he pointed out, the Canal is projected as though operating with other facilities which may or may not be built. Among the specific matters he picked were several that had not received much attention from other speakers and which promised to be crucial: (1) classification of dry and critical years, and (2) relaxation of D1379 criteria.

(1) Classification of Dry and Critical Years

The method for classifying water years has been changed in the EIR from the method used in D1379. The results in the operation study cause a significant change in the number of years when it is assumed the provisions of D1379 can be relaxed. Using D1379 criteria, 24 percent of years would be dry or critical as compared to 32 percent with the method used in the EIR. Since the present method is defined in D1379, it will be necessary for any new method to be approved by the Board following further hearing before it can be implemented as criterion for operation of the project.

(2) Relaxation of D1379 Criteria

The EIR assumes that the State Board will relax the standards for the Delta for dry and critical years contained in D1379, in a manner which will result in less stored water being released for protection of water quality. The assumption is that the criteria for striped bass spawning and Neomysis will be relaxed to the agricultural standard. While the State Board has indicated that relaxation in dry and critical years is probable, both the nature and degree of relaxation chosen by the EIR is an assumption.[30]

One cannot at this time make any summary or conclusion about the Peripheral Canal. Our report covers only some of the hearings and presents in selective fashion only part of the testimony. We have tried to ascertain the most important issues, but typescript from the tapes of all the hearings is being prepared for a government agency and will be made available to us before long. From these volumes, still to be perused, there may emerge other pressing issues. In addition, legislative hearings will certainly bring forward competent testimony on both sides of the question, for a number of organizations are preparing detailed analyses of the Environmental Report as well as position papers about the Peripheral Canal. For the immediate future, we shall, consistent with the guidelines set forth for us by Dr. Castruccio, continue to follow the process by which these vital decisions regarding California water are being made. Our study will take us into the institutional and

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[31] B. Dendy, op. cit., pp. 7-8.

jurisdictional involvement of Federal agencies with state agencies as well as relationships among the state agencies themselves. We will observe the legislative processes as they tackle these complex and long-lasting decisions. And we will continue our consideration of the social, economic, and political environment that impinges on and is influenced by these decisions, all in relation to the potential usefulness of remote sensing.

5.40 LONG-RANGE SOCIAL CONSIDERATIONS

As can readily be seen from the content of the foregoing pages, there exists an intimate and meaningful nexus among the engineering, hydrological, economic, political, ecological, and sociological aspects of water management. The same can be said for the prospects of water management. For this reason, the appropriateness of a many-dimensioned assessment of the full range of identifiable benefits and costs of any course of action becomes clear. It is no longer appropriate, as might have been in the earlier days of using cost-benefit analysis, to take into consideration only one category, as for example, the economic[32] And while there may be divergencies of views about policy among agencies and conflicts of interest among concerned citizens, to say nothing of jurisdictional disputes among levels of government, there is consensus that, as far as water resource management is concerned, the factors that must be taken into account are numerous, complex, and varied. Configurations of water demand are changing; the patterns of the past are no longer reliable. Given the new spatial concentrations of people, the stresses on the hydrological environment are different from what they were in the past. With the present generation's awareness of environmental protection, "public works" no longer enjoy the aura of benevolence that they engendered in a Depression-scarred social environment. (It has been suggested that the TVA at some other time would not have been built.) Mr. John R. Teerink, Director of the Department of Water Resources, in presenting The California Water Plan--Outlook in 1974,[33] acknowledged the importance of the rapidly changing social environment when he explained that it had been deemed necessary to develop not one set of predictions but a range of forecasts "because we believe that California tomorrow will be challenged by increasingly complex issues that will affect the quality of life".[34] Elsewhere, he had remarked that with completion of the projected Peripheral Canal, the era of big construction would end, that public attitudes showed growing opposition to big dams and other environment-altering modes of water management.

As a case in point, he could cite the then-current controversy over the New Melones Dam on the Stanislaus River. In the November, 1974 election, an initiative on the ballot gave citizens the opportunity to express their opinion as to whether the benefits outweighed the costs. In the cost/benefit analysis prepared by the Army Corps of Engineers, the benefits were seen to include flood control, power generation, irrigation, recreation and water quality control, with the jobs for

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[32] Roland N. McKean, Efficiency in Government through Systems Analysis, with Emphasis on Water Resources Development, New York, John Wiley & Sons, Inc., 1958.

[33] State of California, The Resources Agency, Department of Water Resources, Bulletin No. 160-74, presented to California Water Commission on November 1, 1974 in Sacramento.

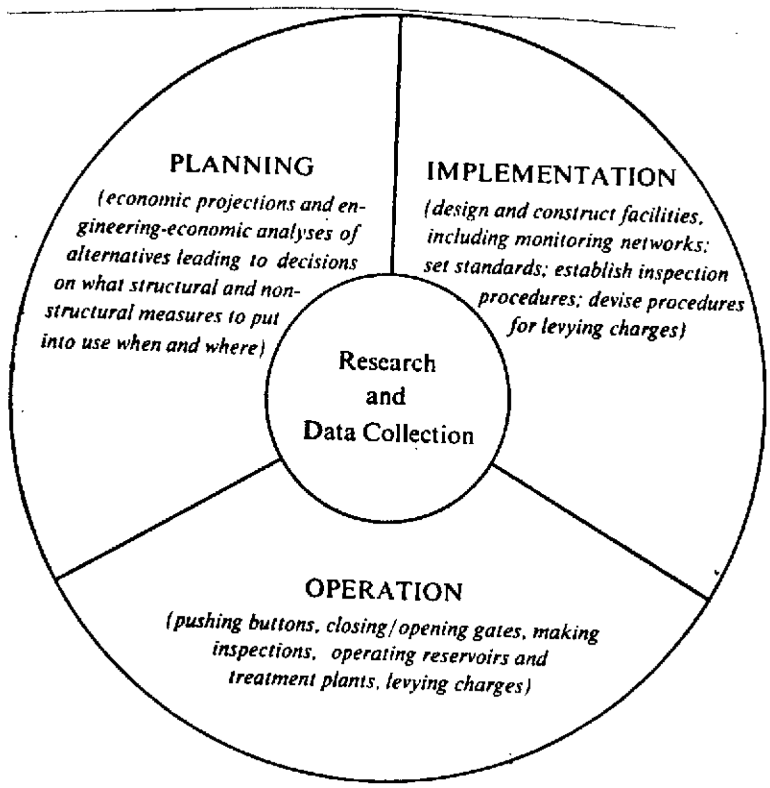
[34] John R. Teerink, "Report of Activities of the Department of Water Resources", California Water Commission, November 1, 1974, p. 4.

***The initiative lost, which meant that opposition was not strong enough to block the proposed construction.**

on-site workers mentioned for good measure. These benefits, as seen by a Berkeley professor,[35] were overestimated, and costs underestimated. While some voters regarded flood control as beneficial, since in 1969 there had been some $10 million worth of flood damage along the river, they questioned the need for a $280 million dam; their contention was that a dam one-fifth of that size would provide protection and not sacrifice a nine-mile stretch of white water as well as historic sites. The Army Corps countered by arguing that the smaller structure was less feasible economically since it could not offer the additional benefits of power generation, irrigation, and so on. The interesting observation can be made that both sides used "objective analysis" as the way to justify their particular point of view. What this seems to illustrate is the old adage, "Verité ci-dessus des Alpes, mensonge delà!"[36]

If we examine the accompanying diagram, Figure 4. Water Quality Management, we cannot fail to see how far, indeed, we have advanced into what Mr. Teérink referred to as "the decade of the environment," where secondary effects must be assessed, alternatives investigated, and implications considered. "Planning" is no longer only a basic engineering task, nor even a tandem relationship between engineering and economics. "Implementation" does not occur in a social vacuum;

FIGURE 4. WATER QUALITY MANAGEMENT*



35 Richard Norgaard, Agricultural Economics, U.C. Berkeley, as quoted in The Daily Californian, October 23, 1974.

36 "Truth on this side of the Alps, falsehood on the other."

*Source: Allen V. Kneese and Blair T. Bower, Managing Water Quality: Economics, Technology, Institutions, Baltimore, The Johns Hopkins Press, for the Resources for the Future, Inc., 1968, p. 7.

"Research and Data Collection" cannot be compartmentalized and set off as a self-contained entity apart from these processes and from "Operation." As stated in The California Water Plan Outlook in 1974:

> "Planning for Water development is a critical element in environmental protection because of the direct effect of water projects on the ecosystem. A proposed water project can no longer be evaluated solely on the basis of a cost and benefit analysis but, instead, must include consideraiton and evaluation of its effects on the environment." [37]

For this reason, as we move into the second half of our fiscal year (to May 1975), we will continue our research on the complicated decision-making processes devolving on the Peripheral Canal. Ahead of us are legislative hearings and legal proceedings; the role and responsibilities of federal agencies will, as suggested by Dr. Castruccio*in his earlier guidelines, be studied. We intend also to carry further the cost-effectiveness studies which began with snow survey inventorying. Aware of the fundamental inadequacies of current applications, we are trying to develop a more balanced perspective. (In this connection, it might be mentioned that our FY 1975 plans call for expansion of this activity and cooperative linkage with the Santa Barbara group. It is anticipated that we will work out an arrangement whereby Dr. Christopher Clayton, an economic geographer from that campus, will be associated with the Social Sciences Group on a part-time basis in specific projects.)

We will also address the long-range social considerations as viewed by the Department of Water Resources and presented in their publication, The California Water Plan, Outlook in 1974.[38] We will concentrate on the four scenarios, compare them with other projections which use a different data base or embody different assumptions, and will focus on key policy issues which have direct bearing on California Water resources. It may be stated again that many facets of our present and future research link directly into other portions of the Integrated Remote Sensing Project, for, essentially, we are all engaged in investigating the ways in which satellite-derived and other technologically advanced imagery can be utilized in the management of natural resources. The function of the Social Sciences Group is to ascertain the ways in which the data can enter into the decision-making processes, their costs and effectiveness, and their potential impact and implications.

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[37] The California Water Plan, Outlook in 1974, op. cit., p. 11

[38] Op. cit.,

With the California Water Project our primary, but not exclusive, focus, we try to develop insights into the very complicated web of factors impinging on the management of resources in order to learn how new sources of information can be accomodated, by whom, and for what purpose. It is patently clear that these decisions do not take place in a technological, economic, political, and social vacuum; decisions regarding resources take place in a real-life, rapidly changing environment. Our task is, therefore, to "map the social landscape," the better to learn where, how, and to what effect new sources of information can prove their mettle. For example, in the decisions regarding the Peripheral Canal and the Delta, the question of environmental impacts is crucial. Similarly, with respect to off-shore drilling for oil and siting of nuclear plants, effects on the natural resources of the region are of vital interest. Continuous monitoring supplied by satellite and other remote sensing technologies may well become a valuable input into management decisions on these matters.

Recognition of the multiplicity of factors bearing on water resource management becomes clear when we review the Department of Water Resource's conception of the future. The Department actually abandoned its long-standing practice of using past experience as a base for making one set of predictions and, instead, developed four different scenarios. Reasons given for this departure from tradition were rapid social changes -- in attitude, values, and outlook, with uncertainty the prevailing mood in the public and private sector. Five factors were mentioned as contributing to this uncertainty:

(1) the recent downward trend in birth rates,

(2) the opening of the Chinese and Russian agricultural markets,

(3) new, stricter air and water quality standards,

(4) future land use policies, and

(5) the impact of recent environmental preservation and enhancement trends.[39]

Population trends are shown in the following Table:* Table 10 (California and U.S. Population and Percent Increase by Decades).

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[39] Outlook, Ibid., p. 31.

* Source: The California Water Plan Outlook in 1974, op. cit., p. 31.

TABLE 10

California and U.S. Population and Percent Increase by Decades, 1920–1974 *

Year	Decade	California population: Millions	California population: Percent increase	U.S. population: Millions	U.S. population: Percent increase
1920	--	3.4	--	107	--
	1920–30	--	68	--	16
1930	--	5.7	--	123	--
	1930–40	--	21	--	8
1940	--	6.9	--	132	--
	1940–50	--	54	--	15
1950	--	10.6	--	152	--
	1950–60	--	50	--	19
1960	--	15.9	--	180	--
	1960–70	--	26	--	14
1970	--	20.0	--	205	--
1972	--	20.5	--	209	--
1974	--	20.9	--	212	--

It will be noted California's rate of growth has been greater than that of the U.S. as a whole but that it shows a slackening. California, like the rest of the nation, has experienced a declining birthrate. Immigration peaked in 1963, dropped in the late 1960's, and then showed an upturn in 1973. The following tables give us the projected population figures, the letters C, D, and E being used by the U.S. Bureau of the Census** and the State Department of Finance to designate population series based on fertility rates, i.e. the average number of children born per woman of child-bearing age.

TABLE 10a

Population Factors*

Alternative projection	Population series	Fertility rate	Net migration
I	C	2.8	150,000
II	D	2.5	150,000
III	D	2.5	100,000
IV	E	2.1	0

Projected California Population*
(in millions)

Alternative projections	1980	1990	2000	2010	2020
I (C-150)	23.0	27.4	31.9	37.2	43.3
II (D-150)	22.8	26.7	30.5	34.6	39.1
III (D-100)	22.7	26.1	29.3	32.8	36.6
IV (E-0)	21.9	23.6	24.7	25.7	26.5

*Source: Ibid., p. 32.

**The letter "C" assumes 2.8 children per childbearing mother; "D" assumes 2.5 children; and "E" assumes 2.1 children per childbearing mother.

Table 10b

Population in California—1972, 1990 and 2020 *
(in thousands)

Hydrologic study area	1972	Alternative future projection: I (Series C-150) 1990	2020	II (Series D-150) 1990	2020	III (Series D-100) 1990	2020	IV (Series E-0) 1990	2020
North Coastal	180	250	390	240	350	230	310	210	230
San Francisco Bay	4,630	5,940	8,670	5,800	7,920	5,680	7,350	5,270	5,700
Central Coastal	840	1,370	2,430	1,340	2,200	1,290	2,030	1,130	1,370
South Coastal	11,240	14,620	22,510	14,260	20,300	13,930	19,140	12,510	13,790
Sacramento Basin	1,210	1,700	2,600	1,670	2,400	1,630	2,230	1,470	1,620
Delta Central Sierra	470	760	1,730	730	1,550	710	1,420	640	930
San Joaquin Basin	440	650	1,140	640	1,010	620	940	560	660
Tulare Basin	980	1,280	2,030	1,250	1,820	1,240	1,730	1,160	1,360
North Lahontan	40	70	110	70	100	70	90	60	60
South Lahontan	240	410	1,040	370	870	370	820	290	380
Colorado Desert	230	350	650	330	580	330	540	300	400
Totals	20,500	27,400	43,300	26,700	39,100	26,100	36,600	23,600	26,500

With production of food and fiber the single most important enterprise affecting use of California's land and water resources, (irrigated agriculture utilizes 85 percent of the water at present), the logic of according agriculture a central role is clear. Alternative levels of future production were premised on these five factors:

-- National population.

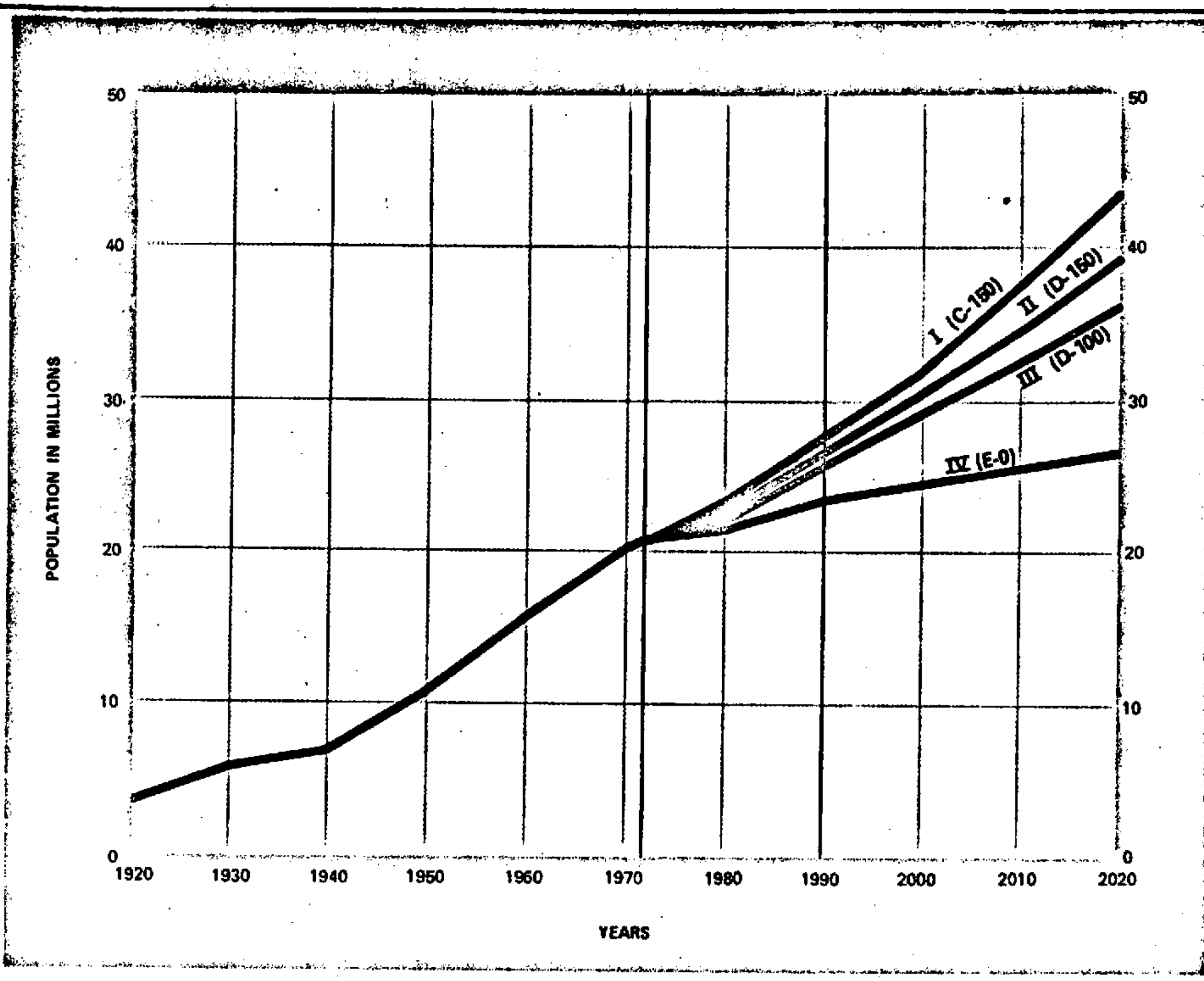
-- Per capita consumption of food.

-- Foreign trade.

-- California's share of national production.

--Per acre yields of California crops.

* Source: Ibid. p. 34.



California Historical and Projected Population Growth**

FIGURE 5

**Source; <u>Ibid.</u> p. 3 2

Figure 5 . (California Historical and Projected Population Growth) shows the historic growth of population in California from 1920 through 1973, with the four alternative projections for the future.

Then, as is seen in Table 11 (Alternative Future Levels for California Agriculture), projections were made on the basis of four different assumptions, with irrigated land areas estimated similarly (Fig. 6 Historic and Projected Irrigated Land Area).

TABLE 11*

Alternative Future Levels for California Agriculture*

Alternative	National population		Net foreign trade		Crop yields		Irrigated crop acreage required (1,000s of acres)	
	Series D	Series E	High	Low	1968	Modified	1990	2020
I	X		X			X	10,600	12,100
II	X			X		X	10,200	11,200
III	X			X	X		9,700	10,300
IV		X		X		X	9,500	9,800

Among the key policy issues about which projections had to be made were those associated with electric energy production. The issue has become pressing because coast siting of power plants has been restricted and construction at inland locations requires fresh cooling water in considerable quantity.

The following are the factors which form the base for assumptions about (1) increase and (2) decrease in consumption of electricity.

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* Source: <u>Ibid.</u>, p. 33.

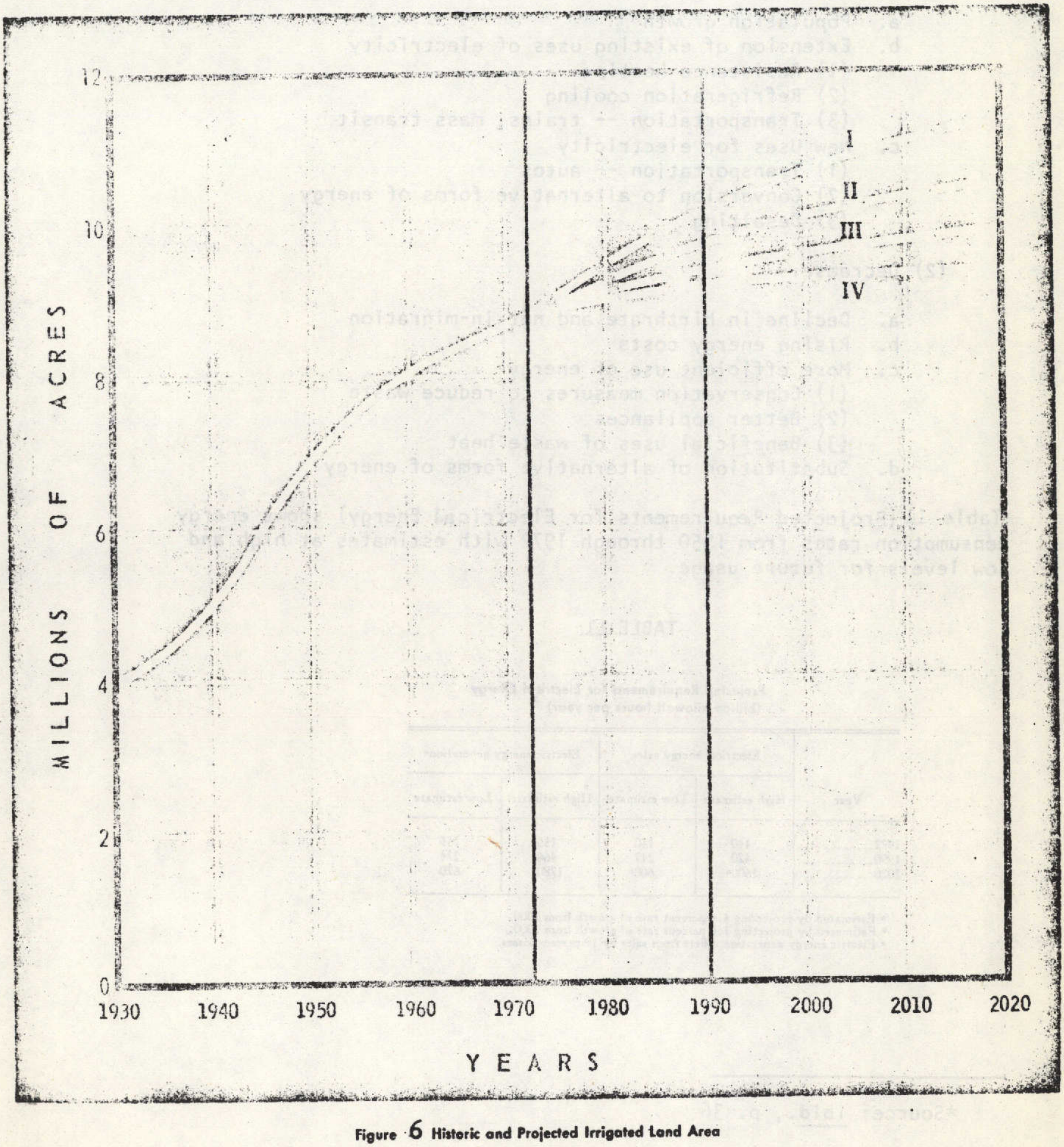

Figure 6 Historic and Projected Irrigated Land Area

Source: Ibid., p. 35.

(1) Increase:

a. Population growth
b. Extension of existing uses of electricity
   (1) Resistance heating
   (2) Refrigeration cooling
   (3) Transportation -- trains, mass transit
c. New Uses for electricity
   (1) Transportation -- autos
   (2) Conversion to alternative forms of energy
   (3) Desalting

(2) Decrease:

a. Decline in birthrate and net in-migration
b. Rising energy costs
c. More efficient use of energy
   (1) Conservation measures to reduce waste
   (2) Better appliances
   (3) Beneficial uses of waste heat
d. Substitution of alternative forms of energy

Table 11 (Projected Requirements for Electrical Energy) shows energy consumption rates from 1950 through 1972 with estimates at high and low levels for future usage.

TABLE 11

Projected Requirements for Electrical Energy (billion kilowatt hours per year) *

Year	Electrical energy sales		Electric energy generation[c]	
	High estimate	Low estimate	High estimate	Low estimate
1972	140	140	155	155
1990	420	247	466	274
2020	1600[a]	600[b]	1780	670

[a] Estimated by projecting 4.4 percent rate of growth from 2000.
[b] Estimated by projecting 3.0 percent rate of growth from 2000.
[c] Electric energy generation differs from sales by 10 percent losses.

*Source: Ibid., p. 36

The four scenarios, embracing alternative futures, represent a first, and important, step in the "new look" in public resource management. We are in the process of analyzing the assumptions and comparing them with the work sponsored by the State Water Resources Control Board.[40] In our many contacts and interviews with responsible officials, we are finding that public works is taking on a new meaning, at every level of government. In Congress, the House Public Works Committee is seeking ways to broaden its vista. Divesting itself of the traditional "pork barrel" image, the Committee is examining the role of public works in population distribution and region development. Its advisory panel is divided into four task groups: (i) population distribution, applying the ecological concept of "carrying capacity" to metropolitan and regional development; (ii) the potential for planning and service delivery within state, substate, and regional governing units; (iii) the role of transportation in population distribution and regional economic development; and (iv) values, assumptions, and implications of alternative federal public works policies.

California legislative bodies are, in like fashion, broadening their vistas to include the wider dimensions of public policy vis-a-vis resource management and planning. As evidence of this, the University of California in its capacity as the "research arm" of the state is developing strong liaison, in which professional people are serving in a resource capacity on important issues. In advance of hearings on the future, Mr. Charles Warren, Chairman of the Assembly Committee on Energy and Diminishing Materials, has asked members of the Social Sciences Group to meet with him and members of several other committees for a discussion session that will alert them to questions that might properly be addressed during these and forthcoming hearings. It is altogether likely that as the relationships with various committees develop, there will be participation with several of other groups in the Integrated Project. Now that data from Skylab, Earth Resources Technology Satellite, and U-2 aircraft have been accepted as evidence in court cases,[41] we can anticipate a useful role in many of the issues as vital to the management of water resources in not only California but the country as a whole.

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40 Bay Valley Consultants, Recommended Water Quality Management Plan, July, 1974.

41 "Space Data Help in Swamp Dispute," The New York Times, August 17, 1974.

CHAPTER 6

A COMPARATIVE COST-EFFECTIVENESS ANALYSIS OF EXISTING AND ERTS-AIDED SNOW WATER CONTENT SYSTEMS

Preliminary Report

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CHAPTER 6

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A COMPARATIVE COST-EFFECTIVENESS ANALYSIS OF EXISTING AND ERTS-AIDED SNOW WATER CONTENT ESTIMATION SYSTEMS

6.100 INTRODUCTION

Problems in managing natural resources often reduce to problems in allocating scarce time and money resources. Technological innovations like ERTS, by dramatically reducing the costs of gathering information, promise to beneficially alter existing time, cost, and capability relationships in many resource management areas. But the path from promise to realization can be a long one, requiring among other things the development of an adequate analytical framework for comparing new and established technologies.

This chapter describes and applies a methodology for comparing different information-gathering technologies. Although the focus here is on a particular resource (water) in a particular context (snow mapping and runoff prediction) over a particular region (the Feather River Watershed of Northern California), the approach can be generalized to cover other natural resource data acquisition situations. It is shown below, moreover, that the theory behind the methodology is far less novel than its application to a resources information problem.

The overriding objective for the work described in this section was stated in our May 1974 annual progress report: "To determine if remote sensing can be cost-effectively integrated with data presently used in the California Cooperative Snow Surveys (volumetric) model to produce potentially more precise and accurate estimates of water supply." (Emphasis added).

Although at this stage we can draw only tentative and partial conclusions concerning the foregoing objective, the potential of remote sensing for aiding in the snow water estimation process appears to be very great indeed. So far our attention has been focused mainly on the cost and performance parameters involved in the existing method of water supply estimation. Preliminary cost and accuracy estimates on roughly equivalent remotely-sensed data have also been calculated. Both sets of estimates will need additional refinement before our initial comparative estimates can be verified. In addition, more work is necessary to determine how remotely-sensed information can best be integrated with existing water yield models on a test basis.

Progress to date is summarized here in a format that blends economic and statistical theory with an operational situation. An initial section briefly describes cost-effectiveness analysis and how it can be used. A following five-part section documents various aspects of the hydrologic modeling methodology now carried on by the Snow Surveys and Water Supply Forecasting Branch of the California Department of Water Resources: their production process, their budget, and the extent, cost and accuracy of their snow surveys. A third section demonstrates the cost-effectiveness methodology by comparing the sample designs and performance of the existing and ERTS-aided snow water content measurement approaches. A final section summarizes the research and discusses conclusions and recommendations for future work.

6.200 COST-EFFECTIVENESS ANALYSIS

Cost-effectiveness analysis is one of several techniques that attempt to apply economic rationality to public investment decision making. Benefit-cost analysis is its closest theoretical relative, although techniques used in systems analysis, operations analysis, planning, programming and budgeting systems (PPBS), and others bear strong resemblance to the cost-effectiveness approach. These techniques all share a common purpose: i.e., to make systematic and quantitative comparisons between alternative resource allocation options, using a logical sequence of steps that can be verified by others.

Traditional resource allocation processes have been a mixture of political, administrative, and professional judgment. Their purpose is typically to find a pattern of production which is most efficient, or lowest cost for a set of desired outputs. Without a price mechanism to allocate output, some other procedure is necessary.

Historically, the new resource allocation techniques developed following World War II as public expenditures grew and oligopolies proliferated in the private sector. The lack of classical market forces in the public sector generated the need for developing alternative approaches to use in guiding government investment decisions. Benefit-cost analysis helped fill that need by supplying an investment project appraisal method closely analogous to that used by businessmen. The major difference is that estimates of social value are used in place of sales value (or profitability) estimates. Benefit-cost analysis techniques were applied first to physical investments like military procurements and water resources projects. By the 1960's these techniques had been refined and extended to human investments such as manpower training and outdoor recreation. More recently, the techniques have found application in government research and development programs and information services like ERTS.

The choice of appraisal methodology depends upon the nature of the investment and the information available. Both benefit-cost and cost-effectiveness analysis contain their own variants, advantages, and limitations. In benefit-cost analysis, every effort is made to quantify in commensurable monetary terms both the benefits and costs stemming from alternative actions. Physical outputs are projected, social values (positive and negative) are estimated for these outputs, and benefits and costs are compared over time, either on a gross annual basis or on a net benefit basis discounted to the present. A complete analysis includes not just immediate benefits and costs to the agency and its clients, but also the spillover benefits and costs to others not directly related to the action in question. The result is a ratio of benefits to costs for each alternative action considered.

Cost-effectiveness analysis, in contrast, allows the use of multiple, non-commensurable measures on the benefit side. Economic benefits are stated in terms of cost savings. The method is specifically directed toward problems in which outputs cannot be evaluated in market prices, but where inputs can, and where the inputs are substitutable at market-developed exchange relationships. Cost-effectiveness analysis thus helps a decision-maker answer questions about how to achieve a given set of objectives at the least cost, or how to obtain the most effectiveness from a given set of resources.

Some kind of cost-effectiveness analysis is involved in any decision concerning resource allocation. In the usual case, a decision-maker relates the costs of alternative scarce resources (inputs) to specified performance standards (outputs) desired from a production process. The decision-maker may be looking for the least expensive way to meet the specifications or for a means of adjusting the specifications to fit a fixed budget. In either case, the decision-maker seeks to establish cost-capability relationships for various combinations of resource alternatives.

Several variants of cost-effectiveness analysis may be distinguished. One type, known in defense circles as a "system configuration study," emphasizes the selection of a particular configuration of system characteristics which will achieve various performance levels at a minimum cost or, conversely, the identification of achievable characteristics which will maximize performance within various funding levels. Such an analysis might be useful, for example, in selecting between various range, speed, and weight characteristics of aircraft with different costs and payloads.

A second type of cost-effectiveness analysis, known as a "force structure study," relates costs and effectiveness of alternative packages of options over time. Also extensively used by military planners, this variety of analysis helps identify the optimum force mix of a phased program like a weapons system through a planning and budgeting period of several years.

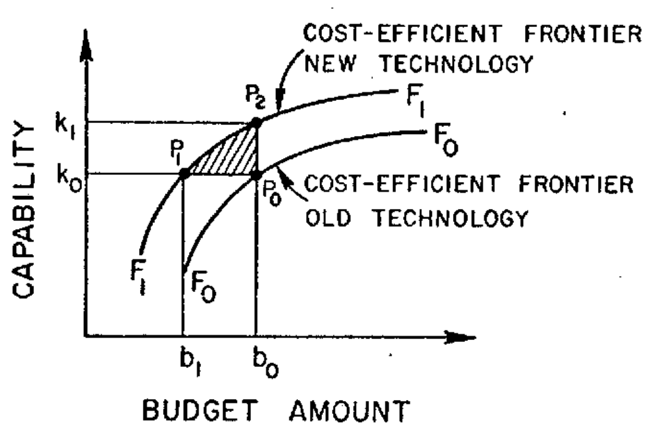
A third type of analysis, called a "system comparison study," emphasizes the comparison of two or more systems for the same mission. Here the focus is on intersystem analysis, rather than the intrasystem approach used in system configuration studies. It is presumed that competing systems already have been optimized as to their internal configurations. It is also presumed that these systems satisfy approximately the same organizational objectives. By examining side-by-side the cost-capability relationships of the competing systems, a decision-maker can assess the marginal improvement promised by alternative systems either in cost savings at various effectiveness levels or in maximum effectiveness at given budget levels. When compared with the other two types of cost-effectiveness studies, the system comparison approach has two distinct advantages:

(1) costs are generally required in less detail, and

(2) the spread of costs over time is usually deemphasized or ignored.

The system comparison type of cost-effectiveness analysis is well-suited for identifying the potential contribution of new technologies to the cost-capability relationships of existing systems. Figure 6.1 illustrates the effect of technological progress on the cost-capability "frontier" of an existing production system. The frontier F_0F_0 shows the maximum capability that can be expected from the present system at a given level of budget. A system producing on the frontier is defined as "cost-effective" because a decrease in cost is not possible without a decrease in capability. A technological advance would beneficially alter this relationship: the cost-efficient frontier would be pushed out to some new set of points F_1F_1. A point P_0 on the old frontier F_0F_0 would now represent an inefficient pattern of production. A set of points in the shaded area of Figure 6.1 would represent an improved

FIGURE 6.1 - EFFECT OF A TECHNOLOGICAL ADVANCE ON A COST-CAPABILITY PRODUCTION FRONTIER



return, with cost-efficient points now lying on F_1F_1 between P_1 and P_2. The effect of technological progress thus ranges between equivalent capability at a lower budget (P_1) and greater capability within the same budgetary constraints (P_2). This model is used later in assessing the effect that ERTS imagery could have on current snow water content estimation procedures in California.

Anyone applying the foregoing investment appraisal techniques should be aware of their potential limitations. Many limitations are related to problems inherent in measurement. Time and money costs ordinarily curtail the extent of measurements that can be undertaken. In addition, certain considerations may be too intangible or subject to too much uncertainty to be measured accurately. Costs may or may not be amenable to precise measurement, while measures of effectiveness are necessarily approximations of a system's ability to achieve certain objectives. Other limitations are related to problems of choice. Human judgment and subjectivity permeate most analyses. Advocates of a particular "party line" regarding a project can often bias the analysis in their favor with a judicious selection of assumptions and relevant factors. A final caveat is that the analytical techniques by themselves are insufficient for informed decision making. Benefit-cost analysis rarely helps with distributional or broad value questions, and cost-effectiveness analysis offers little assistance in guiding the selection of appropriate system-wide objectives.

Most of the shortcomings inherent in public investment appraisal techniques can be reduced by employing a careful research design. Measurement, choice, and insufficiency limitations can all be minimized by placing a problem in its proper context. In the case of a public agency, this usually involves examining and documenting relevant aspects of the organization's structure and performance. Such research can aid in narrowing uncertainty boundaries, in formulating explicit assumptions, and in clarifying organizational objectives. A well-documented qualitative analysis can greatly enhance the reliability and verifiability of a quantitative comparison between investment alternatives.

6.300 CURRENT SNOW SURVEY ACTIVITIES

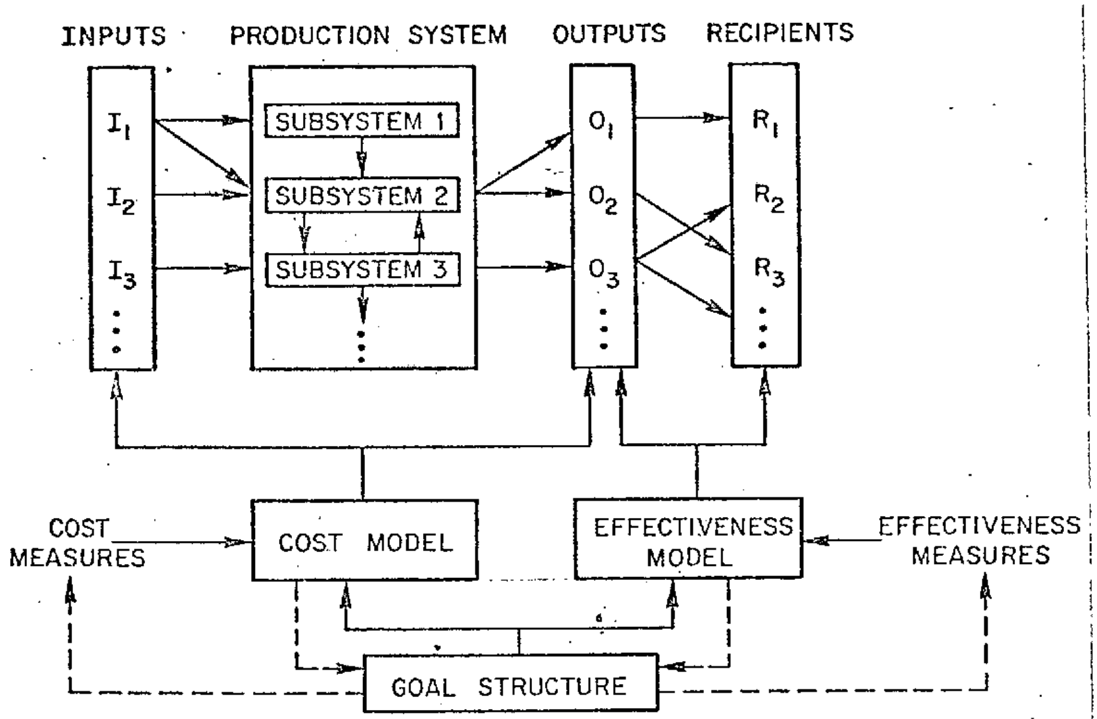
Understanding a problem's context often can be the major part of analyzing and solving the problem itself. Context is especially important in resources information problems that involve determinations about the value of data, information, and decisions. This section documents the qualitative and quantitative context relevant to our cost-effectiveness investigation of snow survey and water supply forecasting activities within the California Department of Water Resources.

6.310 Production Process

Since 1929, the Department of Water Resources (DWR) has coordinated California's program of snow surveys and water supply forecasting. The stated objective of this program is to "reliably predict the State's snow-melt runoff as necessary to meet the annual operating needs of California's water using agencies." The program's product is the water supply forecast. Forecasts are published in DWR Bulletin 120 titled "Water Conditions in California" and issued five times a year. Four reports contain water supply forecasts based on snow conditions as of the beginning of February, March, April and May, respectively. The fifth report is distributed in December and summarizes the previous water year.

DWR water supply forecasts can best be viewed in context with the entire program of snow survey and water supply forecasting activities. Using a systems analysis perspective, the program can be seen as a production process that transforms a variety of inputs into specified outputs. Figure 6.2 portrays this process in a schematic model. The model is sufficiently general to apply to other classes of public services. It represents a structure in which resources of different types (I) are transformed into quantities of outputs (O) and delivered to various groups of recipients (R). The nature of the transformation process is determined by the relative cost of inputs and their substitution possibilities as well as the technical, organizational, and institutional relationships within the production subsystems. The relative quantities of outputs produced and their distribution among recipients depends upon the form of allocation procedure adopted.

FIGURE 6.2 - SCHEMATIC MODEL OF A PUBLIC SERVICES PRODUCTION SYSTEM



The upper portion of Figure 6.2 diagrams the structure of a public services production system. The lower portion of Figure 6.2 outlines how the performance of such a system could be evaluated using a cost-effectiveness approach. For alternative output configurations, the cost model determines the total cost of producing outputs under the assumed system structure and production relationships. The effectiveness model, on the other hand, relates output characteristics to the achievement of system objectives which include satisfying the needs of recipient groups. Measuring costs and effectiveness is not an easy task, as discussed previously, but the measurement process can be simplified if the system's goal structure has incorporated standards that are output-oriented and operational on a system-wide basis.

Our research concerning the DWR snow survey and water supply forecasting activities can be conveniently described in terms of the Figure 6.2 generalized production model. On the input side, we discovered that three classes of resources are used in the snow survey and water supply forecasting production process: (1) personnel and services, (2) materials and equipment, and (3) financial support. These resources are provided by the DWR and around 50 cooperating agencies, or "cooperators." Within the California Cooperative Snow Surveys (CCSS) program four types of cooperators can be identified using unofficial classifications:

- contractor-cooperators, such as the U.S. Forest Service and U.S. Park Service, that provide services and equipment to the CCSS program on a contractual basis;

- "fixed-funding" contributor-cooperators, such as certain water and irrigation districts, that contribute a flat fee to the program each year;

- "variable-funding" contributor-cooperators, such as certain private organizations and water associations, that contribute a varying fee each year depending on the direct costs of snow survey work on their water supply; and

- "services and funding" contributor-cooperators, such as cities and power companies, that provide services and equipment in addition to financial contributions.

Table 6.1 lists the cooperators that participated in the 1974 snow surveys program.

Examination of the DWR snow survey and water supply forecasting production system reveals that information gathered through the CCSS program is just one of several information sources. Snow survey data (regarding snow depth and water content) are combined with data on precipitation, runoff, and water storage in major reservoirs. The resulting information is fed into water-yield algorithms and analyzed by the DWR staff to produce regularly-updated forecasts of water supply.

TABLE 6.1 - AGENCIES PARTICIPATING IN THE 1974 CALIFORNIA COOPERATIVE SNOW SURVEY PROGRAM

Public Agencies

Buena Vista Water Storage District
Central California Irrigation District
East Bay Municipal Utility District
Friant Water Users Association
Kaweah Delta Water Conservation District
Kaweah 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
Omochumne-Hartnell Water District
Oroville-Wyandotte Irrigation District
Placer County Water Agency
Porterville Irrigation District
Sacramento Municipal Utility District
Saucelito Irrigation District
South San Joaquin Irrigation District
St. Johns River Association
Tule River Association
Turlock Irrigation District
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

Source: California DWR Bulletin 120-74 (May 1974).

The forecasts appear formally in the DWR-prepared Bulletin 120. Most of the non-snow survey data are supplied by the U.S. Forest Service, dam operators, and other divisions of the DWR. Activities within the snow surveys production subsystem are coordinated and scheduled by the DWR staff. The DWR also helps by providing occasional safety and training sessions for snow survey crew members, by setting up and maintaining the snow courses, survey equipment, and supply stations, and by providing field and technical assistance as required to meet the forecasting needs of cooperating agencies. Non-DWR cooperators contribute the remaining manpower and perform a majority of the measurements.

The major output of this process has already been described. In any given year, the first four issues of Bulletin 120 are sent to subscribers within ten days after snow conditions have been reported on the first of February, March, April and May, respectively. A fifth issue, containing the October-September water year summary is published in December. The reports contain water runoff forecasts for 20 California watersheds in which snowmelt constitutes a significant portion of the yearly water yield total. In addition, snowpack, precipitation, runoff, and reservoir storage summaries for seven hydrographic areas also appear in these reports. Specialized estimates and forecasts constitute an important secondary output. The DWR forecasting personnel furnish these additional services as requested and required by specific water management groups.

As the primary recipients of the runoff forecasting output, cooperating agencies are better equipped to make decisions about conserving available water supplies. The forecasting information also reaches many other subsidiary agencies, agriculturalists, and institutional groups that are not regular snow survey cooperators.

6.320 CCSS Budget

An agency's budget provides an obvious staring point for evaluating the cost of outputs produced. In the case of the snow survey and water supply forecasting activities of the DWR, we found that the entire production process has been running on an "official" annual budget of around $300,000. About 90 percent of this amount comes from State general fund support. The remainder, about $30,000 a year, consists of reimbursements from CCSS program cooperators.

The DWR snow surveys group has estimated that cooperators contribute services far in excess of their reimbursements. This occurs because many cooperators absorb the state survey costs along with their own snow survey efforts. The DWR estimates (very roughly) the value of these unaccounted services at around $200,000 per year. This implies an "unofficial" snow survey annual budget in the neighborhood of $500,000.

Table 6.2 shows the official version of cooperative snow survey program requirements over a ten-year span. General fund support and reimbursements from cooperators appear as actual figures for years 1966/67 through 1973/74, as estimates in 1974/75, and as projections for 1975/76. General fund entries are more reliable than the reimbrusement figures.

These annual budgets represent a fairly level commitment over the years in terms of DWR personnel. The 1974/75 budget calls for 7 full-time positions, 4 temporary positions, and 1 consultant. Total salaries plus a 67 percent overhead factor equal about $225,000, or nearly 80 percent of the snow survey budget.

Program costs within the budget are allocated about 50:50 between survey support and forecast activities. The DWR's non-salary direct costs for snow survey activities in 1974/75 are budgeted at around $28,000. This includes $19,000 for contractors, $4,000 for flying services and other support, and $5,000 for sensor equipment. These costs are expected to be fully offset by contributions from cooperators. Budgets in future years are likely to contain greater outlays for sensor equipment as automatic sensors and other sophisticated measurement devices are brought into use.

6.330 Extent of Surveys

Our comparative cost-effectiveness methodology requires that competing systems satisfy approximately equivalent objectives. An analysis of snow survey efforts was thus required to establish an adequate basis of comparison. We approached this task by asking a familiar set of questions: what? where? when? who? and how much?

TABLE 6.2 - STATE BUDGET FOR COOPERATIVE SNOW SURVEYS, 1966/67 - 1975/76

YEAR	GENERAL FUND SUPPORT	REIMBURSEMENTS FROM COOPERATORS	TOTAL
1975/76 (Proposed)	$ 285,000	$ 35,000	$ 320,000
1974/75 (Estimated)	253,557	30,835	284,392
1973/74	250,537	68,427	318,964
1972/73	258,552	29,697	288,249
1971/72	242,883	24,487	267,370
1970/71	242,351	17,585	259,936
1969/70	223,880	29,250	253,130
1968/69	191,693		191,693
1967/68	179,180	6,600	185,780
1966/67	183,410	4,800	188,210

SOURCE STATE OF CALIFORNIA BUDGET (1968/69-1974/75) AND "COOPERATIVE SNOW SURVEYS PROGRAM COMPONENT STATEMENT," BUDGET ADDENDUM, 12 JULY 1974.

California's cooperative snow survey program uses three basic means of collecting snow data: the snow measurement course, the aerial snow depth marker, and the automatic snow sensor. Snow depth and water content measurements at some 320 snow courses are the CCSS program's primary source of data. Most courses contain a standard of 10 sample points, usually spaced at 50 or 100 foot intervals, along an established line or configuration. Snow courses are typically located in meadows to avoid extremes of wind, snow accumulation, and ponding. Annual measurements in the same locations provide an index to snow cover for forecasting basin runoff. Aerial markers provide supplementary snow depth information. These marked, vertical poles are frequently placed near snow courses and are usually observed from low-flying aircraft. In the 1974 snow season, 374 observations were made at 160 aerial marker sites. Automatic snow sensors are now being used on an experimental basis at 40 remote sites. These facilitate frequent monitoring and updating of water supply forecasts and are likely to be used more in the future.

Snow survey measurements are performed in 37 river basins lying within 5 hydrographic areas. Since our ERTS-aided snow areal extent information is specific to the Feather River Basin, we were especially interested in knowing more about the snow survey work there and how it compared with the rest of the state. Table 6.3 summarizes the results of our inquiry. It shows for 1970 and 1974 the number of active aerial

TABLE 6.3 - COMPARISON OF SNOW SURVEY EFFORT BY SURVEY TYPE, 1970 AND 1974, FEATHER RIVER BASIN AND ALL STATE BASINS

		AERIAL MARKERS			SNOW COURSES		
		NUMBER ACTIVE	NUMBER OF VISITS	VISITS PER MARKER	NUMBER ACTIVE	NUMBER OF VISITS	VISITS PER COURSE
FEATHER RIVER BASIN	1970	8	24	3.0	26	84	3.2
	1974	9	3	.3	29	125	4.3
	CHANGE	+12%	-88%		+12%	+49%	
ALL STATE BASINS	1970	152	486	3.2	315	864	2.7
	1974	160	374	2.3	323	1014	3.1
	CHANGE	+5%	-23%		+3%	+17%	
RATIO: FEATHER R / STATE	1974	6%	1%		9%	12%	

SOURCE: CALIFORNIA DWR BULLETINS 129-70 (SEPTEMBER 1971) AND 120-74 (MAY 1974).

markers and snow courses and the number of measurement visits made to these sites in both the Feather River Basin and throughout the state. The table also shows for both areas the percentage change in survey effort since 1970. A decline in aerial marker surveys appears to be compensated by additional snow course visits. The bottom of Table 6.3 shows the survey effort in the Feather River Basin as a percentage of total 1974 aerial marker and snow course survey work.

We also asked which cooperators were performing which surveys. The results for snow course visits are summarized in Table 6.4. We found that the Pacific Gas & Electric Company performed about half of the Feather River Basin snow course measurement activity in 1974. DWR personnel performed another third of the measurements. We estimated that the total 1974 survey effort in the Feather River Basin took about 60 days of cooperator time.

6.340 Cost of Surveys

The diagram in Figure 6.2 portrayed how a "cost model" can relate the inputs and outputs of a public services production process. Such apparent theoretical simplicity often obscures a multitude of practical application difficulties. Our cooperative snow survey example is a case in point. Again, the major problem was one of comparison: we had

TABLE 6.4 - COMPARISON OF SNOW SURVEY EFFORT BY COOPERATORS, 1970 AND 1974, FEATHER RIVER BASIN AND ALL STATE BASINS

COOPERATOR	PORTION OF TOTAL SNOW COURSE VISITS PERFORMED BY COOPERATOR		
	ALL STATE BASINS	FEATHER RIVER BASIN	
	1970	1970	1974
US FOREST SVC RANGER DISTRICTS	30%	11%	9%
DWR	16	40	33
PACIFIC GAS AND ELECTRIC CO	14	39	50
NEVADA COOPERATIVE SNOW SURVEYS	13	0	0
OTHER COOPERATORS	27	10	8
TOTAL	100%	100%	100%

SOURCE CALIFORNIA DWR BULLETINS 129-70 (SEPTEMBER 1971) AND 120-74 (MAY 1974), AND SNOW SURVEY INDEX AND MEASUREMENT SCHEDULE 1974.

to isolate the costs of those snow survey subsystems that produce outputs comparable with our ERTS-aided snow survey information. CCSS program budget information, although useful for examining the snow surveys production process as a whole, does not tell us much about the costs of producing intermediate outputs like snow density and water content measurements. Moreover, we were specifically interested in the costs of producing these outputs in our study area, the Feather River Basin, rather than for the entire state.

Intermediate output and geographical limitations led us to focus our cost analysis on individual snow course and aerial marker survey visits. Our cost model thus assumed the following appearance:

$$C_b = m\, c_{am} + n\, c_{sc} + c_i$$

Where C_b = total costs for the production of snow depth and water content data within basin b in year t

m = number of aerial marker measurement visits in year t

n = number of snow course measurement visits in year t

c_{am} = direct cost of an average aerial marker survey measurement visit

c_{sc} = direct cost of an average snow course survey measurement visit

c_i = indirect costs associated with $(m\, c_{am} + n\, c_{sc})$

Estimates for the direct costs of survey work were derived from discussions with DWR snow survey personnel. Based on 1974 survey information, we arrived at the following average cost figures:

$$c_{am} \approx \$\ 15$$

$$c_{sc} \approx \$150$$

Costs of the two survey types thus differ by about a factor of ten. Aerial marker visits are relatively inexpensive because a skilled pilot can overfly and photograph many markers in a short period of time. Snow course measurement visits, because they involve detailed ground measurements, have a higher and wider range of costs. The costs of visits appear most affected by where they are and who performs them. DWR analysts estimate the direct costs of visiting the most accessible snow courses at $50 and $60 each. Some courses can be reached by road or easily by snowmobile or helicopter. Remote courses accessible only by foot can represent as much as $210 each. This would include two men at $40 per day plus expenses plus maintenance of supply cabins. Certain cooperators, by utilizing slack personnel or by combining snow survey work with other operations, can reduce their survey costs considerably. For example, a helicopter normally renting for $150 an hour may average only $50 an hour when used on a regular basis.

Estimates of indirect costs are much harder to derive than direct costs. Our estimation problem is compounded because at this state of our modeling we are concerned with intermediate outputs such as water content determination. The challenge is to isolate only those indirect costs associated with the production of the appropriate intermediate outputs. Indirect costs can be distinguished in the following DWR snow survey activities:

- program direction and coordination of survey work
- communication with cooperators
- preseason aerial marker and snow course setups
- measuring equipment acquisition and maintenance
- training and safety instruction sessions
- formal recording and publication of measurements

Since we have not as yet developed itemized cost estimates for the above categories, we decided to refer generally to indirect costs based on the DWR snow survey budget information discussed earlier. Salaries, plus their 67 percent overhead factor, accounted for almost 80 percent of the budget. Department time was divided almost equally between snow survey and forecasting activities. Nearly all of the foregoing indirect cost categories fall within the survey side of the departmental budget and require extensive labor inputs from salaried personnel. We concluded that the indirect cost factor for water content estimation should thus be no more nor much less than half the overhead factor used with direct salary costs. We chose the more conservative estimate:

$$c_i = .33\ (m\ c_{am} + n\ c_{sc})$$

Using the information regarding visits presented in Table 6.3, we then derived the following survey cost total for the Feather River Basin in 1974:

$$C_{FRB} = m\ c_{am} + n\ c_{sc} + c_i$$

$$C_{FRB} = 3\ (\$15) + 125\ (\$150) = c_i$$

$$= 1.33\ (3\ (\$15) + 125\ (\$150))$$

$$= 1.33\ ((\$45) + (\$18{,}750))$$

$$\simeq \$25{,}000$$

6.350 Accuracy of Surveys

The cost model in Figure 6.2 is counterbalanced by an "effectiveness model" that relates system outputs with user needs and overall goals. Effectiveness, in the context of the snow survey program, implies determining the accuracy and associated accuracy variance of runoff forecasts. In terms of an intermediate output like snow water content, effectiveness indices can be developed by measuring the dispersion of monthly water content estimates about their mean. We performed both types of effectiveness analyses in the course of our research.

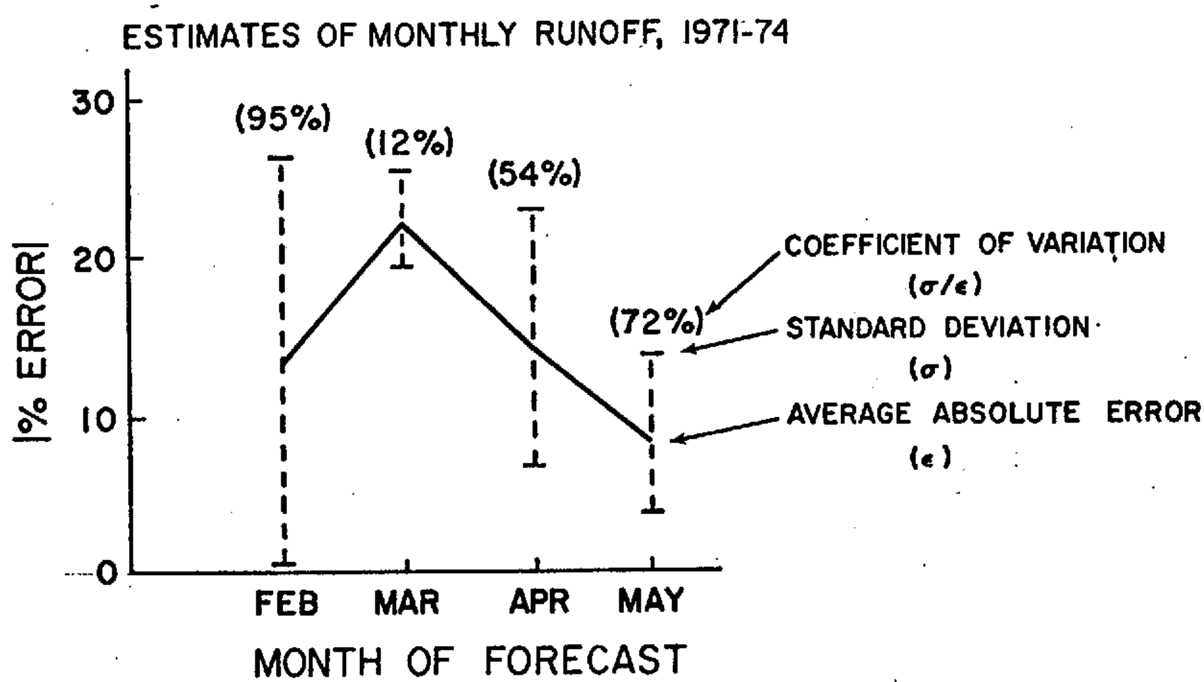
The accuracy of runoff forecasts was examined by comparing monthly forecasts with later records of actual runoff. Forecasts and recorded inflows to the Oroville Reservoir were obtained from DWR Bulletin 120 reports and data supplements. Table 6.5 summarizes the results of our investigation. Average absolute percentage error is plotted against time for four forecast months over years 1971-1974 for estimates of runoff by month (upper graph) and over years 1971-1973 for estimates of runoff by water year (lower graph). The graphs also show standard deviation boundaries (dotted lines) and coefficients of variation (in parentheses).

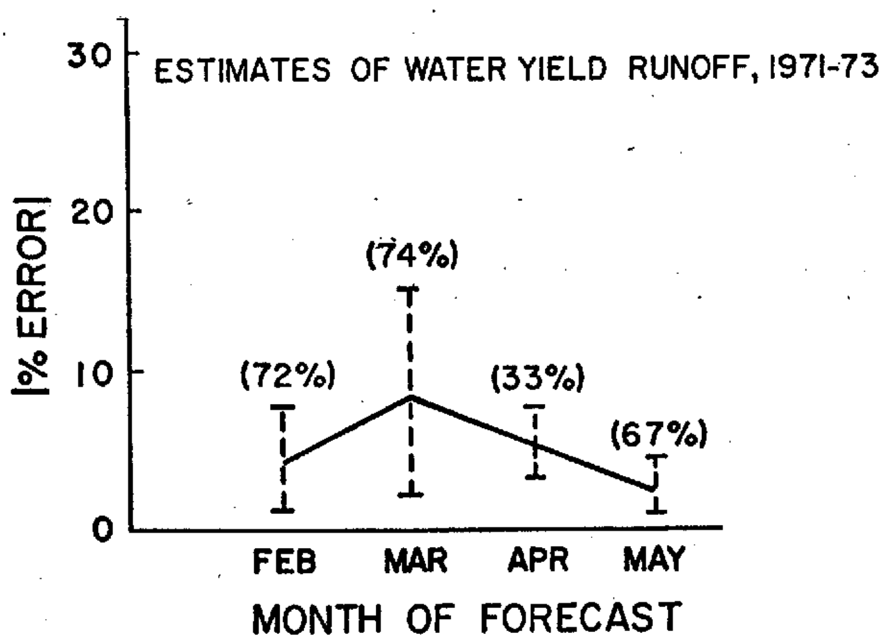
We might expect Table 6.5 to show downward-sloping curves for both monthly and yearly runoff forecasts. Accuracies, in other words, can be expected to improve (absolute errors and standard deviations should drop) with forecasts made later in the snowmelt season when additional data are available. Instead, Table 6.5 suggests that recent forecasts of Oroville Reservoir inflows have generally been more reliable in February than in either March or April. Additional data from less unusual water years will probably reverse this result. Comparison of the two graphs does at least confirm our expectations that runoff forecasts for the water year should be more reliable than forecasts for individual months.

Runoff forecast accuracy can be useful as an effectiveness indicator of the existing snow survey and forecasting production system. But runoff forecasts do not provide direct performance quantification for the intermediate outputs that we wish to compare with our ERTS-derived snow survey information.

Our comparative analysis (see next section) required a common measure of relative performance. The measure selected was allowable error (AE). This quantity enables a researcher to make a probabilistic statement about an estimated value. Here, allowable error defines a confidence interval about the estimated mean water content. The true water content can be expected to fall within this interval with a given probability. Allowable error is expressed as a plus or minus percentage of the estimate mean, that is, as the half-interval width. Calculation of AE is based on a determination of the sample size (n), the coefficient of variation (CV), and a selected Student's-t value corresponding to the

TABLE 6.5: AVERAGE ABSOLUTE ERROR IN RECENT RUNOFF PREDICTIONS IN OROVILLE RESERVOIR





SOURCE: CALIFORNIA DWR BULLETINS 120, ALL MONTHS, 1971-74 probability of having the true water content value fall in the calculated confidence interval. The CV, a measure of sample data dispersion about its mean, is defined as the sample's standard deviation expressed as a percentage of the sample mean.

Bulletin 120 again supplied the data for this performance determination: Feather River Basin water content measurements were summed by month (January through May) for each of four years (1971-74) to determine means, standard deviations, and thus CV's. Months with less than three samples were exluded. The results were summed by month over the four year period to determine average monthly CV's. Selection of confidence probabilities at the 1 and 2 standard error level were then made for representative performance display. Table 6.6 summarizes the results.

Examination of the AE values within Table 6.6 indicates that snow water content is estimated most precisely at the beginning of March. Higher allowable errors (i.e., lower precision for a given level of confidence) in January and February may be due to greater areal snow pack accumulation variability than in March and also perhaps due to lower pack water content stability. The lower sample rate in January also contributes to the relatively high allowable error. The May snow pack variability appears from examination of snow course data to be due to differential melt rates over the watershed. It is possible that the higher April AE may be ascribed to a large snow water content differential between high and low elevation snow courses.

In order to use allowable error as a valid measure of performance it was assumed that snow courses had been randomly allocated over the watershed. In reality this was not the case. In actuality, the CCSS program employs a subjective quasi-random allocation process. The implications of this situation and justification for the use of the allowable error performance comparison criterion are discussed in the next section.

6.400 COMPARATIVE ANALYSIS

In addition to ample qualitative information, judgements about the cost-effectiveness of comparable systems usually require a resourceful use of quantitative methods. Comparative analyses, in other words, must be "custom-tailored" to the uniqueness of each case example. This section describes how we applied a cost-effectiveness analytic framework to the context of our snow survey example.

6.410 Difficulties of Comparison

Real-world complications inevitably force applied cost-effectiveness analyses to deviate from their theoretical counterparts. On the cost side, the question is not one of perfection but of sufficiency. On the performance side, a balance must be struck between what we would like to

TABLE 6.6 - VARIATION AND PERFORMANCE STATISTICS FOR SNOW WATER CONTENT MEASUREMENTS, BY MONTH, FEATHER RIVER BASIN, 1971-74.

Month	No. of Snow Courses Providing Data (n)	Average Coefficient of Variation[1] (ave. CV) (In Percent of Estimated Mean Value)	Allowable Error[2] (AE) (In Percent of Estimated Mean Value)	
			68.3% Level of confidence[3] (.683 probability)	95.0% Level of confidence (.950 probability)
JAN	13	61.58	17.08	37.22
FEB	23	63.38	13.22	27.42
MAR	21	59.51	12.99	27.10
APR	29	73.17	13.59	27.83
MAY	22	94.95	20.24	42.10

1. $$CV = \frac{\hat{Var}(y)}{\hat{\bar{Y}}} \times 100$$

y = reported ave. snow water content value for a given snow course for a given month.

$\hat{\bar{Y}}$ = ave. of snow course water content values for a given month.

$\hat{Var}(y)$ = estimated variance of y.

2. $AE = t \cdot \frac{CV}{\sqrt{n}}$, where t is Student's-t and n is the number of snow courses contributing to $\hat{\bar{Y}}$.

= plus or minus percentage of the estimated mean in which the actual value of snow water content is expected to fall with probability specified via Student's-t.

3. $\frac{CV}{\sqrt{n}}$ or $\frac{\hat{Var}(y)}{\sqrt{n}} \times \frac{1}{\hat{\bar{Y}}} \times 100$ is also known as the sampling error at the one standard error level of confidence.

measure and what can be measured with reasonable accuracy. Overriding both sides are questions concerning the comparability of different production systems.

Ideally, our own study would attempt to compare the existing DWR CCSS volumetric model with an identical model augmented with remotely-sensed snow survey information. Outputs of both models would be keyed to estimates of total water yield. Costs and accuracies would be estimated at least for the entire Feather River Basin, if not for the whole Sierra Nevada.

In reality, our study isolates those portions of the CCSS volumetric model that can be compared with ERTS-derived snow areal extent information developed in the University of California Remote Sensing Research Program (RSRP). An intermediate output--snow water content--is used rather than water yield. This is nevertheless a critical step toward defining the applicability of remote sensing techniques to the possible improvement of water yield forecasts. By individually examining predictor variables such as snow water content, we may determine how precision increases that are made in predictor variable estimates can lead to precision increases in overall predictions. The analysis here thus compares the relative abilities of two systems to generate an intermediate output. Costs and accuracies for the existing model are based on published reports and interviews with DWR staff. Costs and accuracies for the ERTS-aided model are derived from concurrent RSRP work in the Spanish Creek Watershed, an area within the Feather River Basin.

6.420 Comparative Sampling Design

6.421 The ERTS-aided Snow Water Content Estimation System

6.421.1 Objectives

The snow water content estimation method utilized in this study with ERTS information is known as a stratified double sample. Its objective is to combine snow water content information for the whole watershed, as obtained inexpensively from ERTS data, with that gained from a much smaller and more expensive sample of ground based snow courses. In this way a large amount of the variability in basin snow water content is accounted for by use of the ERTS data.

The desired result is that after calibration by regression of ERTS data on snow course data, an overall estimate of basin snow water content is possible at significantly more precise levels than available for the same cost from snow course data alone. In addition, the associated gridding of ERTS data into an image sample unit system allows an in-place mapping of snow water content with respect to known melting environments and stream channels. Such in-place mapping is potentially very useful as an additional data type for improvement of hydrologic model accuracy.

6.421.2 General Procedure

The stratified double sampling plan is described mathematically in Appendix I. The method summarized in section 6.421.3, generally proceeds as follows: First, black and white ERTS transparencies are obtained and transformed to a simulated infrared color composite form (Katibah, 1973). In the color combining process an image sample unit grid is randomly placed over the image so as to cover the watershed of interest. Each image sample unit is then interpreted manually as to its average snow areal extent cover class according to a snow environment-specific technique described by Draeger and Lauer (1973) and in more detail by Katibah (see section 2.200b of this report).

Snow water content is then estimated from the following first case, time specific model:[1]

$$X_i = \left(\sum_{j=1}^{J} (M_{ij})(G_j) \right) \cdot K_i \qquad \text{eq. 4.1}$$

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

M_{ij} = snow cover midclass point expressed on a scale of 0.00 to 1.00 for image sample unit i on the j^{th} ERTS snow season date,

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

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

J = total number of snow season dates considered.

Image sample units utilized in this study represented 980 acre ground areas. Snow cover classes were defined as 0 percent, > 0 - 20 percent, > 20 - 50 percent, > 50 - 98 percent, and > 98 - 100 percent of ground covered by snow.

In order to insure reasonably high correlation between X_i and corresponding ground water content values, y_i, j should equal at least three. As a matter of operating procedure, one or two dates of ERTS imagery would be required during the early snow accumulation season after which ERTS snow water content estimation could proceed for a given date based on a semi-sliding two, three, or more date basis.

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1. Investigation of more sophisticated stochastic model and physical model transforms currently under way.

Under certain circumstances j may only be two. For instance, an early snow season date and the mid-season date of interest may give rise to acceptable ERTS-ground correlations. Or, more powerfully, the first date may consist of an average April 1st snow water content map based on past year's ERTS data. In all cases the sample unit grids on all dates must be in common register with respect to a base date grid location.

In this study, three dates of ERTS imagery, April 4, May 10, and May 28, 1973, for the Feather River Watershed were interpreted for snow areal extent. The resulting areal extent estimates for each image sample unit were transformed to snow water content using equation 4.1. Comparison with the average snow water content for April 1 and May 1, 1973, recorded at snow courses falling in corresponding image sample units yielded a correlation coefficient of 0.85. To quantify the relationship on a time comparable basis, ERTS snow water content data from only the April 4 and May 10 dates were analyzed. A correlation coefficient of 0.77 was achieved[2] between water content data thus derived on these two ERTS dates and the snow course water content data in April and May. In an operational situation, however, ERTS data from early snow season dates would be available for improved snow water content estimation. To conservatively simulate the effect of a third date, only snow presence/absence data from May 28 were added to snow class and presence/absence data from the previous two dates. The resulting correlation coefficient, 0.80, was then used in the analysis.

After the snow water content index for each ERTS image sample unit has been determined, all such units are sorted into strata according to the size of their respective snow water content index. Stratification is used to control the coefficient of variation of the overall basin water content estimate. This is accomplished by the subsequent segregation of the population of image sample units into homogeneous environmental types tending to receive, accumulate, and lose snow at similar rates. Six such strata were used in the effort reported here.

Ground (snow course) sample sizes may be determined (see Appendix I) for individual strata according to the snow survey direct cost budget for the watershed of interest and according to the following stratum specific statistics: relative stratum size, ERTS snow water content variability, ERTS to ground correlation, and ERTS to ground sample unit cost ratio. These sample size calculations may be conducted according

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2. Ground-image sample unit spatial matching was based on the best published data (Bulletin 129). CCSS has recently plotted their Feather River Watershed snow courses on 15 minute USGS quadrangles and these data will be used to check the previous ground ERTS sample unit registration.

to either of two options. Both alternatives involve the measure of stratum size. The first size value consists of the sum of the snow water content indices for all image sample units in a given stratum. The second represents the total number of sample units in the given stratum. If it is desirable to direct the ground sampling to areas of higher snow water content in view of the importance of that water volume to runoff, then the first option is preferable.

In effect, the first stratum size weighting option (based on accumulated ERTS snow water content) allows a more finely calibrated ERTS estimate in areas of higher water content and potentially higher importance in runoff modeling. The effect will be a slightly less precise and less accurate estimate in the more variable low snow water content areas. The second option effectively directs the ground sample to those image strata that are most variable in terms of the snow water content index. Analysis of the Feather River data in this study indicates that such strata are generally those of extremely low snow water content.

Results of this study also show that the first stratum size weighting option (W01) gives overall basin snow water content estimates which are generally 1.4 to 1.6 times as precise as the second (W02). The hydrologist's choice among the two alternatives must ultimately be governed by the relative runoff importance ascribed to the low versus high snow water content areas.

Once stratum ground (snow course) sample sizes have been calculated for a fixed budget, the expected performance may be determined for the snow water content inventory. One standard statistical expression of performance is allowable error (AE). This value was defined previously as the half width of an interval centered on the basin estimate in which the true basin water content value is expected to fall with given confidence probability. Calculation of the expected overall coefficient of variation (CV), selection of the confidence probability (represented by Student's-t), and use of the total snow course sample size (n) allows calculation of AE according to the following formula:

$$AE = (t_{n_{total}-1}) \cdot (CV_{overall}) \qquad \text{eq. 4.2}$$

If the allowable error is not low enough to satisfy snow water content estimation objectives, a larger snow survey budget is required. In this case the hypothesized larger budget level is selected and the sample size and allowable error calculation process is repeated. It should be noted that the calculation of the overall coefficient of variation would be based in part on ERTS data and in part on snow course data. If snow course data are not available then first year snow water content variability estimates may be based on previous ERTS data or supporting time coincident aircraft data alone.

After the allowable error criterion has been met, the calculated number of necessary snow courses per stratum are allocated with equal probability to image sample units within a stratum. This allocation for a given watershed may occur once during the system setup. In such a situation, sample size and AE testing should be performed for the most variable snow water content index month of the snow season. Once the snow courses were established, cost-effective basin snow water content estimation would proceed by use of the double sample regression formulae relating ERTS and ground data. The resulting water content estimate would then be related in combination with other independent variables to water runoff.

Another potentially cost-information advantageous course allocation alternative is possible with the proposed stratified double sampling estimation method. This alternative would involve selecting prior to each snow season a set of ground sample units (snow courses) to be visited only that season. Selection would be based on image sample unit assignment according to previous years of ERTS snow water content index data. In this way much information could be gained on snow pack conditions as they related to a variety of environmental circumstances and runoff. Each month's estimate of basin snow pack water content would be an unbiased value with specified AE constraints. Utilizing an established snow or water content -- runoff relationship, runoff predictions based on the basin snow water content estimate and other common predictor variables could be made in the absence of permanent snow courses. However, in a test period, these temporary ground sample units might have to be supplemental to a set of snow courses active for several seasons that would provide established snow pack - runoff relationships.

For basins where established snow courses already exist, the snow courses would be classified into the appropriate strata. Under this third allocation method, additional courses could then be added, subtracted, or replaced where necessary according to an annual partial course replacement strategy.

6.421.3 Summary of Steps to be Used in Stratified Double Sampling for Snow Water Content Estimation

(1) Create ERTS color composites with appropriate image sample unit grid over watershed(s) of interest.

(2) Estimate snow areal extent by ERTS image sample unit for previous year(s) or current season snow build-up date(s).

(3) Estimate snow areal extent by image sample unit for ERTS snow season date of interest.

(4) Transform snow areal extent data to snow water content data by ERTS image sample unit.

(5) If not already performed, stratify image sample units into ERTS snow water content index classes. Then calculate stratum ground sample unit (snow course) sample sizes to achieve allowable error criteria for the basin snow water content estimate. Stratification and sample size calculation should be performed for the pre-snow season date combination having the most variable snow water content and/or containing the largest water runoff-related snow pack.

(6) If not already performed for the given snow season or snow season date, allocate ground sample units to strata with equal probability within strata.

(7) Calculate the estimate of watershed snow water content according to a summation of stratum regression relationships for ERTS versus ground observations.

(8) Enter the basin snow water content estimate into statistical or physical models to predict water yield.

6.421.4 Assumptions

Based on the foregoing system overview, the following assumptions may be identified for this proposed ERTS-aided snow water content estimation procedure.

(1) The probability distribution (pdf = probability density function in a continuous variable formulation) of X_i, the estimated ERTS snow water content index for image sample unit i, is determined by examination of the 980 acre image sample units. It is assumed that this pdf is the same as the X_i pdf based on examination of 30 acre cells. These smaller cells represent the approximate ground area associated with a snow course located at the center of those 980 acre sample units.

(2) The value of X_i for the 980 acre image sample unit will, on the statistical average, represent the X_i value for the 30 acre cell at the 980 acre sample unit center.

(3) The image sample units can be stratified based on the value of the X_i.

(4) Only the tendency, expressed by the correlation coefficient, of ERTS snow water content estimates to vary with corresponding ground measurements need exist in order to increase basin snow water content estimate precision and consequently decrease ground sample unit size. In other words, only the proportionality between X_i and y_i, and not an absolute ERTS snow water content estimate, is needed for the proper operation of the double sample method.

(5) Frequency and availability of utilizable watershed ERTS imagery is comparable to the frequency of current ground snow course surveys.

(6) Ground sample size over time in a given stratum must be large enough to give a reliable stratum ERTS-to-ground regression coefficient.

The first and second assumptions appear to be reasonably valid based on the strength of correlation coefficients calculated to date. In addition, the importance of the first two assumptions will be diminished as more area and environment specific techniques now under development (e.g., Katibah and Thomas) are applied. The third and fourth assumptions are, under definitions of the image and ground sample unit populations, statistical truisms.

The fifth assumption is generally valid in terms of frequency for several snow zone areas throughout North America. ERTS passes are at 18-day intervals and with a significant amount of next-day sidelap. Consequently, even when cloud patterns obscure portions of the watershed on one day, they may not do so on the following day, and vice versa. Furthermore, the development of historical correlations between nonobscured and obscured sample units may allow relatively accurate snow water content estimations to be made in the case of partial watershed cloud cover situations.

Despite the foregoing possibilities, some regions of North America may have cloud cover frequencies too high to allow effective use of ERTS imagery. In addition, daily water yield forecasts may be required by the public as in the case of flood forecasting. In these cases, the use of meteorological satellite information when correlated on a sample unit basis with ERTS and ground data offers the possibility of more frequent snow water content estimates.

ERTS coverage for other areas is less consistent in terms of availability than for North America. Future operational earth resource satellite and ground tracking systems may provide a better data base in this case. The use of ERTS-correlated meteorological satellite information would also be especially important in such areas.

Currently the availability of ERTS data for near real time forecasting is possible only through the making of special arrangements. Without such arrangements, the data turn-around time for snow water content information may not be rapid enough to be satisfactory.

Assumption number six, involving degrees of freedom for the ERTS-to-ground regression coefficient, is of concern only in those strata having a low calculated ground sample size. In this case, the regression coefficient must be refined from data collected over a number of coincident ERTS and ground measurement periods during the snow season. One alternative to avoid initial low degree of freedom situations, would be to over sample during the first year those strata for which low ground sample sizes have been allocated.

6.422 The Current CCSS Program Snow Water Content Estimation System

6.422.1 Objectives

As stated earlier, the objective of the California Cooperative Snow Survey Program is not to estimate snow water content _per se_. Rather, it is to produce information useful in the prediction of water yield. However, the precision of the snow water content estimate will affect the precision of the water runoff prediction. Thus it is appropriate to attempt to compare the relative abilities of the ERTS-aided and current survey systems to estimate this important water yield predictor variable.

6.422.2 General Procedure

The major features of the CCSS Program's production process and field sampling have been outlined in section 6.300 and particularly subsection 6.330. It was learned that snow courses are not currently allocated over a watershed (e.g., Feather River area) in a random fashion. Instead, the present CCSS Program snow course locations have evolved paralleling the development of snow hydrology sampling theory over the last fifty years (Howard 1974). For example, 30 to 40 years ago snow courses were located primarily according to site accessibility. The next twenty years saw criteria for new snow course location evolve to allow better areal and elevational snow zone sampling. Recently, locational criteria have emphasized snow zone positions with high runoff correlations. Some positions may not have been sampled previously.

Within a given area designated as a desirable snow course location, only certain positions presently satisfy course location criteria. These positions must be essentially open and free from extreme drift, melt, wind, and ponding (Bulletin 129, 1970).

The snow course itself consists of ten points spaced at 50 or 100 foot intervals in one or more transects. Snow depth and weight readings are taken at each point with a Mt. Rose snow sample device. The average snow water content from ten points is then defined as the course snow water content value for the given sample date. Key snow courses are visited near the beginning of each month from January through May, while all snow courses are sampled on or about April 1.

Snow depth markers associated with snow courses and a growing network of experimental automatic snow sensors, both discussed in subsection 6.330, provide supplemental information to the snow course networks.

6.422.3 Assumptions

The basin assumption of the CCSS Program's snow course allocation scheme is that the quantitative-subjective allocation plan will provide data that can be correlated with water yield. As Bulletin 129 points out, snow course measurements should not be taken as an accurate measure of snow water content over a large area without careful study of both the snow course and the area of interest.

It is clear that the proposed ERTS-aided and the current CCSS Program snow water content estimation systems are not identical. However, if the two systems' products are utilized similarly and are based on a concept concerning a representative quantification of the characteristics of watershed snow pack, then a common measure of relative system performance is possible. The intermediate products of both systems are designed to be utilized in water yield prediction. The error of either will affect the runoff prediction in a similar manner. Both are intended to characterize, at least in part, the general variability of the snow pack as it relates to water content.

A common statistical measure of performance is therefore implied. The often-used criterion of probability sampling, known as allowable error (AE) is appropriate here. Consequently, the CCSS snow course system must be considered as a random sample for comparison. To make this assumption and insure an equitable comparison requires that an especially favorable assumption toward the CCSS system be made. This additional assumption is that the CCSS snow courses are randomly located over the entire watershed. In fact, however, they are allocated only to the zone receiving snow that is resident on the ground for significant periods during the middle of the snow season. The result is that CCSS snow water content data will have a smaller coefficient of variation than would be expected if ground sample units were in fact allocated over the entire watershed.

Two sampling frameworks have been considered for the CCSS data in order to allow the best comparability possible between the ERTS-based and current snow water content estimation systems. The first considers the CCSS snow course data as a purely random sample with all observations having equal weights. The results are then directly comparable to those obtained with the ERTS stratum size weighting option based on the number of image sample units in a given snow water content stratum.

The second sampling framework also considers the CCSS snow courses as randomly allocated to image sample units over the watershed. However, snow course data are not weighted equally in estimation of total basin snow water content. Rather they are assigned weights proportional to the water content index size of the ERTS stratum into which the corresponding image sample unit falls. This procedure enables a direct comparison of CCSS results and the first stratum size weighting option discussed in subsection 4.212.

6.430 Performance Comparison

The overall performance of the two snow survey systems was compared in a manner analogous to the cost-effectiveness diagram portrayed in Figure 6.1. This performance comparison was facilitated by identification of three comparative elements: unit costs, sample sizes, and precision. Each is described in turn in the following paragraphs.

6.431 Unit Costs

Since the collection of samples at snow courses is an activity common to the ERTS-aided and the existing snow survey methods, it was possible to apply the same set of costs per ground sample unit to both systems. The unit costs of typical snow course measurement visits were estimated earlier at $150 each (See Section 6.340).

Costs per image sample unit, applicable to only the ERTS-aided survey system, are presented in Table 6.7. These costs were developed along with the sampling methodology described in Section 6.421, and are derived from actual University RSRP snow survey work using 2218 image sample units in the Feather River Watershed. Pre-inventory and inventory costs are shown on both a total cost and cost per image sample unit basis.

The average cost for each of the 2218 image sample units was 13.6¢, of which about 10¢ went toward image interpretation and keypunching. Since most of the processed and unprocessed imagery is useful for later training and comparative analysis, an amortization factor was applied. It was assumed, for example, that two out of three dates of imagery developed for one occasion would be usable over a total of five separate occasions. Specific assumptions about amortization schedules are described in Table 6.7.

6.432 Sample Size

Previous sections have already discussed the sample size determination method employed by the existing snow survey system. The "subjective quasi-random allocation process" described in subsection 6.350 is tailored to fit general CCSS program budget constraints. In subsection 6.340, the 1974 budget for the Feather River Basin snow survey work was estimated at $25,000. This was sufficient for 125 snow course measurement visits and 3 aerial marker measurement visits.

The methodology behind sample size determination in the ERTS-based system was mentioned in subsection 6.421.2 and developed more fully in Appendix I. Table 6.8 shows the number of samples required under various assumptions about budget levels, sample costs, and weighting options. In the ERTS-based system, a relatively small number of snow course measurement visits, or ground sample units (GSU's), are supplemented by 2,218 image sample units (ISU's) covering all but about 5 percent of the Feather River Basin. As described previously, both GSU's and ISU's are allocated among six environmental strata.

For research efficiency purposes, image sample statistics used in calculating sample sizes are based on Spanish Creek Watershed data.

TABLE 6.7 - IMAGE SAMPLE UNIT COSTS FOR AN ERTS-BASED MANUAL SNOW WATER CONTENT INVENTORY

	Total Cost	Cost per ISU[1]
I. Pre-Inventory		
A. Image Acquisition		
3 ERTS dates with 3 bands per date @ $3 per band; the costs of 2 of these dates amortized over 5 dates	$12.60	$.006
Resource Photography		
(Medium Scale Areal Photography for Image Analyst Environmental Type Training)	$14.29	$.006[2]
B. Image Sample Unit		
Grided ERTS Color Composite Print Generation		
Film, Processing, and Printing		
3 dates @ $11 per date		
The costs of 2 of these dates amortized over 5 dates	$15.40	$.007
Labor 0.5 hours per date @$13.50/hr including overhead, 3 dates, the costs of 2 of which are amortized over 5 dates	$ 9.45	$.004

1. Cost per image sample unit assuming 2218 image sample units in the watershed(s) of interest.

2. Two $500 flights amortized over 5 years, 7 dates per year, and two watersheds.

TABLE 6.7 (continued)

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

TABLE 6.8 - SUMMARY OF REQUIRED ERTS-BASED SNOW SURVEY SAMPLE SIZES

GIVEN: ALLOCATE: n' image sample units (ISU's) and n ground sample units (GSU's) among h strata

Monthly Direct Cost Budget c_{direct}	Cost per GSU $c_{n'}$	Cost per ISU $c_{n'}$	Weighting Option	Type of Sample Units	stratum h: h =	1	2	3	4	5	6	Total	
---For all Alternatives---				ISU	n'_h =	503	614	205	393	220	283	$\Sigma n'_h$ =	2,218
$1,000	$150	$.12	W01	GSU	n_h =	0	0	0	1	1	3	$\Sigma n'_h$ =	5
			W02			0	4	0	1	0	0		5
3,000			W01			0	2	1	5	3	8		19
			W02			0	13	1	2	1	1		18
5,000			W01			0	3	2	8	5	13		31
			W02			0	21	3	4	1	2		31
7,000			W01			0	5	3	12	7	19		46
			W02			0	30	4	6	2	3		45
$1,000	$150	$.15	W01	GSU	n_h =	0	0	0	1	1	2	Σn_h =	4
			W02			0	4	0	1	0	0		5
3,000			W01			0	2	1	5	3	8		19
			W02			0	13	1	2	1	1		18
5,000			W01			0	3	2	9	5	13		32
			W02			0	21	3	4	1	2		31
7,000			W01			0	5	3	12	7	19		46
			W02			0	30	4	6	2	3		45
$4,200	$150	$.12	W01	GSU	n_h =	0	3	1	7	4	11	Σn_h =	26
			W02			0	18	2	4	1	2		27
$4,200		$.15	W01			0	3	1	7	4	11		26
			W02			0	18	2	4	1	2		27

The Spanish Creek unit is a sub-basin of the Feather River Watershed. The necessary assumption to validate the use of the Spanish Creek statistics is that the distribution of snow water content classes is approximately the same in both basins. This assumption is justified by inspection of the ERTS snow areal extent data for the Feather's 2,218 image sample units and the corresponding 141 Spanish Creek image sample units for the snow season dates investigated. ERTS to ground correlation coefficients used in the sample size calculations are based on Feather River basin-wide analysis. Appendix II gives numerical results for statistics used in calculation of ERTS-based sample sizes.

The budget levels in Table 6.8 represent the monthly direct costs allocatable to snow survey work. Budget alternatives appear at the \$1,000, \$3,000, \$4,200, \$5,000 and \$7,000 levels. These levels compare with an estimated monthly direct cost in the CCSS program of \$4,200.[3]

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3. From subsection 3.4, the total annual estimated snow survey budget is:

$$C_{FRB} = (mc_{am} + nc_{sc}) + c_i$$

$$\text{or} \quad \underset{\text{Total}}{\$25{,}000} \simeq \underset{\text{Direct}}{\$18{,}800} + \underset{\text{Indirect}}{\$6{,}200}$$

If we assume that direct and indirect snow survey costs accrue uniformly over the snow sampling season, we can estimate how much of the annual snow survey budget is consumed in a "typical" snow survey month.

April and May are "typical" months in our study. Therefore, developing weights from Table 6.6, we can derive a monthly proportionality factor, f:

$$f = \frac{\dfrac{n_{APR}}{\Sigma n + 5} + \dfrac{n_{MAY}}{\Sigma n + 5}}{2}$$

$$f = \frac{\dfrac{29}{113} + \dfrac{22}{113}}{2}$$

$$f = .23$$

By applying f to the annual budget equation, we can derive a monthly estimated snow survey budget:

$$f\,[C_{FRB}] = f[(mc_{am} + nc_{sc}) + c_i]$$

$$\text{or} \quad \underset{\text{Total}}{\$5{,}600} \simeq \underset{\text{Direct}}{\$4{,}200} + \underset{\text{Indirect}}{\$1{,}400}$$

Unit costs for the ERTS-based system are calculated at the $150 level for each GSU and at 12¢ and 15¢ levels for each ISU. Actual image sample unit costs, as presented in Table 6.7 totaled to 13.6¢. Table 6.8 also shows the effect of the two weighting options described in subsection 6.421.2. With the first, W01, sampling is based on ERTS-developed strata boundaries. With the second, W02, sample units are selected in accordance with established techniques of stratified random double sampling.

Resulting sample sizes appear on the right side of Table 6.8. The allocation of the 2,218 ISU's remains the same under each of the alternatives. The number of GSU's increases rapidly as the monthly direct cost budget is increased, but the number and allocation of GSU's is only slightly affected by a 3¢ increase in image sample unit costs. As mentioned before, the two weighting options place different stress on areas of high water content. W01 directs ground samples to these areas, while W02 encourages greater sampling of strata with lower water content.

6.433 Precision

Use of the allowable error (AE) formulation described in subsections 6.350 and 6.421.2 permits a direct cost-capability comparison of the two snow water content estimation systems. Allowable errors were calculated using equation 4.2 for each of the ERTS-based sample sizes shown in Table 6.8. AE's are produced for monthly direct cost budgets of $1,000, $3,000, $5,000 and $7,000, as well as for confidence levels ranging from 80% to 99%. Table 6.9 summarizes AE results for the two weighting options at the 15¢ per ISU level. In addition to AE, confidence level, and budget, Table 6.9 presents coefficients of variation (CV's), Student's-t factors, and the ground sample size appropriate at each CV level.

Table 6.10 presents a corresponding set of AE results for the CCSS system of snow water content estimation. AE's are calculated for four confidence levels on a monthly direct cost budget of $4,200. Appendix III gives the analysis for calculation of allowable error associated with present snow course data. <u>The $4,200 budget level per survey month is our best estimate of the CCSS program's direct costs in the Feather River Basin in 1974.</u> Derivation of the estimate appears in Footnote 3.

The budget and AE relationships presented in Tables 6.9 and 6.10 are translated into graphical form in Figure 6.3. Two graphs are shown, one for each of the weighting options. Instead of a single cost-capability forntier as in Figure 6.1, Figure 6.3 shows a family of production possibility frontiers with four confidence levels ranging from 80% to 99%. At the $3,000 monthly budget level, for example, an ERTS-based snow water content sampling system (in the Feather River Basin) could be expected to produce results with a ±4.3% AE nine times out of ten or at a ±5.2% AE ninety-five times out of a hundred.

One production possibility of the existing system of snow water content estimation is represented by a family of points at the $4,200 monthly budget level. These points were developed in Table 6.10 for

TABLE 6.9 - SUMMARY OF ERTS-BASED SNOW WATER CONTENT ESTIMATION PRECISION

Weighting Option 1 (WO1)
Cost per ISU = 15¢

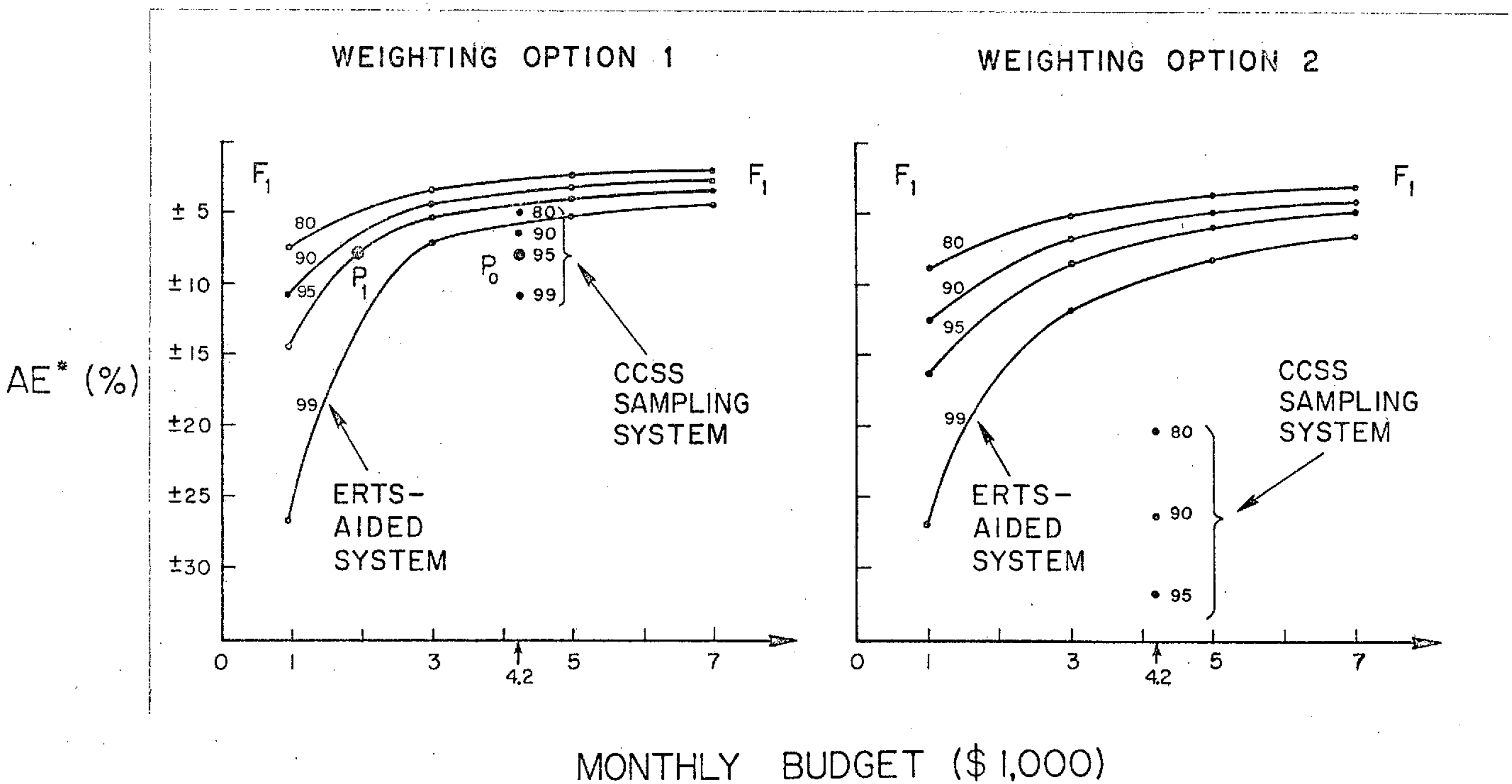
Confidence Level (%) 1-α	Monthly Budget ($)	CV	t	d.f. + 1	AE (%)
99	1000	4.60	5.841	4	26.87
99	3000	2.49	2.878	19	7.17
99	5000	1.92	2.743	32	5.27
99	7000	1.60	2.690	46	4.30
95	1000	4.60	3.182	4	14.64
95	3000	2.49	2.101	19	5.23
95	5000	1.92	2.040	32	3.92
95	7000	1.60	2.015	46	3.22
90	1000	4.60	2.353	4	10.82
90	3000	2.49	1.734	19	4.32
90	5000	1.92	1.695	32	3.25
90	7000	1.60	1.681	46	2.67
80	1000	4.60	1.638	4	7.53
80	3000	2.49	1.330	19	3.31
80	5000	1.92	1.309	32	2.51
80	7000	1.60	1.308	46	2.09

Weighting Option 2 (WO2)
Cost per ISU = 15¢

Confidence Level (%) 1-α	Monthly Budget ($)	CV	t	d.f. + 1	AE (%)
99	1000	5.98	4.604	5	27.53
99	3000	3.97	2.898	18	11.51
99	5000	2.98	2.750	31	8.20
99	7000	2.47	2.690	45	6.64
95	1000	5.98	2.776	5	16.60
95	3000	3.97	2.110	18	8.38
95	5000	2.98	2.042	31	6.09
95	7000	2.47	2.016	45	4.98
90	1000	5.98	2.132	5	12.75
90	3000	3.97	1.740	18	6.91
90	5000	2.98	1.697	31	5.06
90	7000	2.47	1.680	45	4.15
80	1000	5.98	1.533	5	9.17
80	3000	3.97	1.333	18	5.29
80	5000	2.98	1.310	31	3.90
80	7000	2.47	1.301	45	3.21

FIGURE 6.3: COST-CAPABILITY COMPARISON OF SNOW WATER CONTENT SAMPLING SYSTEMS

FEATHER RIVER BASIN 1973



* ALLOWABLE ERROR AT 80%, 90%, 95%, AND 99% LEVELS OF CONFIDENCE

TABLE 6.10 - SUMMARY OF CCSS SNOW WATER CONTENT ESTIMATION PRECISION

Weighting Option 1 (W01)
Cost per ISU = 15¢

Confidence Level (%) 1-α	Monthly Budget ($)	CV overall	t @ d.f.=20	AE (%)
99	4200	17.47	2.845	10.85
95	4200	17.47	2.086	7.95
90	4200	17.47	1.725	6.58
80	4200	17.47	1.325	5.05

Weighting Option 2 (W02)
Cost per ISU = 15¢

99	4200	70.29	2.845	43.64
95	4200	70.29	2.086	32.00
90	4200	70.29	1.725	26.46
80	4200	70.29	1.325	20.32

the 80%, 90%, 95%, and 99% confidence levels, and are directly comparable with the family of curves developed for the ERTS-based sampling system. Point P_O identifies the CCSS system's production possibility at the 95% level of confidence. Point P_1 identifies an output of similar precision and accuracy in the ERTS-based system. The cost advantage per snow survey month is represented by the distance between P_O and P_1. In this case, under weighting option 1, the ERTS-based sampling system shows approximately a $2,300 savings over the existing system. The two systems may be similarly compared at other confidence levels.

In addition to facilitating direct cost comparisons between systems, Figure 6.3 also portrays how sampling precision is affected by the two weighting options. Both systems show greater precision with W01 than with W02. The existing snow water content estimation system, however, demonstrates a four-fold improvement with W01 over W02. Such evidence indicates that existing sampling techniques could be significantly improved by using strata boundaries similar to those in the ERTS-based system.

6.500 CONCLUSION

6.510 Summary

This chapter has described a study comparing two technologies for gathering water supply information. The study has been guided by an objective outlined in our May 1974 progress report: i.e., to see if remote sensing data from ERTS can be cost-effectively integrated with data used in existing hydrologic models to produce improved water supply estimates.

At this stage of our research, we have focused attention on a major predictor variable and intermediate output of the existing water supply forecasting system--the snow water content estimate. Our operating objective thus has been to compare the performance of the existing system to produce snow water content estimates with that of an ERTS-aided system. "Performance" in this context refers to both the cost and precision of the output estimates.

For comparative analyses, cost-effectiveness theory requires that competing systems satisfy similar organizational objectives. This restriction facilitates a side-by-side examination of comparable systems by enabling a decision-maker to assess the marginal advantage promised by alternative systems either in (1) cost savings at various levels of effectiveness, or in (2) effectiveness increases at various budget levels.

The California Cooperative Snow Survey program, the existing production system of water supply forecasts in California, was examined qualitatively and quantitatively. The study looked at the CCSS production process, their budget, and their snow surveys. Preliminary results showed that the cost of this snow survey and runoff forecasting program ranges between

$300,000 and $500,000 per year. In comparison, the annual cost of snow survey work in the Feather River Basin was estimated at $25,000. The average direct cost of measuring snow water content at each of the state's 323 snow courses was estimated at $150 per measurement visit.

Automatic processing of ERTS-1 imagery makes possible an alternative system of producing snow water content estimates. Using a stratified double sampling scheme, ERTS data for three dates were selected to augment conventional snow course measurements. Individual image sample units (ISU's) were interpreted manually according to environmentally-specific snow areal extent cover classes. The watershed was stratified into six strata (by snow water content index) to control the variability of the overall basin snow water content estimate. In addition, two stratum size weighting options were developed: in the first, W01, ground sample units (GSU's) were selected according to ERTS-developed strata boundaries; in the second, W02, ground samples were selected in accordance with conventional techniques of stratified random double sampling. A total of 2,218 ISU's at a cost of 13.6¢ each were utilized in the Feather River Basin. These were combined with a much smaller number of GSU's (snow course measurements) at $150 each to produce a range of performance characteristics for snow water content estimates at alternative budgets and precision levels.

A comparison of the two systems' performance characteristics indicates a decided advantage for the ERTS-aided system of snow water content estimation. Our principal conclusions are listed below.

6.520 Major Conclusions

6.521 Cost Savings

Total estimated costs of the two production systems may be compared at many levels of effectiveness. Figure 6.3 showed the CCSS system producing at a direct cost budget level of $4,200 per snow survey month; point P_0 identified one production possibility at that budget. Point P_1, representing an output of equivalent precision and accuracy on the ERTS-aided system's production schedule, showed a $2,300 cost savings. Extrapolated over the full range of survey months, this would imply a savings of around 50 percent ($13,300) over the existing annual snow survey budget for the Feather River Basin.

6.522 Increased Precision

Advantages of the ERTS-aided system are also apparent on the capability or effectiveness side. At a given budget level, the proposed snow water content estimation system produced results 4.9 times more precise than the existing system when W02 was applied. Under W01, the ERTS-aided system was more than 1.8 times more precise than the current CCSS system when existing snow courses were stratified into snow water content strata based on ERTS data. Without this stratification, the ERTS-aided system (under W01) was 7.2 times more precise than the conventional approach. A comparison of weighting options showed that the

ERTS-aided system under W01 estimated overall watershed snow water content with approximately 1.0 to 1.6 times the precision of the same system using W02.

The ERTS-aided system with weighting option 1 yielded the most precise estimates of total watershed snow water content. For a $5,000 monthly budget, this approach estimated true basin snow water content to within ± 3.92% ninety-five times out of a hundred. The precision of basin water content estimates could be improved still further by using techniques that increase the correlation of orbital to ground snow water content estimates. Smaller image sample units, more environment-specific snow class interpretations, and automatic processing of satellite digital data are some of the more promising of these techniques.

The choice between weighting options is dependent upon the researcher's objectives. W02 will give more precise estimates for fringe snow zone areas. If fringe areas are important during some periods of flood forecasting, then W02 with the ERTS-aided system will produce the better results. However, if overall basin snow water content is highly correlated with either short- or long-term water yield, then W01 is more appropriate.

6.523 Additional Abilities

The ERTS snow areal extent-snow water content transform presented here is only a first case model. Yet it yields correlations with ground sample data on the order of .80. More sophisticated stochastic and physical transform models now being developed should push this correlation significantly higher. The result will be greater snow water content estimation precision at the same level of budget.

The ERTS-to-ground correlation coefficient of .80 was achieved using satellite imagery specific to two ground survey dates plus minimal information from a third date. In an operational situation, however, detailed early-season and/or previous-snow-season ERTS data would be available in combination with the snow date of interest, this additional information should further increase the correlation coefficient and produce an even more cost-effective snow water content estimation.

An ERTS-aided snow water content estimation system offers several additional possibilities for future snow survey work:

- One biproduct of the ERTS-derived image sample unit data is an in-place mapping of snow water content with respect to known melting environments and stream channels. Such time- and place-specific snow melt records could be used to aid in the selection of new snow course sites or in the placement of automatic snow sensors. Snow pack and stream channel juxtaposition data could also be used in refined models of runoff timing.

- Human and automatic analysis of daily meteorological statellite data, when correlated with less frequent ERTS and ground data, offers the possibility of extremely frequent watershed snow water content updating.

- Hydrologic models of the future will conceivably integrate remote-sensing and meteorological data with automatic ground-based snow sensing equipment. Real-time information eventually could be generated for entire watersheds of subbasins, depending on the need to assess the impact of a major storm or a minor subdivision. The continued refinement of remote sensing-aided snow water runoff estimation procedures is likely to be a necessary input into future water resource management practices.

6.530 Major Recommendations

The foregoing conclusions suggest that remote sensing promises great potential for aiding in the snow water content estimation process. Our findings are further enhanced by the fact that snow water runoff is one of the major sources of water supply within the California Water Plan, as well as in many parts of the world. Improved methods of identifying, monitoring, mapping, and modeling our snow water resources at this time can lead to improved methods of predicting and managing this resource in the future. ERTS-derived imagery, when used to augment existing hydrologic models, thus appears to resemble a classic "technological advance" when analyzed with a cost-effectiveness framework.

Our conclusions, however, should remain tentative pending additional study. We can identify a number of activities and tasks to be performed in a variety of areas, but most of them can be classified into simultaneous work on modeling, testing, evaluation, and implementation processes. These categories are discussed below in pairs.

6.531 Modeling and Testing Process

Back in the production process diagramed in Figure 6.2, we described how various inputs were transformed into the California Cooperative Snow Survey program's snow water forecasting outputs. The proposed ERTS-aided system augments those inputs with remote sensing imagery and slightly modifies the subsystem components that produce the intermediate output of snow water content estimates. In this context, the following tasks can be suggested:

- More work is needed to refine the integration of ERTS data with the CCSS (volumetric) model. This would entail experimenting with methods to produce more precise snow water content estimates as well as examining other parameters in addition to water content estimates.

- Other hydrologic models such as the dynamic CCSS model or the River Forecasting Center model should be tested to see if ERTS-derived inputs can be employed successfully.

- Other data inputs such as meteorological data should be examined to see how a combination of ERTS and meteorological data might be used to enhance the availability and precision of existing snow water runoff forecasts.

- Additional studies should be performed in other watersheds to compare with our Feather River Basin study. Such studies could help verify our results as well as isolate particular basin-specific parameters which influence snow water content estimates.

6.532 Evaluation and Implementation Process

The Figure 6.2 production process diagram is also useful for portraying the close relationship between all four of our categories. Evaluation is a necessary part of a comparative test run between models; the implementation process helps define how the system may be better organized to meet the needs of recipients. We can suggest several remaining tasks in the evaluation and implementation areas:

- Existing cost and effectiveness results should be further verified, refined, and expanded. The CCSS cost estimates are still very rough and can use additional scrutiny. Likewise, RSRP cost estimates and precision results should be compared with similar work when completed in the future. Broadening the analysis to include capital costs is also important. Potential users must consider start-up costs before they can implement a potentially more effective information-gathering system.

- An examination of sensitivity issues should logically follow additional test cases. For example, it would be useful to know how snow water content estimations are affected by specific changes in latitude, climate, and geography.

- An extension of the analysis into benefits issues is also a necessary part of a thorough evaluation process. Cost-effectiveness analysis measures benefits in terms of cost savings. By studying the primary and secondary net benefits accruing from more frequent and more precise information, we can better identify the ultimate beneficiaries and the value of the cost savings to them.

- A strong user orientation is required in any technological application process. Identification of beneficiary groups is a help in this direction, but actual implementation of an ERTS-aided snow water content estimation system would involve close collaboration with user-agency personnel and significant technical assistance. With sufficient encouragement from potential user-agencies, the RSRP should be prepared to help furnish the expertise necessary for testing ERTS-aided models in a more operational environment.

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APPENDIX I - SAMPLE SIZE DETERMINATION FOR WATERSHED SNOW WATER CONTENT ESTIMATION UTILIZING STRATIFIED DOUBLE SAMPLING WITH REGRESSION ESTIMATION

The objective of this appendix is to present, and in some cases to derive, optimal sample size and relative sampling rate formulas that will minimize the estimated variance of the quantity (total watershed snow water content) to be estimated. Much of the mathematical discussion builds on material presented by Cochran (1963) and Raj (1968).

The sampling design proposed for precise estimation of total watershed snow water content is known as stratified double sampling. With this approach, the watershed as depicted on a satellite image is separated into a continuous grid of rectangular sampling units. For each sampling unit i, an estimate is made of the areal extent of snow as interpreted from satellite imagery. These decisions are based on known vegetation-terrain-snow extent relationships and appearances on the imagery. These estimates for each sampling unit are then transformed into a snow water content value, X_i, based on multiple date satellite data.

The significant advantage of this approach is that snow-state information is available for the whole watershed. A very small ground sample of the sample units depicted on the imagery gives rise to actual snow water content values, y_i. These ground values may then be used to calibrate, through a regression model, the satellite data. Since satellite information significantly correlated to snow variability is available from throughout the basin, the calibrated estimate leads to a more precise estimation of snow water content than possible through ground simple random sampling alone. Stratification of the image sample units into classes based on the relative size of the satellite snow water content estimates increases further the precision of estimation. In general double sampling will be prefered to ground simple random sampling in a given stratum if (based on Cochran 1963)

$$\rho_h^2 > \frac{4c_{n_h} c_{n'_h}}{(c_{n_h} + c_{n'_h})^2}, \qquad \text{eq. 1.1}$$

where

h = stratum index,

$\hat{\rho}_h$ = estimated correlation between image and ground data values for stratum h,

c_{n_h} = unit direct cost of obtaining data from a ground sample unit in stratum h, and

$c_{n'_h}$ = unit direct cost of obtaining data from an image sample unit in stratum h.

The estimation model for a given stratum is assumed to be a simple linear regression relationship relating image and ground data as follows.

$$\hat{Y}_h = A_h N_h \hat{\bar{Y}} = A_h N_h (\hat{\bar{y}}_h + b_h (\hat{\bar{X}}_h - \hat{\bar{x}}_h)) \qquad \text{eq. 1.2}$$

where

h = stratum index,

$\hat{Y}_h$ = total of estimated quantity (snow water content) for stratum h,

$\hat{\bar{Y}}_h$ = estimated mean of quantity for stratum h,

A_h = area per image sample unit,

N_h = total number of image sample units in stratum h,

$\hat{\bar{y}}_h$ = estimated average quantity for stratum h based on a sample of ground sample units,

$\hat{\bar{x}}_h$ = estimated average quantity for stratum h for a sample of image sample units corresponding spatially to the ground units sampled,

$\hat{\bar{X}}_h$ = estimated average quantity for stratum h, based on the estimates from all image sample units in stratum h, and

b_h = estimated regression coefficient between y_h and x_h.

An estimate for the total snow water content over all strata in the area of interest is given by

$$\hat{Y}_{total} = \sum_{h=1}^{L} \hat{Y}_h \qquad \text{eq. 1.3}$$

where L = total number of strata.

Noting the relationship in equation 1.2 between $\hat{Y}_h$ and $\hat{\bar{Y}}_h$ it may be concluded that sample size determinations to meet precision criteria for either will be the same. Thus for convenience, the following sampling rate derivations will be expressed for estimation of $\hat{\bar{Y}}_{total}$.

The optimum sampling rate between image and ground sample units for a given stratum may be derived (Thomas 1974 based on Cochran 1963) as

$$\lambda_{opt_h} = \frac{n_h}{n'_n} = \sqrt{\left(\frac{(1-\hat{\rho}_h)^2}{\hat{\rho}_h^{\,2}}\right) \cdot \frac{c_{n'_h}}{c_{n_h}}} \qquad \text{eq. 1.4}$$

where n_h = ground sample size for stratum h, and

n'_h = image sample size for stratum h.

It can be shown that for mean quantity estimation the optimal ratio of ground sample size for stratum h to the total ground sample size is (Thomas 1974)

$$\frac{n_h}{n_{total}} = \frac{N_h\hat{S}_h(1-\hat{\rho}_h^{\,2}(1-\lambda_{opt_h}))^{\frac{1}{2}}/\sqrt{c_h}}{\sum_{h=1}^{L}(N_h\hat{S}_n(1-\hat{\rho}_h^{\,2}(1-\lambda_{opt_h}))^{\frac{1}{2}}/\sqrt{c_h}} \qquad \text{eq. 1.5}$$

where N_h = total number of image sample units in stratum h,

$\hat{S}_h$ = estimated standard deviation for sample unit data values in stratum h based on ground sample information if available, otherwise based on image sample unit data,

$\hat{S}_{st_h} = \hat{S}_h(1-\hat{\rho}_h^{\,2}(1-\lambda_{opt_h}))^{\frac{1}{2}}$,

= estimated standard deviation of the estimate for stratum h, and

$$c_h = (\lambda_{opt_h})c_{n_h}+(1-\lambda_{opt_h})c_{n'_h} \qquad \text{eq. 1.6}$$

= optimal average ground plus image sample direct cost per sample unit

Dividing both sides of equation 1.5 by the inverse of $\hat{\bar{Y}}_h$, the average estimated snow water content per image sample unit in stratum h, gives

$$\frac{n_h}{n_{total}} = \frac{N_h CV_h(1-\hat{\rho}_h^{\,2}(1-\lambda_{opt_h}))^{\frac{1}{2}}/\sqrt{c_h}}{\sum_{h=1}^{L}(N_h CV_h(1-\hat{\rho}_h^{\,2}(1-\lambda_{opt_h}))^{\frac{1}{2}}/\sqrt{c_h})} \qquad \text{eq. 1.7}$$

where CV_h = the coefficient of variation for stratum h. This value is often multiplied by 100 so as to be expressed as a percentage value.

When N_h is used to represent stratum size as in eq. 1.7, then weighting option 2 (W02) is used in defining n_h/n_{total}. Under W02 those strata with the largest area and most variability, given constant $\hat{\rho}_h$ and c_h, will be sampled most intensively on the ground. As it often happens in major watersheds, the most variable and sometimes larger strata will be those occupying fringe snow zone areas. Hence eq. 1.6 will tend to allocate ground sample concentrations to strata containing relatively small snow water content totals. If snow quantity in these strata is highly correlated to water yield in near real-time forecasting situations, then this weighting option may be prefered. This option would then give the most precise estimates for those relatively low total snow water content strata.

However, if the snow water content for high total water content strata is most important to either real-time water yield or longer term water supply forecasting, then another weighting option (W01) is preferable. W01 is based on stratum weights defined by the accumulated snow water content estimate over all image sample units in that stratum. That is

$$\hat{X}_h = \sum_{i=1}^{I_h} X_{hi} \qquad \text{eq. 1.8}$$

where I_h = total number of image sample units in stratum h, and

X_{hi} = snow water content estimate for image sample i in stratum h.

Thus for WO 1 we have

$$\frac{n_h}{n_{total}} = \frac{\hat{X}_h CV_h (1-\hat{\rho}_h{}^2(1-\lambda_{opt_h}))^{\frac{1}{2}}/\sqrt{c_h}}{\sum\limits_{h=1}^{L} (\hat{X}_h CV_h (1-\hat{\rho}_h{}^2(1-\lambda_{opt_h}))^{\frac{1}{2}}/\sqrt{c_h})} \qquad \text{eq. 1.9}$$

When total budget is fixed, n_{total} may be calculated by (Thomas 1974)

$$n_{total} = \frac{(C-c_o)\sum\limits_{h=1}^{L} (N_h CV_h (1-\hat{\rho}_h{}^2(1-\lambda_{opt_h}))^{\frac{1}{2}}/\sqrt{c_h})}{\sum\limits_{h=1}^{L} N_h CV_h (1-\hat{\rho}_h{}^2(1-\lambda_{opt_h}))^{\frac{1}{2}}\sqrt{c_h}} \qquad \text{eq. 1. 10}$$

expressing S_h in terms of the coefficient of variation, CV_h, and noting

C = total snow survey budget for estimation of snow water content in the watershed of interest including both direct and indirect costs,

c_o = total indirect cost portion of budget, C, for snow water content estimation in the watershed of interest, and

$c_{direct} = C-c_o$ = total direct cost portion of budget, C, available for snow water content sample unit measurements in the watershed of interest.

Equation 1.10 is applicable to weighting option 2, while the appropriate substitution of $\hat{X}_h$ for N_h gives the derivation for n_{total} in the case of WO1, viz:

$$n_{total} = \frac{(C-c_o)\sum\limits_{h=1}^{L} (\hat{X}_h CV_h (1-\hat{\rho}_h{}^2(1-\lambda_{opt_h}))^{\frac{1}{2}}/\sqrt{c_h})}{\sum\limits_{h=1}^{L} (\hat{X}_h CV_h (1-\hat{\rho}_h{}^2(1-\lambda_{opt_h}))^{\frac{1}{2}}\sqrt{c_h})} \qquad \text{eq. 1.11}$$

Ground sample sizes may then be calculated for each stratum according to

$$n_h = (n_{total})(\lambda_{opt_h})(\frac{n_h}{n_{total}}) \quad . \qquad \text{eq. 1.12}$$

For optimum image-ground sampling rates the number of image sample units per stratum is then given by

$$n'_n = (n_h)(\frac{1}{\lambda_{opt_h}}) \quad . \qquad \text{eq. 1.13}$$

The total estimated direct cost of snow water content measurement for the watershed of interest will then be

$$c_{direct\ est.} = \sum_{h=1}^{L} (n_h c_{n_h} + n'_h c_{n'_h}) \qquad \text{eq. 1.14}$$

$$= \sum_{h=1}^{L} c_{direct\ est._h} \quad .$$

However in most cases, due to the relationship between equations 1.6 and 1.13, $c_{direct\ est.}$ will exceed the given c_{direct}. Thus the number of ground and image sample units must be adjusted downward so that $c_{direct\ est.}$ and c_{direct} will be equal. This adjustment is performed by calculation of

$$c_{dif.} = c_{direct\ est.} - c_{direct} \qquad \text{eq. 1.15}$$

and determining the proportion of the total direct cost residing in a given stratum,

$$c_{prop_h} = \frac{c_{direct\ est._h}}{c_{direct\ est.}} \quad . \qquad \text{eq. 1.16}$$

Then the sample size reduction factor, K_{r_h}, to apply to both n_h and n'_h for a given h is

$$K_{r_h} = (c_{prop._h})(c_{dif.})(c_{dif.}/c_{direct}) \quad . \qquad \text{eq. 1.17}$$

In some instances the calculated image sample unit size, n'_h, may exceed the total number of possible sample units, N_h, in a given stratum. When this occurs n'_h must be set equal to N_h and λ_{opt_h} reset to n_h/N_h. The money saved

$$c_{save_h} = (n'_h - N_h)(c_{n'_h}) \qquad \text{eq. 1.18}$$

is then reallocated to other strata not having n'_h exceed N_h. This may be done by calculating

$$c'_{direct\ est.} = \sum_{(h\varepsilon d)} c'_{direct\ est._h} = \sum_{(h\varepsilon d)} c_{direct\ est._h} - c_{save_h} \qquad \text{eq. 1.18}$$

for all strata having n'_h exceed N_h (comprising set D) and obtaining

$$c'_{direct} = c_{direct} - c'_{direct\ est.} \qquad \text{eq. 1.20}$$

Then new n_h and n'_h are calculated with the new direct budget, c'_{direct}, for those strata not belonging to set D. In this way n_h and n'_h are obtained by an iterative application of boundary conditions and associated adjustment procedures.

A final sample size correction is appropriate to the snow water content estimation procedure. Since it is specified that all image sample units in a given stratum be examined, the additional cost over the optimum n'_h sample size,

$$c_{additional_h} = (N_h - n'_h)(c_{n'_h}), \qquad \text{eq. 1.21}$$

must be taken into account. The procedure utilized consists of adjusting downward the corresponding ground sample size, n_h, for the stratum of interest. Thus

$$n_h = n_h - ((n_h)(\frac{c_{additional_h}}{c_{n_h}})) \quad \text{eq. 1.22}$$

After final calculation of n_h and n'_h, we may proceed to determine the expected precision of the final watershed snow water content estimate. It is first necessary to calculate an expected overall measure of that estimate's variability. From Thomas (1974)

$$\hat{V}(\hat{\bar{Y}}_{total}) = \sum_{h=1}^{L} (W_h)^2 \frac{1}{n_h} \hat{S}_h^2(1-\hat{\rho}_h^2(1-\lambda_{opt_h}))$$

$$- \sum_{h=1}^{L} (W_h)^2 \frac{1}{N_h} \hat{S}_h^2(1-\hat{\rho}_h^2(1-\lambda_{opt_h})) \quad \text{eq. 1.23}$$

where $\hat{V}(\hat{\bar{Y}}_{total})$ = the estimated variance of $\hat{\bar{Y}}_{total}$

W_h = a stratum weight

and the last sum on the right represents the finite population correction. Expressing equation 1.23 in terms of the coefficient of variation we have

$$CV^2_{overall} = \sum_{h=1}^{L} (W_h)^2 \frac{1}{n_h}(CV_h^2(1-\hat{\rho}_h^2(1-\lambda_{opt_h}))$$

$$- \sum_{h=1}^{L} (W_h)^2 \frac{1}{N_h}(CV_h^2(1-\hat{\rho}_h^2(1-\lambda_{opt_h})) \quad \text{eq. 1.24}$$

For stratum weighting option 1

$$W_h = \frac{\hat{X}_h}{\sum_{h=1}^{L} \hat{X}_h} \quad \text{eq. 1.25}$$

and for stratum weighting option 2

$$W_h = \frac{N_h}{\sum_{h=1}^{L} N_h} \quad . \qquad \text{eq. 1.26}$$

Then if precision is defined in terms of allowable error, AE, we have for a given budget structure

$$AE = (t_{n_{total}-1})CV_{overall} \qquad \text{eq. 1.27}$$

where $t_{n_{total-1}}$ = Student's-t with $n_{total-1}$ degrees of freedom corresponding to a chosen level of confidence, $1-\alpha$, and

AE = the half-width of an interval, usually expressed as a percentage of the estimated value, in which the actual watershed snow water content is said to lie with probability $1-\alpha$.

APPENDIX II - STATISTICS USED IN THE CALCULATION OF SAMPLE SIZES AND ALLOWABLE ERRORS FOR THE REMOTE SENSING-AIDED SNOW WATER CONTENT ESTIMATION SYSTEM

Table II.1 gives the results for ERTS snow water content statistics based on Spanish Creek Watershed data. These statistics are used to represent Feather River Basin values due to the similarity in snow water content class distribution between the two basins for the snow season dates investigated.

Table II.2 gives the ERTS snow areal extent and resulting snow water content indices corresponding to ground data for the Feather River Watershed. The resulting correlation between ground (y_{ave}) and X_3 is 0.85, between y_{ave} and $X_{3'}$ is 0.80, and between y_{ave} and X_2 is 0.77. Since more than two dates will be available in most operational snow water content estimation situations, a conservative value of 0.80 was selected as the correlation coefficient to be used in the sample size analysis. Correlation coefficients could not be calculated individually for all strata. This situation resulted from the lack of adequate degrees of freedom for snow courses falling in individual ERTS snow water strata. Examination of several months of data may allow stratum specific correlation coefficients to be calculated.

The above CV_h, $\hat{X}_h$, W_h, N_h, and $\hat{\rho}_{X_{3'},y_{ave}}$ statistics were substituted into formulas given in Appendix I to calculate ground and image sample sizes. These figures were also used to calculate the overall basin coefficient of variation, $CV_{overall}$, used in determining allowable error for the basin estimate of total snow water content.

TABLE 11.1 - ERTS SNOW WATER CONTENT STATISTICS BASED ON SPANISH CREEK WATERSHED DATA FOR APRIL 4, MAY 10, AND MAY 28, 1974

Stratum Index (h)	ERTS Snow Water Content Estimate Range	Ave. Snow Water Content Index Per Image Sample Unit $\overline{X}_h = \frac{\sum_{i=1}^{I_h} X_{hi}}{I_h}$	Standard Deviation For X_{hi} σ_h	Coefficient of Variation $CV_h = \frac{\sigma_h}{\overline{X}_h} X100$	Total Snow Water Content Index $X_h = \sum_{i=1}^{I_h} X_{hi}$	Stratum Weight Based on Snow Water Content $W_h = \frac{X_h}{\sum_{i=1}^{6} X_h}$	Number of Image Sample Units for the Spanish Creek Watershed N_h^*	N_h^*/N^*	Number of Image Sample Units For the Feather River Watershed $N_h=2,218\left(\frac{N_h^*}{N^*}\right)$
1	0.00-<0.10	0.0000	0.0000	0.00	0.00	0.0000	32	0.2270	503
2	0.10- 0.35	0.1833	0.1194	65.14	7.15	0.0304	39	0.2766	614
3	<0.35-<1.00	0.7808	0.1883	24.12	10.15	0.0432	13	0.0922	205
4	1.00-<3.00	2.0480	0.4404	21.50	51.20	0.2178	25	0.1773	393
5	3.00- 5.00	3.9557	0.4525	11.44	55.38	0.2356	14	0.0993	220
6	>5.00	6.1750	0.9672	15.66	111.15	0.4729	18	0.1277	283
							$N^*=141$		N=2,218

CCSS Snow Course Index (i)	ERTS ISU Snow Areal Extent Data Corresponding to Snow Course Location[2]: Snow Class (Date 1)	Midpoint S_{1i}	Snow Class (Date 2)	Midpoint S_{2i}	Snow Class (Date 3)	Midpoint S_{3i}	Intermediate Statistics: $M_{2i} = \sum_{j=1}^{2}$ snow class midpoints $= \sum_{j=1}^{2} S_{ji}$	$M_{3i} = \sum_{j=1}^{3} S_{ji}$	K_{2i} = Number of times corresponding ISU had snow class > 1 for j=1,2	K_{3i} = Number of times corresponding ISU had snow class > 1 for j = 1,2,3	Resulting Snow Water Content Indices: $X_{3i} = (M_{3i})(K_{3i})$ Based on: 3 dates snow class 3 dates snow presence/absence	$X_{3'i} = (M_{2i})(K_{3i})$ Based on: 2 dates snow class 3 dates snow presence/absence	$X_{2i} = (M_{2i})(K_{2i})$ Based on: 2 dates snow class 2 dates snow presence/absence	Average April-May Snow Water Content in Inches of Water as Determined from CCSS Ground Survey Measurement[3] (Y_{ave_i})	The Resulting Correlations Between ERTS and Ground Snow Water Content Measures:
47	5	.99	5	.99	5	.99	1.98	2.97	2	3	8.91	5.94	3.96	83.30	
49	5	.99	5	.99	3	.35	1.98	2.33	2	3	6.99	5.94	3.96	73.30	
54	5	.99	5	.99	4	.74	1.98	2.72	2	3	8.16	5.94	3.96	51.75	$\rho_{X_3, Y_{ave}} = 0.85$
53	5	.99	4	.74	2	.10	1.73	1.83	2	3	5.49	5.19	3.46	49.95	
179	5	.99	5	.99	4	.74	1.98	2.72	2	3	8.16	5.94	3.96	47.15	
56	5	.99	3	.35	1	.00	1.34	1.34	2	2	2.68	2.68	2.68	38.80	$\rho_{X_{3'}, Y_{ave}} = 0.80$
52	5	.99	4	.74	3	.35	1.73	2.08	2	3	6.24	5.19	3.46	34.45	
360	5	.99	4	.74	1	.00	1.73	1.73	2	2	3.46	3.46	3.46	29.50	
51	5	.99	5	.99	2	.10	1.98	2.08	2	3	6.24	5.94	3.46	26.85	
359	5	.99	2	.10	1	.00	1.09	1.09	2	2	2.18	2.18	2.18	26.20	$\rho_{X_2, Y_{ave}} = 0.77$
48	5	.99	3	.35	2	.10	1.34	1.44	2	3	4.32	4.02	2.68	26.00	
55	5	.99	3	.35	1	.00	1.34	1.34	2	2	2.68	2.68	2.68	25.10	
58	5	.99	3	.35	2	.10	1.34	1.44	2	3	4.32	4.02	2.68	23.80	
290	5	.99	4	.74	1	.00	1.73	1.73	2	2	3.46	3.46	3.46	16.75	
280	5	.99	3	.35	1	.00	1.34	1.34	2	2	2.68	2.68	2.68	13.25	
355	4	.74	1	.00	1	.00	.74	.74	1	1	.74	.74	.74	6.70	
354	3	.35	1	.00	1	.00	.35	.35	1	1	.35	.35	.35	3.70	
353	4	.74	1	.00	1	.00	.74	.74	1	1	.74	.74	.74	1.30	

1. Ground-image sample unit spatial matching was based on the best published data (Bulletin 129). CCSS has recently plotted their Feather River Watershed snow courses on 15 minute USGS quadrangles and these data will be used to check the previous ground ERTS sample unit registration.

2. Date 1 = April 4, 1973; Date 2 = May 10, 1973; Date 3 = May 28, 1973.

3. Snow water content measured near the first of each month.

TABLE 11.2 - ERTS SNOW AREAL EXTENT DATA AND RESULTING SNOW WATER CONTENT INDICES FOR THE IMAGE SAMPLE UNITS (ISU's) TENTATIVELY[1] LOCATED OVER AREAS IN WHICH CORRESPONDING SNOW COURSES EXIST FOR THE FEATHER RIVER WATERSHED, CALIFORNIA

APPENDIX III - DETERMINATION OF ALLOWABLE ERROR FOR CCSS SNOW COURSE DATA

Ideally, two or more ERTS survey dates before a snow prediction date are desirable for high ERTS to ground snow water content correlations. In such a situation, ERTS snow water estimates using equation 4.1 would be made for the date of interest. A direct comparison would be made for ground data of that date. However, interpreted ERTS snow areal extent data were not available to this study for an additional month preceding April 1973. Therefore the average of CCSS April and May 1st snow water content values was chosen as the ground data against which to compare corresponding ERTS estimates.

The California Cooperative Snow Survey's snow course data for the Feather River Basin are given in Table III.1. Snow water content information for April and May 1973 is listed along with the average values for the two dates. The second column from the right gives the average values sorted highest to lowest. These are in turn sorted into ranges based on ERTS snow water content strata proportions.

In order to calculate a basin snow water content allowable error, a coefficient of variation (CV) among snow courses must be determined. This operation can be performed if it is assumed that the snow courses are randomly allocated to image sample units throughout the Feather River Watershed. This assumption was justified in section 4.223. It actually favors performance of the CCSS model, since the courses are actually not allocated to all areas of the watershed. Thus they do not sample completely snow water content variability within a basin. However,

TABLE III.1 - CCSS SNOW COURSE DATA FOR APRIL AND MAY 1973

CCSS Course Index (i)	April SWC* y_{A_i}	May SWC y_{M_i}	Average of April and May SWC Y_{ave_i}	Simulated ERTS Stratum No.
47	84.0	82.6	83.30	6
49	76.7	69.9	73.30	6
54	56.0	47.5	51.75	6
53	55.0	44.9	49.95	5
279	52.9	41.4	47.15	5
56	46.5	31.1	38.80	5
395	47.6	36.0	36.80	5
52	41.3	27.6	34.45	5
360	37.2	21.8	29.50	4
51	31.2	22.5	26.85	4
359	33.2	19.2	26.20	4
48	28.2	23.8	26.00	4
55	28.9	21.3	25.10	4
58	30.2	17.4	23.80	4
361	24.6	12.8	18.70	4
290	21.3	12.2	16.75	4
280	17.6	8.9	13.25	4
355	13.4	0.0	6.70	3
394	12.2	0.0	6.10	3
354	7.4	0.0	3.70	3
353	2.6	0.0	1.30	2
$n =$	21	21	21	
$\bar{y} =$	35.62	25.28	30.45	
$\hat{\sigma} =$	21.39	22.07	21.61	
$CV = \frac{\hat{\sigma}}{\bar{y}} \times 100 =$	60.05	87.31	70.96	

*Footnote: SWC = Snow Water Content in Inches as was also pointed out in the text, it is not the present intent of the snow course network to sample all snow water content strata in a complete fashion.

After assuming simple random sampling, the coefficient of variation is calculated for each snow data set by determining the sample standard deviation, dividing it by the sample mean and multiplying the result by 100. These statistics are generated at the bottom of Table III.1 for the April, May, and average snow water content data sets.

As seen in Table III.1, the resulting CV for the averaged data set is 70.96 percent. This value can be adjusted by the finite population correction

$$fpc = \frac{N-n}{N} = \frac{2218-21}{2218} = .9905 \qquad \text{eq. III.1}$$

where N = total number of image sample units in a basin, and

n = total number of image sample units ground sampled,

to give a corrected CV of 70.29 percent.

The calculated CV is substituted into equation 4.2 to give an allowable error figure. This allowable error value may then be directly compared to the AE results for the ERTS weighting option 2 method. On the other hand, to compare weighting option precision figures to CCSS AE values requires an additional consideration. For strict statistical comparability (based on Cochran 1963), a weighting of the snow course observations similar to that performed on ERTS strata is necessary. This amounts to treating the CCSS sample as one selected with probability proportional to the water content size of the ERTS stratum in which they would be expected to fall. The estimated variance for such a sample would then be (based on Cochran 1963)

$$\hat{V}(\hat{\hat{Y}}_{pps}) = \frac{1}{nM_o} \sum_{h=1}^{6} \sum_{i=1}^{I_h} M_{hi} (\overline{y}_{hi} - \hat{\hat{Y}})^2 \qquad \text{eq. III.2}$$

where

$$M_o = \sum_{h=1}^{6} \sum_{i=1}^{I_h} M_{hi},$$

$M_{hi} = X_h$ = total snow water content index for stratum h based on ERTS data,

n = sample size (no. of snow courses),

I_h = number of snow courses falling in snow water content strata h as determined from Table III.1,

$\overline{y}_{hi}$ = estimated snow water content value for snow course i of stratum h, and

$\hat{\hat{Y}}$ = estimated mean snow water content of all snow courses for the sample, defined here as the mean of the averaged snow water content ground values.

Substitution of the appropriate data into equation III.2 allows the calculation of a CV of 17.64 percent. Adjustment for the finite population correction gives 17.47 percent. This value may then be used in equation 4.2 to generate AE figures which can be compared to the results of the ERTS weighting option 1 method.

The sensitivity of the CV calculated via equation III.2 to a change in data assumptions should be examined. This analysis is relevant here since the proportion of snow courses in a given ERTS stratum range does not in fact match the proportion defined for the watershed according to data given in Appendix II. That is, probability proportional to estimated size sampling would not likely result in the snow course set currently operated by the CCSS.

Table III.2 summarizes the CCSS and ERTS strata size proportions based on the number of ground and image samples respectively falling in various strata. The ERTS proportions show the h=6 and h=5 case. The stratum size 5 (h=5) case was included to determine changes in calculated CV if the first ERTS stratum were dropped. The ratios of ERTS to ground strata proportions are shown in the two right-most columns. Applying these ratios, or relative stratum size correction factors, to formula III.2 then gives a measure of sensitivity of the calculated CV to ERTS-CCSS stratum size inconsistencies.

The result of the sensitivity analysis is that for h=6 the CV drops approximately 1% relative to the previous calculated value. For h=5, the CV rose on the order of 1%. Due to the small offsetting changes, the originally calculated CV value, 17.47 percent, is utilized for AE calculations in this study.

TABLE III.2 - CCSS AND ERTS SYSTEM STRATA SIZE PROPORTIONS

CCSS			ERTS				Stratum Size Proportion Ratios	
h	n_h (1)	$\frac{n_h}{n} = R_{CCSS}$	n_h (2)	$\frac{n_h}{n} = R_{ERTS_1}$	n_h (3)	$\frac{n_h}{n} = R_{ERTS_2}$	$R_1 = \frac{R_{ERTS_1}}{R_{CCSS}}$	$R_2 = \frac{R_{ERTS_2}}{R_{CCSS}}$
1	0	0.0000	32	0.2270	---	---	---	---
2	1	0.0476	39	0.2766	39	0.3578	5.8109	7.5168
3	3	0.1429	13	0.0922	13	0.1193	0.6452	0.8348
4	9	0.4286	25	0.1773	25	0.2294	0.4137	0.5352
5	5	0.2381	14	0.0993	14	0.1284	0.4171	0.5393
6	3	0.1429	18	0.1277	18	0.1651	0.8936	1.1554
Σ =	21	1.0001	141	1.0001	109	1.0000		

1. For entire Feather River Basin.

2. Spanish Creek Watershed data: Distribution of snow classes assumed approximately equal to the Feather River Basin distribution.

3. Spanish Creek Watershed data omitting stratum 1.

CHAPTER 7

ERTS AS AN AID IN TIMBER VOLUME INVENTORY

A Special Presentation to Office of Applications, NASA Hdqts. Funded under NASA Grant No. NGL05-003-404

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CHAPTER 7

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7.00 INTRODUCTION

Under some rather broad guidelines as set forth in our ERTS-1 contract the Remote Sensing Program investigated the utility of ERTS to provide useful information for wildland resource management. To investigate the information content of the ERTS data we used both human and computer discriminant analysis techniques to extract information from raw photographic data, color enhanced data and computer compatible tapes. Early in the investigation we determined that the human could delineate general vegetation types in environmentally similar areas using the raw bulk color composite images. We also determined that the computer could identify, down to the plant community level, species composition, stand density and some stand condition information. It became apparent that the ERTS data could not meet all of the wildland resource manager's needs, but that it could provide a basis for sampling the wildland environment. From this basic research the Remote Sensing Research Program at the University of California began to develop techniques to utilize the information available from the ERTS satellite in multistage sampling schemes.

By March 1973 progress had been made to the point where discriminant analysis could be made at the plant community level, delineation of large environmental areas could be made to control a discriminant analysis procedure, multistage sampling strategy and estimation procedures had been developed, large scale photograhic capabilities were available, and user requirements had been defined. The information requirements had been determined for forestry, range, land use, recreation, engineering and land use planning.

Due to time constraints on our ERTS-1 study, it was decided that only a single-parameter inventory could be concluded within the contract limitations. Based on the work completed by Langley under the Appollo program and the fact that one of the single most important parameters to the forest manager, timber industry, and resource policy maker is saleable timber volume, this was the single parameter selected for inventory and assessment.

The results which we obtained in the Plumas National Forest, Quincy Ranger District timber volume inventory were encouraging. The variance of the final estimate was reduced far below the expected value and sample size was reduced as a result of this. The ERTS data contributed to the overall success of the inventory by providing a quick, consistent, and inexpensive means of providing the first stage work for allocating samples and providing initial estimates of timber volume. It also provided a unique new type of information. This was the "in-place" mapping of the wildland vegetation which allowed a much more efficient allocation of samples than had ever before been possible. After the timber volume inventory was completed, it was even more apparent that there was information contained in the ERTS data far beyond the "timber volume only" information that was estimated and confirmed by the original inventory.

As a result of the study and the presentation at the ERTS program review, the Remote Sensing Program's timber inventory study was considered to be nearly operational and follow-on funding was provided. The objective of the extension study was to complete the timber volume inventory and expand it to a total timber resource inventory at the management level. Working with the people from the U.S. Forest Service on the Plumas National Forest, further definition of the overall needs for timber resource information was obtained and a sampling scheme developed to utilize, as fully as possible, the ERTS multispectral scanner data as processed in the discriminant analysis routines. The final field work was completed on September 28, 1974 and the data analysis is now in progress to complete this total timber resource inventory.

As a result of the success of the timber volume study and the work being conducted this year for the total timber resource, the Remote Sensing Program was asked to provide this report on the cost-effective information regarding the timber volume study and as a follow-on, to determine the cost benefit and cost effectiveness of the total timber resource inventory being completed this summer under ERTS extension funding.

7.10 THE NEED FOR TIMBER VOLUME SURVEYS

Sound forest management practices are dependent upon the availability of accurate, timely and economical forest inventory data, which includes timber inventory volume surveys. Forest inventory requirements in the intensively managed temperate regions of the world include data not only on timber volume but also on timber stand condition, ownership, soils, bedrock geology, surface geology, mineral extraction, subsurface water, surface water, vegetation, wildlife, land use, land productivity, climate, historical and cultural patterns, population, market values, and transportation. However, 28% of the world's land area is covered by forest, containing some 12½ trillion cubic feet of timber. Only a small portion of this vast area is intensively managed. Within the non-intensively managed or unmanaged forests, low-cost "volume only" surveys are needed, as man for the first time finds it possible to start placing these forests under management.

7.11 Volume surveys within the United States

In 1970 the annual demand for timber in the United States reached a level of 56 billion board-feet of which 8% was imported. The National Commission on Materials Policy reported in August, 1973 that by the year 2000 annual supplies of both hardwood and softwood would fall short of projected annual demand by about 20 billion board-feet.

In April, 1973 the President's Advisory Panel on Timber and the Environment reported that the current trend in application of the Forest Service timber management planning guidelines on each national forest indicates that the Forest Service will be unable to respond with any significant increase in timber supply (allowable cut) from national forests during the coming decade. Consequently, the nation's increasing demand for timber will be met mainly through increased imports, increased utilization of wood materials currently being harvested and increased utilization of forest lands currently considered marginal for purpose of timber production. Timber volume surveys are needed within these marginal lands since little or no inventory information exists. Vast acreages of Pinon-Juniper forest in the western U.S. are increasingly being used for charcoal production and are being considered as a source of pulpwood, fuelwood, fence posts, and Christmas trees. Likewise, unsurveyed stands of Oak are being used by the furniture, packing and pulp industries, and Eucalyptus is beginning to be utilized for pulp and paper. Bottomland hardwood forests in the Southern U.S. and low-density, low volume softwood stands in Alaska are additional sources of cellulose available for meeting the increase in demand for wood, but for the most part, these forests have never been adequately surveyed in terms of timber volume.

Nevertheless, the U.S. will probably rely more heavily on tropical forests for meeting future demands. The Forest Service reported in the publication entitled "The Outlook for Timber in the U.S.," updated October, 1973, that in spite of growing world demands for timber products, potential increased harvests in Canada and the tropics should meet U.S. import requirements.

7.12 Volume surveys outside the United States

By the year 2000 total world wood consumption will double -- with the largest increases occurring in wood used for pulp. It was noted by the Secretariat for Commission VI of the 7th World Forestry Congress in October, 1972 that world supplies can meet this increased demand as long as exports can be expanded. However, it was pointed out by the National Commission on Material's Policy in August, 1973 that:

> "the optimistic views about growing demand for wood and the ability of the world's forests to meet the demand are clouded by lack of adequate inventories, appraisals and plans for much of the forested areas of the world."

Without a doubt, the greatest need for regional forest volume surveys today is in the relatively less developed tropical regions of the world, including much of Central America, northern and central South America, central Africa, and Southeast Asia. It has been estimated that the tropical forests in these areas comprise approximately 40% of the world's total forest area. Latin America, for example, with its vast reserves, harvested less than 4% of the world's industrial wood during the period 1967-69.

The need for forest surveys in tropical regions stems from a combination of several interrelated factors. Many of the countries in these areas are not highly industrialized, many are not rich in sources of foreign exchange, and in many cases do not possess an abundance or diversity of natural resources. However, in many cases they do have potentially valuable forest resources and relatively inexpensive sources of labor. Thus the forest represents a possible source of material for export, if there is foreign capital for internal development. Also, as industrialization grows and populations increase, there is often a critical need for raw materials for construction and fuel. This is complicated by the fact that in many tropical countries tremendous areas of forest are converted to agriculture (it has been estimated that in Latin America alone, 5 to 10 million hectares of forest land are cleared annually for agriculture).

It is apparent that there exists a critical need for rational, far-sighted development of forests in the less developed tropical regions as opposed to the haphazard liquidation of the resource that has so often occurred. As all foresters know, one of the first requirements for orderly forest management is an accurate, timely inventory of the extent, location, and quality of the resource. Useful forest inventories are lacking, however, in many less-developed countries.

The difficulty of obtaining forest inventories by means of conventional techniques is greatly complicated by variations in the composition of the forests themselves, and the attributes of the regions in which they occur. In many cases tropical forests are composed of a mixture of dozens or even hundreds of species, only 10% or so of which may be commercially valuable for lumber. Before significant investment is made in developing the necessary transportation and processing facilities, it is necessary to know where the greatest volumes of the more valuable species exist. Because the inventory often entails the estimation of proportions of species in various forest types rather than the more simple measurement of relatively pure stands as occur in more temperate regions, forest inventories in tropical regions present some rather unique and as yet unsolved problems in technique.

Finally, the fact that many tropical forest regions are virtually inaccessible on the ground presents serious problems in the implementation of conventional inventory techniques. The cost of getting a man to a ground plot, if possible at all, may be extremely expensive and time consuming. Thus, techniques utilizing ERTS and aircraft data which reduce the number of ground plots may prove to be particularly useful and cost effective in the tropics.

Unlike other timber volume inventory procedures, an ERTS based inventory provides an inplace mapping and estimate of volume by type of the resources with a confidence statement about the accuracy of that estimate. With this information the monitoring of the effect of disaster is more easily handled. If a disaster such as fire, flood, landslide, avalanche, tornado, typhoon, hurricane or insect/disease attack should occur, the area affected can be analyzed using ERTS data on the before and after basis. Estimates of the new total can then be made and the damage evaluated.

An example of where a low-cost ERTS-based survey could have been employed, had it been available, is the insect infestation problem which recently occurred in Honduras. The pine and pine-hardwood forests in Honduras are found on more than 27,000 km^2 of land containing some 134 million m^3 of timber. Since most of the land in Honduras is too mountainous for agricultural uses, the expanding population, expected to reach nearly 2 million people by 1984, is dependent mainly on timber production for providing work and wages. In 1962 a bark beetle epidemic occurred, caused by unknown reasons. By 1964 more than 5,000 km^2 were affected and not until August, 1965 had the infestation lost its epidemic character. Surveys subsequent to the epidemic showed that the average loss of pine volume to the bark beetle had been 20%. At 1964 prices, Honduran pine lumber brought an average of $36 per cubic meter on the export market. If all the volume of pine lost in the epidemic had been cut and sawn into lumber, the exportable portion would have brought Honduras more than 300 million dollars in revenue -- nearly 75% of the GNP for the entire country in 1964.

Obviously this national disaster, like hundreds of others that could be cited here, greatly affected the economic and social stability of the country in which it occurred. Likewise, with an ever expanding dependence of the U.S. on imported wood supplies, the future effects of these disasters on quantity, quality and prices of world wood supplies will without a doubt become increasingly critical. Consequently, not only will developing nations want to inventory and monitor catastrophic events occurring in their own forests, but also the U.S. will want to keep a watchful eye on these occurrences.

In summary, in terms of the utilization and management of raw materials from the forested areas of the world, regional "volume only" estimates have limited but valuable applications. These applications mainly are surveys of marginal forest lands within the U.S., surveys of tropical forests and surveys of the effects of catastrophic events occurring in forested areas throughout the world.

7.20 DESCRIPTION OF MULTISTAGE VARIABLE PROBABILITY SAMPLING FOR TIMBER VOLUME ESTIMATION

Variable probability sampling methods which are employed to estimate total timber volume utilize three variables proportional to timber volume in generating the selection probabilities: (1) "volume" estimates of the ERTS picture elements based on the spectral signatures on four bands and subsequent training and classification; (2) volume estimates of plots on 1:1,000 scale color prints, based on local photo-volume tables and (3) tree volume estimates from large scale photos, based on crown diameters and tree height estimates.

When this scheme is used, where the probability of selection is proportional to the estimated volume, the effort is focused on the areas of higher timber volume and thus adds to the overall cost-efficiency.

7.21 Method of Estimation

The method of estimation is 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) is obtained by listing the volume estimates of the sampling units (x_i), and dividing them by the total

of volume estimates $T_i = \sum_{i=1}^{n} x_i$. Thus, $p_i = \frac{x_i}{\sum_{i=1}^{n} x_i}$.

A sample of a chosen size is then drawn by applying random integers from 1 to T_i and observing the probability interval and the corresponding sampling unit which contains the randomly selected integers (see Table III).

STAGE I Classification of ERTS-1 Data and Primary Sample Unit Selection

ERTS data tapes of the area are classified using a supervised classifier such as the CALSCAN* point-by-point maximum likelihood classification routine. The coordinates of administrative boundaries and of broad vegetation types are identified

*CALSCAN is the RSRP version of the LARS-Purdue pattern recognition program adapted to the CDC 6600/7600 system at the University of California, Berkeley.

TABLE III EXAMPLE OF SAMPLE UNIT SELECTION WITH PROBABILITY-PROPORTIONAL-TO-ESTIMATED-SIZE (PPES). SAMPLE UNIT 4 WAS SELECTED BY DRAWING A RANDOM INTEGER (313) BETWEEN 1 AND $T_c = \sum_{i=1}^{n} x_i = 10000$.

POPULATION OF SAMPLE UNITS i	ESTIMATED SIZE OF SAMPLE UNIT x_i	CUMULATIVE TOTAL OF ESTIMATES $\sum_{i=1}^{n} x_i$	PROBABILITY OF SELECTION $p_i = \frac{x_i}{\sum_{i=1}^{n} x_i}$
1	120	120	120/10000=0.0120
2	73	193	73/10000=0.0073
3	27	220	27/10000=0.0027
4	115	335[1]	115/10000=0.0115
5	66	401	66/10000=0.0066
6	90	491	90/10000=0.0090
.	.	.	.
.	.	.	.
.	.	.	.
n	48	T_c=10000	48/10000=0.0048

1 Sample unit 4 is included in the sample resulting from drawing random integer 313.

2 T_c = Cumulative total of all sample unit estimates in the population.

on the tapes so that only those picture elements associated with forest land are classified and incorporated into the inventory. This stratification procedure considerably reduces the costs of classification and is required for administrative purposes.

Classification should be based on a small number of timber volume classes, for example (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 is trained to recognize each of the timber volume classes based upon photo interpreter selection of training cells according to tree crown closure and average crown diameter (or other variables related to volume for the study area). The training cells can be selected from interpretation of existing resource photography from scales of 1:15,840 to 1:130,000. Each of the training cells is located on the ERTS digital tapes. Point-by-point classification of all ERTS data points within the area proceed by assigning each data point (picture element) to a training class that it most nearly matches. The results are grouped into the selected timber volume classes.

The classified data of the area are divided into rectangular sampling units (called primary sampling units). The size of these sampling units is based on (1) a practical area which can 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, (3) the variation between SU's. and (4) the ability to transfer the PSU's to a photo or map base.

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

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

2. The weighted total volume for each volume class (estimated size).

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.

A sample of n_h out of the N_h PSU's is then drawn from administrative-general vegetation type stratum h with probability proportional to estimated size (ppes) of timber volume. The locations of the selected PSU's are transferred from the ERTS classified and raw images to aerial photography (and maps) to facilitate locating them accurately from the air when they are photographed from a lower altitude as part of the second stage of the timber inventory.

The estimate of the total volume then becomes:

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

where: L = total number of administrative-general vegetation type 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 Volume Estimation on Low Altitude Photography

Two 35 mm or 70 mm cameras are then used to obtain low altitude photography of the selected primary sampling units at two different scales. A short focal length, wide-angle lens is used to acquire complete coverage of each sampling unit at an approximate scale of 1:7,500, and a long focal length is used to obtain large scale stereo triplets, scale approximately 1:1,000, from which to make precise photo estimates of plot and tree volume. The camera with the telephoto lens must be equipped with a motorized film drive to enable each stereo triplet to be taken within one second at five second intervals while the camera with the wide-angle lens can be operated manually to obtain single frames at five second intervals. The photo coverage for each PSU consists of ten stereo triplets and ten wide angle photographs.

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

The approximate scale of each photo is then determined, and a circular plot is drawn around the photo plot center. The timber volume in each photo plot is estimated by referring to local photo-volume tables based upon interpretation of percent crown closure and measurement of average stand height using a parallax bar (such as Chapman, 1965 for the Sierras).

To estimate the total volume (y_{hi}) of the $i^{\underline{th}}$ PSU, a sample of n_{hi} out of the N_{hi} secondary sampling units is drawn with ppes. This gives:

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

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

$$\hat{y}_{hij} = \sum_{j=1}^{J} \frac{1}{p_{hij}} \frac{A_{hij}}{a_{hij}} \frac{1}{n_{hij}} \sum_{k=1}^{n_{hij}} \frac{\hat{y}_{hijk}}{p_{hijk}}$$

where: $j = 1,2,\ldots,J$ refers to the CALSCAN volume strata

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

A = area (indexes as above)

a = sampled area (indexes as above)

n = sample size (indexes as above)

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

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

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

In the third stage, all trees of merchantable size within each selected photo plot are pin-pricked and numbered. For each of these trees, the average crown diameter is determined based on the longest and shortest dimensions of their crowns and an estimate of tree height obtained from the wide angle photos. After adjustments for scale, the average crown diameter and estimated tree height are used as a relative measure of the merchantable volume of wood in the individual trees. To estimate the total volume of the $k^{\underline{th}}$ plot, a sample of n_{hijk} out of the N_{hijk} tertiary sampling units (trees) are drawn with ppes (using this estimate of tree volume). Then:

$$\hat{y}_{hijk} = \frac{1}{n_{hijk}} \sum_{l=1}^{n_{hijk}} \frac{y_{hijkl}}{p_{hijkl}}$$

where: p_{hijkl} = the selection probability of the $l^{\underline{th}}$ sample tree of the $k^{\underline{th}}$ plot of the $j^{\underline{th}}$ volume stratum of the $i^{\underline{th}}$ PSU of the $h^{\underline{th}}$ stratum.

y_{hijkl} = the dendrometer-measured volume of the $l^{\underline{th}}$ sample tree of the $k^{\underline{th}}$ plot of the $j^{\underline{th}}$ volume stratum of the $i^{\underline{th}}$ PSU of the $h^{\underline{th}}$ stratum.

A two-man crew with a Barr and Stroud optical dendrometer measures the selected trees. The large scale (low altitude) photographs are 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 is measured in order to obtain a more accurate estimate of the scale of the photo plot. The dendrometer measurements are entered into a computer program to calculate merchantable stem volumes for the individual trees.

Combining the various stages above, the entire estimator becomes:

$$\hat{V} = \sum_{h=1}^{L} \frac{1}{n_h} \sum_{i=1}^{n_h} \sum_{j=1}^{J} \frac{1}{p_{hij}} \frac{A_{hij}}{a_{hij}} \frac{1}{n_{hij}} \sum_{k=1}^{n_{hij}} \frac{1}{p_{hijk}} \frac{1}{n_{hijk}} \sum_{l=1}^{n_{hijk}} \frac{y_{hijkl}}{p_{hijkl}}$$

7.22 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 the 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:

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

which has an unbiased estimator:

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

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

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

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

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

Determination of Sample Size and size of PSU's.

From the usual confidence statement

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

n may be obtained for a fixed precision level, (e.g. 5% of Y at 95% confidence level,) as follows:

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

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

Since

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

then

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

and

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

The value of S^2 is unknown in most applications and has to be estimated. Recalling that the population consists of N primary sampling units as a result of the partitioning of the forest on the ERTS image, the population variance S^2 is obtained by

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

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

The discriminant classification provides 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 give the total volume of the PSU. More formally,

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

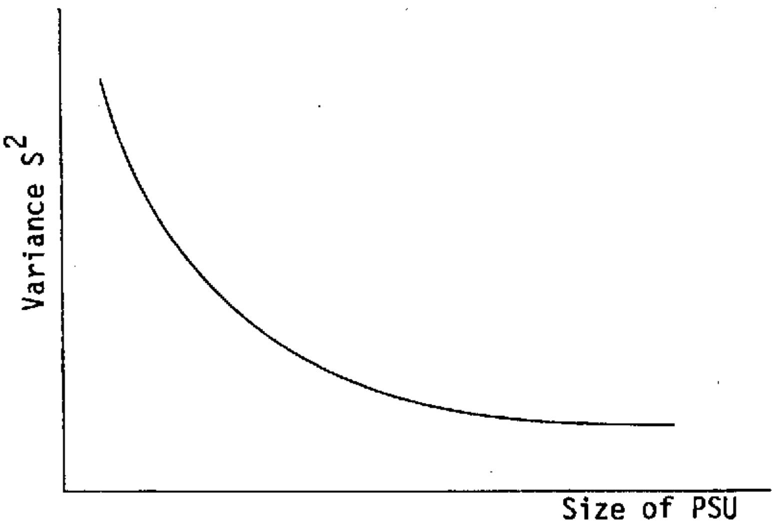
where $k=1, \ldots, m$ is the index no. for rows of picture elements in PSU

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

w=volume weight for c

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

This approach also enables a study of the 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 may be obtained:



Similarly, by varying the sample unit width and length for a fixed size of PSU, and observing the S^2, respectively, the optimal width/length ratio is found. The outcome of this particular study has to be qualified by practical considerations, e.g. those related to the procurement of the aerial photos of PSU's for subsequent sampling, the travel time within and between flight lines, and the ability to accurately locate the PSU's on maps and resource photography.

As a result, a rectangle of size 45 x 5 picture elements (404m x 2575m) has been selected as the optimum size of the PSU.

Using the coefficient of variation (CV) and a 95 percent level of confidence, the number of PSU's is found by

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

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

Example,

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

Assume CV = .18

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

Then

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

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

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

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

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

Then

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

7.30 COMPARISON OF THE COST-EFFECTIVENESS OF AN ERTS BASED TIMBER VOLUME INVENTORY AND A CONVENTIONAL TIMBER VOLUME INVENTORY

New operational systems for information gathering have come about with the advent of ERTS-1 and its space-age technologies. In order to evaluate their overall contribution to resource management, economic analysis has been employed. This form of analysis has proven valuable as one of several inputs to the decision making process.

In this section the results are reported for a study assessing the cost effectiveness of a multi-stage sampling technique for estimating timber volume utilizing ERTS in one stage. This was accomplished by comparing the estimated cost of the latter technique with the estimated costs of a more conventional multi-stage sampling method using an area of approximately 1 million acres. In the first part of this paper we examine these two approaches as comparative models; the assumptions of the cost-effectiveness analysis are then presented; the economic theory behind the benefit estimation follows; and finally, the benefit estimation is described.

Both the "ERTS" model and the "conventional" model had a three-stage sampling design in which a timber volume estimate was made at each stage; however, it was here that the similarity ended. In the first stage of the conventional model the initial stratification and sample set-up were done by human interpreters working on resource photography, whereas in the ERTS model the CALSCAN discriminant analysis of ERTS imagery accomplished these tasks.

In the second stage the primary sampling units of the conventional model were photographed at a scale of 1:4,000 as opposed to the larger scale of 1:1,000 used in photographing the PSU's in the ERTS model. In this stage it was assumed that the timber volume estimate produced by the ERTS model would be more accurate than the conventional model, due to the initial precision of the CALSCAN estimate and the work done on the larger scale photography.

From this assumption, we were able to allocate to the ERTS model a smaller ground sample size in the final stage. Specifically, two .4 acre ground plots were considered necessary in each PSU for the ERTS model and seven in each PSU for the conventional model.

Our conventional model resembled a sampling method recently used by the U.S. Forest Service in the Stanislaus National Forest. We did, of course, modify this sampling method to fit our computer system. In estimating the costs for the conventional model, we were guided by some relevant cost data derived from the actual Stanislaus inventory as well as from our own research in the costs of the various photo interpretation techniques. On the other hand, the costs of the ERTS model were developed from projections based on its application in the Quincy Ranger District of the Plumas National Forest.

7.31 Assumptions

For the purposes of the study, a number of assumptions were made as follows: (1) only the operating costs, and not the total costs were considered for each model; (2) the value of information from both methods was assumed to be the same, i.e. the quality, quantity and timeliness of the information of both systems had the same impact on tastes or preference; (3) costs were based on obtaining a 95% level of confidence; (4) aerial photography, which was used in both models, was considered to be free of charge since it is readily available in the U.S.; (5) the cost of the ERTS tapes for the study area was the only cost component of the ERTS system considered here; (6) the labor cost for both studies was based on University of California rates; and (7) all computer costs were based on G.S.A. contract rates.

7.32 Economic Theory

To derive the benefit estimation for the ERTS model, cost-effectiveness analysis can be used since the assumption has been made that the two models are equal in respect to value of information. From an economic standpoint, then, we may assess this value of information on cost considerations only. The question we are concerned with resolving is simply: which model provides the information with the least expense, or more broadly, which model reflects the optimum level of production? Inherent in this question is the value judgement that society benefits from a constant or increased amount of goods and services acquired with less inputs, i.e. lower costs.

In cost-effectiveness analysis we are interested in generating a curve which represents the maximum capability of the system for each level of expenditure. That is, an increase in the budget will always be matched by an increase in capability, and likewise a decrease in the budget will have the opposite effect. What we arrive at finally is a cost curve, or so called "production frontier", composed of the set of cost-efficient points as seen in the curve F_1F_1 in Figure 1.

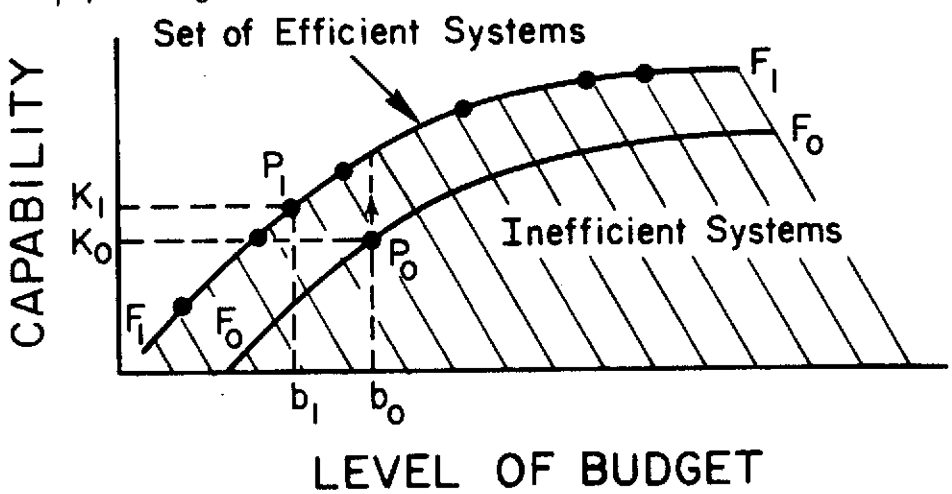


Figure 1. The Cost Curve F_1F_1 reflects the increase in efficiencies associated with the introduction of new technologies.

We want to examine closely the impact which the new technology (i.e., the ERTS model) has on the production frontier. Theoretically, the production frontier will shift outward to the left with the introduction of new technologies. As shown by the graph, when this occurs a previously efficient system at point P_0 on the curve F_0F_0 becomes inefficient because the same capability now can be obtained at a lower budget expenditure. The decision maker must approach this new condition in either of two ways: (1) as an equal capability efficiency problem or (2) as an equal budget efficiency problem. In the first, the decision is whether the cost benefits (i.e. savings) associated with the same level of capability are worth the investment in new hardware of the alternate system. In the second, on the other hand, the decision is whether the increased capability at the same level of budget is worth the investment. (Willow Run Laboratories, 1972, pp. 90-96.)

7.33 Results and Conclusions

To apply cost-effectiveness analysis to the ERTS model and the comparative conventional model it was necessary to determine the production frontiers, of each model for a 95% confidence level (t) and the associated costs. This was accomplished in both models by calculating various sample sizes (PSU's) with each sample size corresponding to a specific allowable error. In this regard, it was determined that the largest percentage of variable costs are directly related to the size of the sample area.

In the conventional model the number of primary sampling units over a range of allowable errors was found by using a statistical exercise outlined by Cochran (1953) on the inventory figures found in the Timber Management Plan of the Stanislaus National Forest. Using this procedure an estimate of the population coefficient of variation (CV) was obtained (59%). The figures obtained for the conventional model were:

AE	PSU's	Ground Plots	Total Costs
20%	6	42	$31,427
15%	9	63	34,688
10%	18	126	44,600
5%	62	434	92,941

A complete break-down of the costs may be found in Table 2.

In order to derive the production frontier for the ERTS model the following equation for sample size determination (n) was used (see pp. 11-12 for a more complete treatment of the equation):

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

CV is the coefficient of variation for the ERTS model estimator, a measure of population and sampling variability as well as measurement errors. The estimator in this case was based on probability proportional to estimated size.

The magnitude of CV depends largely on the quality of auxillary information which, if good, would reduce the variation associated with the estimator. The auxillary information in this case would be the timber volume estimate generated by CALSCAN.

Since we had not inventoried the Stanislaus National Forest we had to arrive at an estimate of the CV by utilizing our experience of inventorying the Quincy Ranger District of the Plumas National Forest. In this inventory the CV obtained was 22% whereas the Forest Service estimate of the population variability for this area was 80%. From this finding we made the assumption that for the area of northeastern California we could expect to reduce the population variability arrived at in a conventional inventory by approximately 75%. Consequently, we determined the CV for the ERTS model to be 15% for the Stanislaus (25% of 60%). The figures arrived at were:

AE	PSU	Ground Plots	Total Cost
20%	5	10	$11,526
15%	7	14	12,304
10%	12	24	14,494
5%	37	74	26,074

A complete break-down of costs may be found in Table 3.

From this information the following production frontier curves were generated as seen in Figure 2:

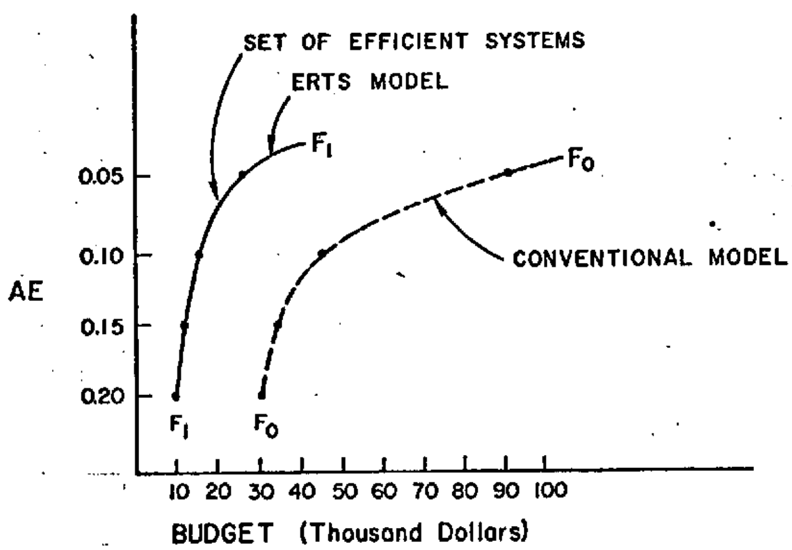


Figure 2. Curve F_1F_1 represents the production frontier of the ERTS multistage sampling model and shows the latter to be a more efficient system than the conventional model, represented by the curve F_0F_0.

It is clear that the ERTS model was a more efficient system of inventorying and therefore should replace the conventional design. As shown in Table 1, the estimated cost-effectiveness ratio increased as the allowable error diminished. At a 10% AE the benefit was 3.08:1 and at a 5% AE it was 3.56:1. This gain in efficiencies was largely the result of the following two main cost differences: (1) first stage procedures and (2) map generation. As to the first, in the conventional model the initial stratification of the area was done mainly by human interpreters using resource photography whereas in the ERTS model, operating on ERTS data, CALSCAN provided a point by point classification of the area at a lower cost and with greater precision. With this higher level of precision, coupled with the work done on large scale stereo triplets, a less costly sampling scheme was obtainable.

As to the second difference, that of map generation, this study found that a WRIS black-and-white boundary map of a township at a scale of 4 inches to a mile could be processed by computer for approximately $200. Using the ERTS model system, on the other hand, a color-coded township map of the same scale could be processed for roughly $50.

Although the cost efficiency approach to benefit analysis provides a good estimator, it does not consider the tastes or the preference of society. The analysis therefore, does have some weakness when one considers that society sometimes places a greater value on inefficient systems rather than efficient ones.

Benefit-cost analysis, if properly used, can serve as an evaluation tool; its conceptual limitations must, however, be taken into account whenever decisions about procedure and policy must be made. Undue reliance on a "technological quick-fix", especially when quantitative manipulation is possible, can encourage short-run measures that may ultimately ignore or violate long-term consequences. No easy approaches to the larger context are offered here, but as possible costs and returns are brought to the surface for comparison and critical appraisal, it can be expected that the decision-making process will be improved so as to improve the management of forest resources and, ultimately, even to appeal to the public's environmental interests.

TABLE 1: Cost Comparison Summary at a 95% Confidence Level

Task	ERTS Model				Conventional Model			
	20% AE 5 PSU's 10 Ground Plots	15% AE 7 PSU'S 14 Ground Plots	10% AE 12 PSU's 24 Ground Plots	5% AE 37 PSU's 74 Ground Plots	20% AE 6 PSU's 42 Ground Plots	15% AE 9 PSU's 63 Ground Plots	10% AE 18 PSU's 126 Ground Plots	5% AE 62 PSU's 434 Ground Plots
I Stratify/ Classify	$ 2,267	$ 2,313	$ 2,428	$ 3,003	$ 5,145	$ 5,145	$ 5,145	$ 5,145
II Photo Acquisition/ Interpretation	$ 437	$ 583	$ 946	$ 2,923	$ 396	$ 557	$ 1,114	$ 3,585
III Ground Data Collection	$ 976	$ 1,255	$ 2,091	$ 6,552	$ 3,764	$ 5,576	$11,013	$37,777
IV Data Summary & Map Generation	$ 3,290	$ 3,290	$ 3,290	$ 3,290	$ 9,700	$ 9,700	$ 9,700	$ 9,700
Sub-Total	$ 6,970	$ 7,441	$ 8,755	$15,768	$19,005	$20,978	$26,972	$56,207
Administrative Costs (27%)	$ 1,882	$ 2,009	$ 2,364	$ 4,258	$ 5,132	$ 5,664	$ 7,283	$15,176
Overhead (30.2%)	$ 2,674	$ 2,854	$ 3,358	$ 6,048	$ 7,290	$ 8,046	$10,345	$21,558
TOTAL	$11,526	$12,304	$14,478	$26,074	$31,427	$34,688	$44,600	$92,941
Cost-effective Ratio	2.73:1	2.82:1	3.08:1	3.56:1				

TABLE 2: Conventional Model Cost Breakdown at a 95% Confidence Level

	.20 AE 6 PSU's 42 Ground Plots	.15 AE 9 PSU's 63 Ground Plots	.10 AE 18 PSU's 126 Ground Plots	.05 AE 62 PSU's 434 Ground Plots
I. PRE Photo/Ground [1]				
A. Resource Photo Procurement	NO COST	NO COST	NO COST	NO COST
B. Labor				
1. Delineation of Boundaries A $7.00/hr	714.00	714.00	714.00	714.00
2. Plotting effective areas	630.00	630.00	630.00	630.00
3. Interpreter training	56.00	56.00	56.00	56.00
4. Type delineation & classification	3,633.00	3,633.00	3,633.00	3,633.00
5. Sample set-up	112.00	112.00	112.00	112.00
Labor sub-total	5,145.00	5,145.00	5,145.00	5,145.00
II. Photo Acquisition & Interpretation [2]				
A. Aircraft - $28/hr.	42.00	63.00	126.00	434.00
B. Pilot & Crew - $15/hr.	23.00	34.00	68.00	233.00
C. Film Processing $32/flight line	78.00	117.00	234.00	806.00
D. Annotation of film $10/ " "	60.00	90.00	180.00	620.00
E. Interpretation of photos $20/ " "	120.00	180.00	360.00	1,240.00
F. Selection of Ground Plots	20.00	20.00	40.00	40.00
G. Travel to & from Stanislaus	53.00	53.00	106.00	212.00
Photo acquisition sub-total	396.00	557.00	1,114.00	3,585.00
III. Ground Data Collection [3]				
A. Travel - vehicle @$9.40/day	254.00	376.00	743.00	2,547.00
B. Crew - 2 men @$40/day each	2,160.00	3,200.00	6,320.00	21,680.00
C. Per diem days X 2 X $25/day	1,350.00	2,000.00	3,950.00	13,550.00
Ground data sub-total	3,764.00	5,576.00	11,013.00	37,777.00
IV. Data Summary & Map Generation				
A. Computer analysis of Gnd & Photo data @$40/day	160.00	160.00	160.00	160.00
B. Generation of summary statistics @$40/day	40.00	40.00	40.00	40.00
C. Report preparation & reproduction	650.00	650.00	650.00	650.00
D. Computer-time	250.00	250.00	250.00	250.00
E. Map Generation	8,600.00	8,600.00	8,600.00	8,600.00
Data summary sub-total	9,700.00	9,700.00	9,700.00	9,700.00
Sub-Total	19,005.00	20,978.00	26,972.00	56,207.00
Administrative (27%)	5,132.00	5,664.00	7,283.00	15,176.00
OVERHEAD (30.2%-Subtotal & Admin.)	7,290.00	8,046.00	10,345.00	21,558.00
TOTAL	31,427.00	34,688.00	44,600.00	92,941.00

[1] Cost estimates were based on the photo interpretation costs reported in "Analysis of Remote Sensing Data for Evaluating Vegetation Resources" by Forestry Remote Sensing Laboratory, University of California, Berkeley, 30 September 1972.

[2] The aircraft costs were based on flying 4 flight lines an hour and flying a maximum of 16 flight lines a day.

[3] Ground data collection costs were based on completing 1.6 ground plots per day

TABLE 3: ERTS Model Cost Breakdown at a 95% Confidence Level

	.20 AE 5 PSU's 10 Ground	.15 AE 7 PSU's 14 Ground	.10 AE 12 PSU's 24 Ground	.05 AE 37 PSU's 74 Ground
I. PRE Photo/Ground				
A. Tape Acquisition	$ 360.00	$ 360.00	$360.00	$ 360.00
B. Tape Reformatting				
1. Tape	7.75	7.75	7.75	7.75
2. Computer time 1/4 hr @$40/hr	10.00	10.00	10.00	10.00
3. Operator	2.25	2.25	2.25	2.25
C. Intensive Area Extraction				
1. Computer 1/2 hr @40/hr	20.00	20.00	20.00	20.00
2. Operator 1 hr @ 5/hr	5.00	5.00	5.00	5.00
D. Delineation and Extraction of Administrative Unit				
1. Photo Reduction	15.75	15.75	15.75	15.75
2. Digitizer with operator 2 hr @16.50	33.00	33.00	33.00	33.00
3. Computer mask generation				
a. computer	12.50	12.50	12.50	12.50
b. operator 3 hr @5	15.00	15.00	15.00	15.00
E. Training of Classifier (60 classes)				
1. Computer display terminal 8 hr @40/hr	320.00	320.00	320.00	320.00
2. Image Analysts 40 hr @7.00/hr	280.00	280.00	280.00	280.00
3. Statistical analysis (LBL) 10 A 12	120.00	120.00	120.00	120.00
4. Selection of channels & classes 16 hrs @5	80.00	80.00	80.00	80.00
F. Discriminant analysis run				
computer	630.00	630.00	630.00	630.00
analyst	80.00	80.00	80.00	80.00
G. Generation and selection of PSU				
computer	120.75	120.75	120.75	120.75
analyst	40.00	40.00	40.00	40.00
H. Location of PSU				
computer	52.00	73.00	125.00	383.00
analyst	63.00	88.00	151.00	468.00
Subtotal	$2,267.00	$2,313.00	$2,428.00	$3,003.00

TABLE 3: Continued

	.20 AE 5 PSU's 10 Gnd Plots	.15 AE 7 PSU's 14 Gnd Plots	.10 AE 12 PSU's 24 Gnd Plots	.05 AE 37 PSU's 74 Gnd Plots
II. Photo Acquisition and Interpretation[4]				
A. Aircraft $28/hr	35.00	49.00	84.00	280.00
B. Pilot and Crew $15/hr	18.75	27.00	45.00	150.00
C. Film & processing $32/flt. ln.	160.00	224.00	384.00	1,184.00
D. Annotation of film $10/" "	50.00	70.00	120.00	370.00
E. Interpretation of photos $20/" "	100.00	140.00	240.00	740.00
F. Selection of Ground plots	20.00	20.00	20.00	40.00
G. Travel to & from Stanislaus	53.00	53.00	53.00	159.00
Subtotal	436.75	583.00	946.00	2,923.00
III. Ground data collection[5]				
A. Travel - vehicle @$9.40/day	66.00	85.00	141.00	442.00
B. Crew - 2 men @$40/day each	560.00	720.00	1,200.00	3,760.00
C. Per diem X 2 X $25/day	350.00	450.00	750.00	2,350.00
Subtotal	976.00	1,255.00	2,091.00	6,552.00
IV. Data Summary and Map Generation				
A. Computer analysis of Ground and Photo data 4 days @40/day	160.00	160.00	160.00	160.00
B. Combining ERTS and Ground data 1 day @40/day	40.00	40.00	40.00	40.00
C. Generation of Summary Statistics 1 day @40/day	40.00	40.00	40.00	40.00
D. Generation of Maps	2,150.00	2,150.00	2,150.00	2,150.00
E. Report preparation and reproduction	650.00	650.00	650.00	650.00
F. Computer time	250.00	250.00	250.00	250.00
Data Summary Subtotal	3,290.00	3,290.00	3,290.00	3,290.00
Subtotal	6,970.00	7,441.00	8,755.00	15,768.00
Administrative (27%)	1,882,00	2,009.00	2,364.00	4,258.00
Overhead (30.2%)	2,674.00	2,854.00	3,358.00	6,048.00
TOTAL	11,526.00	12,304.00	14,476.00	26,074.00

[4] The aircraft costs were based on flying 4 flight lines an hour and flying a maximum of 16 flight lines a day

[5] Ground data collection costs were based on completing 1.6 ground plots per day

7.40 THE FUTURE OF HUMAN-COMPUTER PROCESSED ERTS MSS DATA IN RESOURCE INVENTORY, MAPPING AND ASSESSMENT

An interdisciplinary inter-agency renewable resource survey, inventory and mapping system based on computer analyzed ERTS multispectral scanner data appears to be a cost-effective alternative to the independent information gathering procedures now being used. This statement is supported by the increasing evidence that through proper human-computer analysis of ERTS multispectral data much of the information necessary for resource allocation, management, inventory assessment, and mapping can be obtained very cost-effectively. By complementing this ERTS derived data base, through the use of minimal analysis of small scale photography, large-scale photography and ground data, one can meet or exceed the current information gathering standards imposed on the various agencies involved in the management of our renewable natural resources.

The primary characteristics of this cost-effective integrated information gathering system include:

a. Broad uniform data base

b. Suitable spatial resolution

c. Suitable spectral resolution

d. Direct computer compatibility

e. Periodic coverage

f. Systematic coverage

g. Geometric fidelity

The spatial and spectral resolution characteristics of the digital data appear to be nearly optimum for computer mapping of surface vegetation characteristics at the plant community level over a vast majority of the U.S. wildland areas. The picture element-by-picture element processing of this digital data provides acre-by-acre discrimination of surface characteristics. This provides information at a higher order of resolution and consistency than can be cost-effectively obtained by photo interpretation of conventional resource photography having a scale of 1:15,840 and 1-3 foot ground resolution when using 10-40 acre mapping minimums.

The systematic coverage from ERTS provides a uniform computer-compatible data base over large areas allowing the surface characteristics' analysis to be done by environmentally similar units rather than by the arbitrary administrative, political or management units currently in use. Because of this consistency over broad environmental units and the precision and accuracy of the computer analysis of the ERTS data, samples can be allocated more efficiently. This increased efficiency significantly reduces the number of samples required, further reducing the cost of the total information gathering system.

The geometric fidelity, spatial resolution and computer compatibility of the analysis and sampling combine to make for simple and inexpensive overlaying of administrative management boundaries, ownership boundaries and political boundaries. With these boundaries overlain, information can be extracted from the environmentally oriented ERTS data base in the combinations required to meet administrative, management, ownership and policy information needs.

The final yet extremely important component in the ERTS system is its ability to provide periodic coverage with essentially identical spectral and geometric characteristics. This makes the overlaying of data,acquired at desired dates,accurate and relatively inexpensive. This overlay of data allows the periodic updating of the resource information base through the identification and mapping of changes in the surface characteristics. It has been shown that ERTS resolution will allow the detection and mapping of timber harvesting operations, fire damage, wind damage and land-use change. This information on change can then be used to allocate samples to assess the change rather than completely reworking the information base, as is currently done.

The following is a brief description of the steps that would be used for inventory, assessment and mapping of the renewable resources using ERTS multispectral scanner data as the base for this environmentally oriented information collection system.

1) To allow the use of optimum discriminant analysis procedures and photo-ground sample allocation, environmentally similar sub-areas would be delineated over very broad areas. For example, in the Sierras of Northern California the area would be divided into four basic environmental strata: a) eastside pine, b) high elevation true fir, c) mixed conifer and d) oak woodland.

2) The next step in the procedure would be the general picture element-by-picture element discriminant analysis of the ERTS digital data within the delineated environmental areas. This analysis would classify the area into the following land use categories as defined by Anderson in Geological Survey Circular 671: a) urban and built-up land, b) agricultural land, c) range land, d) forest land, e) water, f) non-forest wet land, g) barren land, h) tundra and i) permanent snow and ice field.

3) Within each of the broad classes, a detailed discriminant analysis would be run to further sub-divide classes of high interest. For example, within the forest lands the discriminant analysis would be designed to separate the forest lands by type and condition class. In the range land areas, the analysis would be directed towards the separation of plant communities relating to productivity, potential productivity, and intensive management requirements.

4) At this point the results of the environmental strata delineation, surface category definition, and the detailed discriminant analysis would be used to allocate samples to areas where more precise and accurate estimates are required. For example, in the forest surface category within one or more general environmental types, samples could be allocated for timber volume estimation, growth estimation and timber type determination.

5) The scale and type of photography appropriate to the resource being surveyed will then be flown and interpreted. In the rangeland areas, the interpretation would be for species composition, soil surface characteristics, and vegetation condition. In the forested areas the interpretation would include forest type, condition class, volume, site characteristics and recreation potential.

6) A small number of selected photo plots would then be visited on the ground to obtain the final and most precise estimates of the parameters of interest.

7) A smaller number of selected photo plots would be established as permanent ground plots to be visited in future inventories. Such remeasurement plots would allow inferences to be made concerning plots not revisited, while at the same time allowing new plots to be measured. In this manner, a more complete sample of the diversity inherent in the environment could be made, thus allowing even narrower confidence bands to be placed around estimates of environmental quantities.

8) All photo plots, ground plots and permanent plots would be precisely located in a ground coordinate system that would be tied through control points to the ERTS coordinate system used in the original discriminant analysis procedure. Using this precise plot location information the photo plots would be matched to the ERTS discriminant analysis results. The results of the classification of the located picture elements and the photo interpretation of the large scale photos and ground data would then be established. The establishment of this relationship between the photo-ground results and the ERTS results and the confidence in that relationship would be used in the next step in the inventory to summarize data by management unit, administrative area, and political boundaries.

9) The administrative, management, ownership, and political boundaries would then be digitized and overlain on the results of the discriminant analysis. From the relationship established between the photo ground analysis and the ERTS discriminant analysis and this ability to extract the discriminant analysis results by arbitrary units of interest, summary and mapping of environmental information could be performed for the various administrative and interest groups as needed.

10) To obtain necessary statistics for planning, policy and administration at the regional, state and national levels, the results from various environmental units would be added together to provide information for the higher levels of management, planning and policy making within the various agencies and branches of government.

11) To update the information base, ERTS data would be obtained periodically and overlaid on the original ERTS data base. Using the training areas from the previous date and a few additional training areas to define major changes, a discriminant analysis would be done to detect and map changes in the environment such as logging, urban development, hydroelectric development, fire and wind-throw. After a significant level of change has been identified, mapped, and assessed using the ERTS data, a supplemental quantity of conventional and large scale photography could be acquired to update the sampling base. Based on the information obtained from these human analyzed photos a very small number of plots would be selected for measurement on the ground to update the relationship between the ERTS data and the photo-ground data. It is important to note that the sample allocation for photo plots and ground work would be mainly in the areas where changes have occurred and with a few permanent plots maintained to tie the inventory on the second date to the inventory on the first.

12) To allow the efficient utilization of this data, the discriminant analysis results and statistical summaries would be made compatible with the existing resource allocation models (RAM) and the natural resource information systems (NRIS).

13) The unique characteristic of the ERTS discriminant analysis providing an in place mapping of the surface characteristics makes it ideal as an input to a dynamic resource allocation and model simulator. This futuristic approach to resource allocation, resource management and yield prediction would include a number of auxillary inputs such as meterological satellite data, topographic information and ground station information.

There are several data gathering statistical analysis techniques and data processing techniques that must be put together to provide an operational system. The current operational status of these techniques is shown in Table IV. The current status of the individual discipline oriented ERTS based estimation and mapping is shown in Table V.

Table IV

Operational status of data collection
and information processing technology

	Operational	Testing	Implementation	Research and Devel.	Planning	Proposed
Ground Data Collection	X					
Delineation and Processing of Homologues	X[1]					
Discriminant Analysis for Land-Use	X					
Discriminant Analysis for Vegetation Type and Condition Class	X[1]					
Sample Design and Plot Allocation	X[1]					
Large Scale Photo Acquisition and Interpretation	X[1]					
Location of Photo Ground Plots in Discriminant Analysis Results		X				
Correlation of Photo Interpreter Ground Evaluation with ERTS Classes for Evaluation of Site, Type and Condition for:						
A. Timber		X				
B. Range			X			
C. Land-Use		X				
D. Protection				X[4]		
Overlay of Administrative, Ownership and Management Boundaries	X[2]					
Adding of Local Environmentally Based Surveys to Obtain Regional Estimates				X		
Subdivision of Environmental Areas to Provide Estimates by Management Unit, and Administrative Unit, and Agency Jurisdiction		X				
Provide Data to Resource Allocation Model (RAM)						X
Provide Data to Natural Resource Information System (NRIS)					X[3]	
Develope and Provide Data to Dynamic Resource Allocation Model and Simulator (DRAMS)						X

1. The procedures are operational but are being made more cost-effective through continuing research.
2. The process is operational but accuracy and efficiency need to be improved.
3. Bureau of Land Management study.
4. USFS study for wildland fuel mapping.

Table V

Current status of ERTS based estimation and mapping capabilities

	OPERATIONAL	TESTING	IMPLEMENTATION	DEVELOPMENT	RESEARCH	PROPOSED
VOLUME ESTIMATION AND MAPPING	X					
GROWTH ESTIMATION AND MAPPING		X				
CONDITION CLASS MAPPING AND AREA ESTIMATION		X				
LAND-USE MAPPING AND AREA ESTIMATION	X					
SITE DETERMINATION AND MAPPING					X	
CHANGE DETECTION AND MAPPING			X			
WATERSHED PARAMETER MAPPING		X				
FIRE HAZARD MAPPING		X				
RANGELAND VEGETATION MAPPING	X					
HIGH INTEREST SITE IDENTIFICATION		X				
RANGELAND POTENTIAL PRODUCTIVITY MAPPING					X	
RANGELAND ANNUAL PRODUCTIVITY ESTIMATION						X
WILDLAND FUEL CONDITION DETERMINATION					X	

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CHAPTER 8

COST-EFFECTIVENESS COMPARISON OF EXISTING AND ERTS-BASED TOTAL TIMBER RESOURCES INVENTORY SYSTEMS

Preliminary Report

A Special Presentation to Office of Applications, NASA Hdqts. Funded under NASA Grant No. NGL05-003-404

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CHAPTER 8

COST-EFFECTIVENESS COMPARISON OF EXISTING AND ERTS-BASED TOTAL TIMBER RESOURCES INVENTORY SYSTEMS

8.000 INTRODUCTION

Economic analysis is an integral part of the process by which new technologies find practical applications. In its brief history, ERTS-1 has demonstrated great promise for beneficially altering the time, cost, and capability relationships existing in many resource management areas. ERTS offers some of the most direct cost savings in resource inventory work, where budgets are particularly sensitive to reductions in the costs of gathering information.

This study examines the utility of ERTS imagery in a total timber resource inventory application. In California's million-acre Plumas National Forest, an ERTS-based sampling technique is compared with inventory methods similar to those currently employed by the U. S. Forest Service. The two sampling systems are evaluated as to their relative cost-effectiveness. Comparison is possible because both systems produce the same sort of output: information about timber growth and yield potential for a variety of forest vegetation types and stand condition classes. Such information is indispensible for the timber management planning process.

The study's major elements are summarized below in four sections. First, the general assumptions behind the analysis are outlined. This is followed by a brief description of the economic theory of cost-effectiveness analysis. A third section compares the two systems both in terms of their sampling designs and their costs. Finally, comparative results and conclusions follow.

8.100 ASSUMPTIONS

A number of assumptions were made to facilitate the analysis. Paralleling cost-effectiveness theory, it was assumed that both the existing and ERTS-based systems operate on their respective production frontiers. With respect to sampling design, the ERTS-based system was assumed capable of achieving the same gains in stratification as the existing system. Assumptions regarding costs were as follows: only operating costs were considered for each system; aerial photography was considered free of charge in the existing inventory system; the cost of ERTS tapes was the only cost allocated from the ERTS program; and data summary costs and administration and overhead rates for both systems were assumed to be equal.

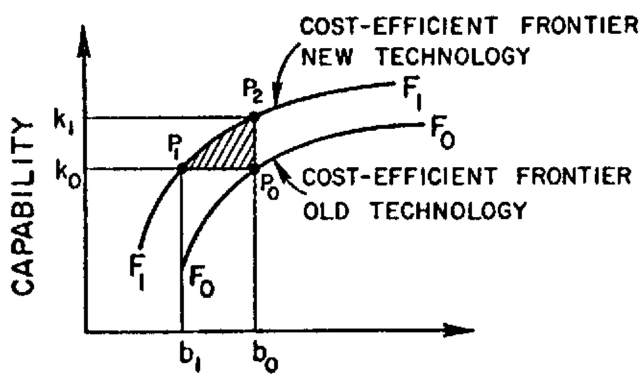
8.200 ECONOMIC THEORY

Cost-effectiveness analysis helps a decision-maker answer questions about how to achieve a given set of objectives at the least cost, or how to obtain the most effectiveness from a given set of resources. Economic benefits are described in terms of cost savings. One variety of cost-effectiveness analysis is the "system comparison study." Here, the cost and capability relationships of two or more systems with the same output are examined side-by-side. It is commonly presumed that the competing systems have already been optimized as to their internal configurations. This type of analysis enables a decision-maker to assess the marginal improvement promised by alternative systems.

A comparative cost-effectiveness analysis was used in this study since the two systems involved provided approximately equivalent information. From an economic standpoint, the question to be resolved is simply: which system provides the information with the least expense, or more broadly, which system reflects the optimum level of production? Inherent in this question is the value judgment that society benefits from a constant or increased amount of goods and services acquired with less inputs, i.e. lower costs.

The theory behind cost-effectiveness analysis may be expressed graphically. Figure 1 illustrates the effect of technological progress on the cost-capability "frontier" of an existing production system.

FIGURE 8.1: EFFECT OF A TECHNOLOGICAL ADVANCE ON A COST-CAPABILITY PRODUCTION FRONTIER



The frontier F_0F_0 shows the maximum capability that can be expected from the present system at a given level of budget. A system producing on the frontier is defined as "cost-effective" because a decrease in cost is not possible without a decrease in capability. A technological advance would beneficially alter this relationship: the cost-efficient frontier would be pushed out to some new set of points as on F_1F_1. A point P_0 on the old frontier F_0F_0 would now represent an inefficient pattern of production. A set of points in the shaded area of Figure 1 would represent an improved return, with cost-efficient points now lying on F_1F_1 between P_1 and P_2. The effect of technological progress thus ranges between either equivalent capability at a lower budget (P_1) or greater capability within the same budgetary constraints (P_2).

A decision maker will want to examine closely the impact which a new technology has on the production frontier. He may approach this objective in either of two ways: (1) as an equal capability efficiency problem, or (2) as an equal budget efficiency problem. In the first, the decision is whether the cost benefits (i.e. savings) associated with the same level of capability are worth the investment in new hardware of the alternative system. In the second, the decision is whether the increased capability at the same level of budget is worth the investment.

8.300 COMPARISON OF SYSTEMS

Real world complications tend to force applied cost analyses into a compromise with theoretical perfection. Most of the application difficulties encountered in this study concerned the development of a suitable basis of comparison for the two timber resource inventory systems. Ideally, an applied analysis would directly compare inventory systems while holding constant the time and location of a representative and comprehensive inventory. In reality, modifications were necessary to fit existing cost and performance data into a comparable framework. The main application problems encountered in this study may be highlighted as follows:

- The ERTS-aided inventory was performed on the Plumas National Forest in 1974. Although the analysis assumes a cost-efficient production system, the "first run" nature of the Plumas/ERTS-1974 inventory leaves room for improved cost-performance relationships.

- The last U.S. Forest Service (USFS) inventory on the Plumas National Forest was performed in 1969.

- Forest-Service inventory techniques have been steadily evolving since 1969. Based on current Forest Service inventories in other forests, it is likely that a hypothetical Plumas/USFS - 1974 inventory would have a different cost-performance relationship than the actual Plumas/USFS - 1969 inventory.

The next two subsections on comparative sampling design and costs describe how the above considerations were addressed operationally.

8.310 COMPARATIVE SAMPLING DESIGNS

8.311 Forest Service Sampling System

8.311.1 Output

The system is designed to provide information input to the timber management planning process for the USFS lands and to provide information for the National Forest Survey on both public and private lands. Primary emphasis is on providing information in a form which may be easily linked with the Forest Service Resource Allocation Model (RAM). Estimates of growth and yield are required by various categories of management opportunities, or activity classes in the RAM terminology. A significant part of the definition of activity classes is the physical state of the resource as defined by major forest vegetation types and stand condition classes. The vegetation type and condition class provide for a logical stratification of the forest, and within each stratum estimates of yield and growth are the major parameters for which estimates are desired.

8.311.2 General system features

Stratification of the forest into forest type and stand condition categories is a major feature of the design. Operationally this stratification is obtained by producing a forest type map using recent aerial photography and, if available, previous type maps as source data. The completed type maps are then digitized and entered into the WRIS (Wildland Resource Inventory System) mapping system and a summary of acreages by strata is produced.

Based on the acreages and strata weights produced by the WRIS system, a stratified two-stage sample is undertaken to obtain sample data for the parameters of interest. Allocation of samples is made proportional to acreage in each stratum; typically there are 15 to 20 strata. The stage one sample consists of a number of townships or primary sampling units (PSU's) selected with a probability proportional to the number of acres in the stratum of interest. The stage two sample, conducted within each selected PSU, consists of selecting two plot locations at random within the township and the stratum of interest. At each plot location, a cluster of 5-point samples provides the opportunity for measurement of the variables associated with the parameters of interest. Individual trees are selected for measurements using "point sampling" techniques (Husch, et al., 1974). Tree volumes are obtained using Forest Service volume tables.

8.311.3 Sample size and allocation

Based on Forest Service experience with several other California forests, it is probable that a sample size of no more than 150 ground plots (5-point clusters) or 75 PSU's would be taken on the Plumas National Forest with the precision requirements of ± 5 percent allowable error at the 1 standard error level of confidence (0.68 probability). Stratification of the population would produce 15 to 20 strata.

8.312 ERTS-based Sampling System

8.312.1 Output

The ERTS based system is designed to produce essentially the same information as the Forest Service system. Specific measurement techniques vary somewhat from the USFS system. However, the basic growth and yield output by major vegetation types and condition classes remains the same.

8.312.2 General system features

Again, stratification is an important first step in the process. It is accomplished by a pointwise discriminant analysis using the CALSCAN package of programs to analyze raw ERTS MSS data. At the present time, stratification has been limited to four classes of major forest type. However, with further work it is expected that a more detailed stratification will evolve comparable to that of the USFS system. This level of detail for estimation purposes is currently achieved by summarizing estimates by domains of interest within the population (Cochran, 1963). Based on the results of the stratification, a multistage sample is undertaken as follows.

The stage one PSU's are defined as 45 x 5 pixel units and are selected with varying probabilities in the same manner as the USFS stage one sample. The stage two sample consists of 10 photo plots selected within each of the selected PSU's. The photo plots are located on a flight line through the center of the PSU; exact location is governed by the center points of large scale photographic images (1:1,000±). Observations are made on each photo plot including classification into a detailed type and condition class, and determination of species, height and crown diameter for each tree located within a 0.4-acre circular plot.

Stage three provides a double sampling link with the ground by selecting a restricted random sample of photo plots for further detailed measurement on the ground. The restriction is that samples are obtained in each type and condition class proportionally to the number of photo plots in each class. Ground measurement of the same physical area interpreted by a photo interpreter included detailed classification of the type, condition, terrain, and vegetation, as well as species, diameter, increment, and tree class for each tree. Stage four provides a double sampling link between basic tree measurements and more precise measures of volume, surface area, and height obtained using an optical dendrometer.

Trees are selected for detailed measurement using Grosenbaugh's "3-P" sampling scheme (1965). In stage five additional growth data are taken using remeasurement of USFS permanent plots in an effort to improve growth estimates and utilize an existing sampling scheme.

8.312.3 Sample size and allocation

Sample size and allocation decisions always have a degree of uncertainty associated with them. This is true of both the USFS system and the ERTS-based system. The USFS system sample size figures were based largely on experience gained on forests in the southern part of the state and hence may or may not reflect the actual number which might be necessary to achieve the desired precision. The ERTS-based system, on the other hand, has different uncertainties in addition to those associated with population characteristics. Further, in both cases planning has been based on volume as the one parameter of interest, but in fact both surveys estimate a number of parameters in addition to volume.

Based on preliminary results of the Plumas 1974 timber inventory, the population coefficient of variation for volume was estimated to be 125% based on a sample of 55 ground plots. Twenty USFS permanent plots selected at random showed a coefficient of variation (CV) for basal area to be about 60% so it is possible that the 125% figure is high. However, this figure was chosen as a reasonable basis for assumed population characteristics in these comparisons.

The figure of 150 ground plots for the USFS system in relation to the 125% CV for volume implies a gain due to stratification equivalent to a 75% reduction of the simple random sample size of 625 which would be required to meet necessary precision requirements. It is assumed that the ERTS-based system has achieved a similar gain. This degree of success in stratification has not been completely documented at this time; however, early indications are that as development of the system proceeds this level will be achieved. Further, there may be other factors relative to the costs of each stratification technique which will compensate for this assumption.

The remaining major component in the sample allocation problem relates to the double sampling link between large scale photo measurements and the ground measurements. In the longer term the whole design problem will be considered in a multistage framework; unfortunately, however, the time frame restricts the design to addressing certain major components separately. Details of the double sampling allocation model are given in Appendix I along with a tabular summary of sample sizes for given assumptions of CV, cost ratios, and correlations between ground and photo measurements. The preliminary results of the 1974 inventory indicate CV=1.25 and a ratio of photo measurement costs to ground measurement costs of 1:18. The actual correlation obtained was r = .60. However, certain measurement and training problems encountered as well as the narrow time frame indicate that the 0.8 level of correlation is likely to be achieved as techniques improve. These parameters coupled with a 75% reduction due to expected gains in stratification would lead to a sample size of 74 ground plots and 418 photo plots. Similar figures could be completed for other precision levels if desired. This compares with the actual sample sizes for the 1974 inventory of 55 ground plots and 400 photo plots. Additionally, several variables are being used in the regression relationships relating ground and photo measurements rather than just volume alone. These may further reduce necessary sample sizes.

Sample size calculations for both ground plots (n) and photo plots (n') are listed below for four levels of allowable error at a one standard error level of confidence.

Allowable Error (%)

Sample size	5	10	15	20
n	74	19	9	9
n'	418	105	47	47

8.320 COMPARATIVE COSTS

8.321 Forest Service Sampling System

Costs for the existing timber resource inventory system were estimated from discussions with Forest Service personnel and from actual cost figures of recent (1974) USFS inventories in California. Table 1 summarizes the activities and costs of a hypothetical USFS timber inventory performed in the Plumas National Forest in 1974. The table groups activities and costs into four principal categories: stratification activities, ground data collection, data summary, and administration and overhead. Each category merits a brief discussion.

8.321.1 Stratification activities

The existing USFS sampling system would require that almost two-thirds of a Plumas inventory budget be spent on activities relating to sample stratification. A large part of this work would be performed by outside contractors. Table 1 breaks the stratification process into four phases. Pre-stratification activities are performed by the USFS and consist of resource photo procurement, preparation of background materials, and other minor tasks. The direct costs of this effort are minimal. The manual phase of stratification is performed almost entirely

TABLE 1: COSTS OF A USFS-STYLE TIMBER INVENTORY SAMPLING SYSTEM PLUMAS NATIONAL FOREST, 1974*

		Performed by: contractor	Performed by: USFS	
Stratification Activities				
Pre-stratification		$ ---	$No cost	
Manual	(90 tm @ $500 ea)	45,000	---	
Digital: WRIS	(90 tm @ $200 ea)	---	18,000	
Site selection			1,000	
Ground Data Collection	(120 gp @ $100 ea)	12,000	---	
Data Summary			1,300	
Subtotal		$57,000	$20,300	
Administration	(10% on contracted costs) (30% on USFS costs)	---	11,800	
Overhead	(3% on contracted costs) (30% on USFS costs)		7,800	
Total Cost (Nearest $1,000)				$97,000

*Allowable error = ± 5% at 1 standard error level of confidence (.68 probability)

tm= township maps
gp= ground plots

by a contractor. This consists of photo delineation and type map preparation. The USFS assists the contractor by providing aerial photos, existing timber stand maps, plot reference tags, aluminum nails, ground plot record sheets, a field handbook, and the time of a project supervisor. Contractor bids for stratification work in 1974 averaged about $500 per township map. Since the Plumas National Forest covers 90 township maps, the phase would cost a minimum of $45,000. USFS direct costs are included later with administration and overhead. The digital phase of stratification is performed by USFS staff. Information received from the contractor is digitized and entered into the WRIS mapping system. Costs here are about $200 per township map, or about $18,000 to fully map the Plumas. The site selection phase of the stratification process is performed by USFS staff. Direct costs for this phase are difficult to estimate since much of the site selection can be performed automatically. A minimal cost of $1,000 is presumed.

8.321.2 Ground data collection

The USFS regularly contracts out their inventory plot location and measurement activities. Ground data collection costs in the 1974 California inventories varied widely depending upon the contractor, forest, and terrain. Costs are usually stated in dollars per ground plot, now based on a 5-point plot cluster system.[1] Contracted sampling costs in 1974 ranged from a low of around $70 to a high of about $125 per ground plot. Informed guesses as to how many ground plots the USFS would require to perform a current inventory on the Plumas range from a low of 90 to a maximum of 150. Total ground data collection costs thus could be as low as $6,300 or as high as $18,750. A middle-range figure of $12,000 was chosen for the entry in Table 1. This is based on 120 ground plots at $100 each. Note that the gains assumed for ERTS stratification (8.312.3) were conservatively biased in the other direction, using a USFS sample size of 150 ground plots.

8.321.3 Data summary

Following the stratification and ground data collection tasks, the information gathered must still be summarized into a form suitable for later reference and for use in developing timber resource management plans. This data summary task is performed by USFS staff and the associated costs are difficult to isolate. For the purposes of this study, existing system and ERTS-based system data summary costs are assumed equal at $1,300.

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1. The 1969 USFS Plumas inventory ground sampling was based on more expensive 10-point plot clusters.

8.321.4 Administration and overhead

In addition to the identifiable direct costs, the Forest Service sampling system incurs indirect costs in the form of administration expenses and overhead. Since the USFS could be expected to contract out about three-quarters of the costs of a Plumas National Forest inventory, indirect expenses might be lower than expected. University of California administration and overhead rates on the ERTS-based system are estimated at about 60 percent of direct costs. Using similar rates for the USFS system, administration costs equal \$12,000 and overhead is an additional \$8,000. This estimate is based on an equal administration-overhead expense split on USFS direct costs and a 10 percent - 3 percent split on contracted costs.

8.321.5 Total estimated costs

A summation of the above items brings the total estimate for a USFS-style inventory of the Plumas National Forest to \$97,000. This is necessarily a rough approximation, but if anything, it is biased to the low side. Ground data collection costs, for example, could be as much as 50 percent higher if the maximum estimate of plots is required.

8.322 ERTS-Based Sampling System

Cost estimates for the ERTS-based sampling system were developed along with the sampling methodology described in 8.312. Table 2 summarizes the results of this effort. Unlike the Forest Service cost information, estimated for only one sample size and level of precision, the ERTS-based cost data were easily translated into a variety of sampling size and precision levels. Moreover, cost figures for the ERTS-based system were available at a greater level of detail than for the USFS system. Disaggregated costs for the ERTS-based system subtasks are displayed in Appendix II. Costs for the basic activity categories shown in Table 2 are described briefly here.

8.322.1 Pre-photo/groundwork

Most of the costs within this category can be considered as "start-up" expenses. Appendix II lists nine subtasks: tape acquisition, tape reformatting, test area extraction, delineation and extraction of administrative boundaries, training of classifiers, discriminant analysis run, generation and selection of PSU's, and location of PSU's. Costs associated with these subtasks are for the most part unaffected by changes in the level of sampling precision. Table 2 assumes a multidate analysis, useful for enhancing ERTS information value and comparing timber stands over time. The addition of two extra dates triples the costs of tapes and increases the cost of computer operations. Multidate analysis adds about \$3,000 to the pre-photo phase, bringing total pre-photo costs to around \$7,100.

TABLE 2: COSTS OF AN ERTS-BASED TIMBER INVENTORY SAMPLING SYSTEM PLUMAS NATIONAL FOREST, 1974

Allowable Error*	+ 5%	± 10%	± 15%	± 20%
Ground Plots	74	19	9	9
Pre-Photo/Groundwork	$ 7,100	$ 7,100	$ 7,100	$ 7,100
Aerial Photo/Interpretation	4,200	3,000	2,500	2,500
Ground Data Collection ($185/gp)	13,700	3,500	1,700	1,700
Data Summary	1,300	1,300	1,300	1,300
Map Generation (90 tm @ $90 ea)	8,100	8,100	8,100	8,100
Subtotal	$34,400	$23,000	$20,700	$20,700
Administration (27%)	9,300	6,200	5,600	5,600
Overhead (30.2%)	10,400	7,000	6,300	6,300
Total Cost (nearest $1,000)	$54,000	$36,000	$33,000	$33,000

*Allowable error at 1 standard error level of confidence (.68 probability)

tm= township maps
gp= ground plots

This additional amount, however, is designed in part to reduce the cost of subsequent steps by reducing the total number of lower stage sample units required. These reductions are facilitated by improved stratification accuracy.

8.322.2 Aerial photo interpretation

Aerial photography acquisition and interpretation costs were developed from a sample of 55 ground plots. Photo acquisition costs are considered as relatively fixed, while photo interpretation costs vary in proportion to the number of ground samples needed for each level of precision. Total costs for this category are about $4,200 at a 5 percent allowable error level.

8.322.3 Ground data collection

Consisting of mileage, wages, and per diem charges, costs in this category are directly related to the number of ground plots sampled. For 55 ground plots, data collection costs were $185 per plot. This is much above the $100 figure estimated for the USFS plots, but reflects a high mileage figure and the use of a dendrometer in place of less accurate timber volume tables. At the $185 rate, ground data collection costs for 74 plots approach $13,700.

8.322.4 Data summary and map generation

Both data summary and map generation costs remain constant over varying levels of precision. Costs for the ERTS-based data summary amounted to $1,300, half of which were report preparation and reproduction. Actual map generation costs were below $45 per township map, but to assure comparability an inflated unit cost of $90 per map is used here. Even this figure represents a considerable savings over the USFS map-production system where WRIS maps were estimated at $200 each. The total cost for 90 township maps is $8,100.

8.322.5 Administration and overhead

Indirect costs in the ERTS-based system are applied fully to all the above cost categories. At University of California rates, administration and overhead charges add 57.2 percent to direct costs. For a 5 percent allowable error level, administration and overhead together account for $20,000.

8.322.6 Total estimated costs

Estimated ERTS-based system costs, when rounded to the nearest $1,000, total $54,000 for a 74-ground plot sampling effort at a 5 percent allowable error level. Costs for lower levels of precision stabilize at around

$33,000. In contrast to the USFS-style inventory system costs, which were purposely estimated on the low side, the total costs of the ERTS-based system are biased in the opposite direction. The inclusion of multidate analysis capability, extensive training for image analysts, high labor and mileage rates, and added costs for map generation insures against understating the costs of the ERTS-based inventory system.

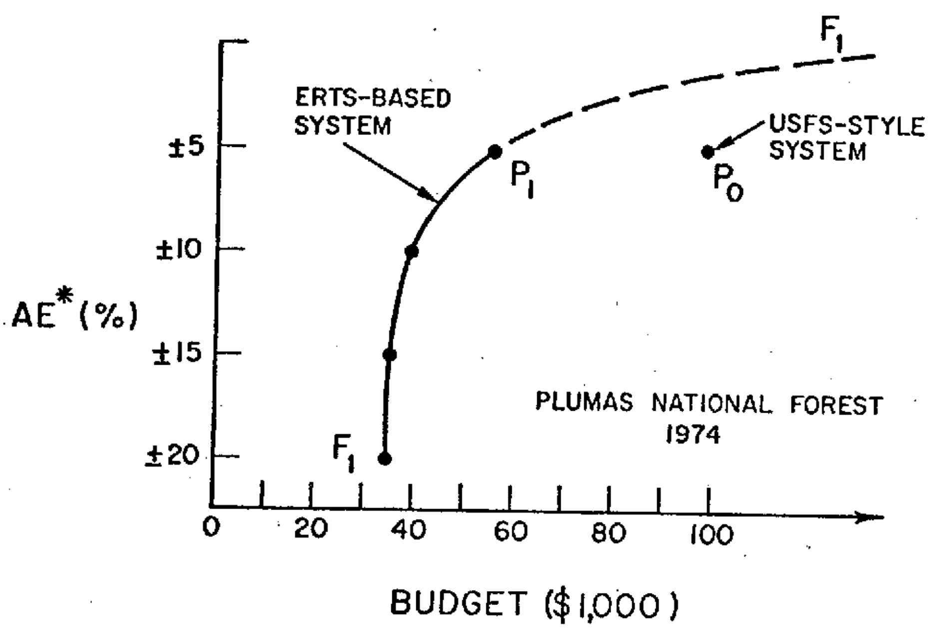
8.400 RESULTS AND CONCLUSIONS

The foregoing information facilitates a direct comparison of the two inventory systems on a cost-effectiveness basis. Figure 2 compares the two systems in a manner analogous to Figure 1. Tables 1 and 2 supply the relevant cost and capability data for each system.

Point P_O in Figure 2 represents one production possibility of the existing timber inventory system. Here, total costs for a USFS-style inventory of the Plumas National Forest in 1974 are estimated at $97,000. This budget amount is sufficient to produce inventory information with an allowable error of ± 5 percent at a level of confidence of one standard error (0.68 probability).

Four production possibilities of the ERTS-based inventory system are represented along frontier F_1F_1 in Figure 2. Each point portrays the budget required to attain a given level of inventory precision. Point P_1, at the ± 5 percent allowable error level, is directly comparable with point P_O. Here, the ERTS-based system shows a $43,000 (or 44%) advantage over the existing timber inventory system. On a cost per acre basis, the ERTS-based inventory at 4.7¢ per acre compares favorably with the USFS-style inventory at 8.4¢ per acre.

FIGURE 8.2: COST-CAPABILITY COMPARISON OF TIMBER INVENTORY SAMPLING SYSTEM



* ALLOWABLE ERROR AT 1 STANDARD ERROR LEVEL OF CONFIDENCE

The ERTS-based inventory system derives its advantage from two principle sources of cost savings: (1) initial stratification procedures, and (2) low-cost map generation. Automatic processing substantially reduces the amount of manual effort required in both activities. Initial stratification in the existing inventory system is performed mainly by human interpreters using resource photography and previously-produced forest type maps. The ERTS-based system, by utilizing a cost-effective blend of automatic processing techniques and computer-training inputs by human interpreters, allows substantial reductions in stratification and map generation.

The integration of automatic processing with stratification activities in the ERTS-based system also enables the generation of low-cost, digitized township maps. This study found that color-coded ERTS-based maps could be produced for one-quarter to one-half the cost of comparable black-and-white USFS WRIS township maps. The regular availability of ERTS imagery enhances the value of this type of map for use in updating wildland data bases.

In spite of the cost-effectiveness advantages promised by an ERTS-based timber inventory system, much additional investigation remains beyond the scope of this study. A more comprehensive analysis would include at least the tasks mentioned below.

(1) An examination of assumptions. Some of the assumptions made in this study require additional attention. For example, it was assumed that both systems are currently operating upon their respective cost efficiency frontiers. In actuality, the efficiencies of both systems can probably be improved; but the early-development nature of the ERTS-based system suggests the opportunity for greater improvement. Assumptions regarding equivalent gains in stratification should similarly be scrutinzied. There is a good chance that ERTS will provide even higher stratification gains after procedures are developed better relating ERTS and ground-based data. This is due to ERTS' consistency and acre-by acre resolution ability. Assumptions about output comparability also require examination. It may be that an ERTS-based inventory system is capable of producing an output which adds new dimensions to forest management planning practices. Increased inventory frequency could be an example here. Finally, capital costs could be examined in addition to operating costs. User agencies must also consider the start-up costs of implementing a potentially more efficient inventory system.

(2) An examination of sensitivity issues. The ability to identify those areas that most affect a system's cost and capability relationships is an essential part of a complete analysis. For example, it would be useful to know how the cost-effectiveness of an ERTS-based inventory system is affected by changes in forest size or heterogeneity. Additional case examples are required for a thorough investigation of the sensitivity issue.

(3) An examination of the benefits issues. Cost-effectiveness theory measures benefits in terms of cost savings. To better forecast the impact of investment in a new project or program it is useful to carefully analyze the resulting net benefits and beneficiaries. From this study, it can be expected that the primary benefits of an ERTS-based system would be cost savings to user agencies. Such organizations could apply these savings to extend the capability of the system, to develop other subject areas within the inventory design such as soil characteristics, or to initiate or expand other desired programs. Stratification of private as well as public lands is an example of capability extension. Another source of benefits would stem from the system's ability to deliver resource information and associated acquisition cost data not otherwise available. Inplace mapping of timber volume, type, and condition class and more efficient allocation of sample units are examples of additional information types. A thorough examination of benefits issues would help place values on such benefits.

(4) An examination of implementation issues. Cost-effectiveness analysis is but one tool in the process by which new technologies become applied technologies. Many other issues must be examined during the implementation process. Of foremost importance is familiarity with the decision and administrative structure of the user agency. An ERTS-based timber inventory system may be able to offer significant cost savings to user agencies, in terms of both the user's operating and capital costs, but non-cost considerations may prove more important. An understanding of and collaboration with the user agency's organizational dynamics is a necessary prerequisite in achieving a successful integration of an ERTS-based system with existing USFS inventory systems.

Appendix 1: Optimum Sample Allocation in Double Sampling for Regression

1. References: Raj, 1968, Sampling Theory and Cochran, 1963, Sampling Techniques.

2. The population variance for the double sampling estimator is given as

$$V(\bar{y}_{ds}) = \frac{s_y^2 (1-\rho^2)}{n} + \frac{\rho^2 s_y^2}{n'} = \frac{s_y^2}{n} \left[1-\rho^2\left(1-\frac{n}{n'}\right)\right] \tag{1}$$

The cost function is assumed to be

$$TC = Cn + C'n' \tag{2}$$

Notation is as follows:

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

ρ = correlation coefficient between y and x, the auxiliary information

n' = sample size for large sample where only x is measured

n = sample size for small sample where x and y are measured

TC = total variable cost of sampling

C = cost of making an observation for the small sample

C' = cost of making an observation for the large sample

If a desired precision level D is specified, we would like to minimize TC. Using LaGrangian multipliers:

$$\min \Pi = Cn + C'n' + \lambda^2 \left[\frac{s_y^2 (1-\rho^2)}{n} + \frac{\rho^2 s_y^2}{n'} - D\right] \tag{3}$$

$$\frac{\partial \Pi}{\partial n} = C - \lambda^2 \frac{s_y^2 (1-\rho^2)}{n^2} \tag{4}$$

$$\frac{\partial \Pi}{\partial n'} = C' - \lambda^2 \frac{\rho^2 s_y^2}{(n')^2} \tag{5}$$

$$\frac{\partial\pi}{\partial\lambda^2} = \frac{S_y^2\ (1-\rho^2)}{n} + \frac{\rho^2\ S_y^2}{n'} - D \tag{6}$$

Setting (4) and (5) equal to zero and combining terms

$$\lambda^2 = \frac{Cn^2}{S_y^2\ (1-\rho^2)}$$

$$\lambda^2 = \frac{C'\ (n')^2}{\rho^2 S_y^2}$$

Then,

$$\lambda^2 = \frac{Cn^2}{S_y^2\ (1-\rho^2)} = \frac{C'\ (n')^2}{\rho^2\ S_y^2}$$

$$\lambda^2 = \frac{Cn^2}{C'(n')^2} = \frac{S_y^2\ (1-\partial^2)}{S_y^2\ \rho^2}$$

$$\lambda^2 = \frac{n^2}{(n')^2} = \frac{C'\ (1-\rho^2)}{C\ \rho^2}$$

$$\lambda = \frac{n}{n'} = \sqrt{\left(\frac{C'}{C}\right)\left(\frac{1-\rho^2}{\rho^2}\right)}\ . \tag{7}$$

From (1),

$$\frac{D^2}{t^2} = \frac{S_y^2}{n}\ [1 - \rho^2(1-\lambda)] \tag{8}$$

where $\frac{D^2}{t^2}$ = Desired Sampling Variance

or $\quad D = t\sqrt{V\ (\bar{Y}_{ds})}$

Then we have

$$n = \frac{t^2\ S_y^2}{D^2}\ [1 - \rho^2(1-\lambda)] = [1 - \rho^2(1-\lambda)]n_{srs}$$

where $n_{SRS} = \frac{t^2\ CV^2}{AE^2}$,

$$n = n_{SRS}\ [1 - \rho^2(1 - \lambda)] \tag{9}$$

3. Double sampling is more desirable than simple random sampling according to Raj (p. 151), if

$$\rho^2 > \frac{4cc'}{(c+c')^2}$$

For the Plumas, assuming $\frac{c'}{c} = \frac{1}{10}$ maximum

$\frac{(4)(1)(10)}{(10+1)^2} = .33 = \rho^2$, So if $\rho \geq .57$, double sampling is preferred.

4. Given ρ, CV, AE, C', and C sample size may be determined using equations given above.

$$\lambda = \frac{n}{n'} = \sqrt{\left(\frac{c'}{c}\right)\left(\frac{1 - \rho^2}{\rho^2}\right)} \tag{10}$$

$$n = \frac{t^2\ CV^2}{AE^2}\ [1 - \rho^2(1 - \lambda)] \tag{11}$$

$$n' = n/\lambda \tag{12}$$

5. For the Plumas 74 inventory a series of calculations was made with various assumptions for ρ, CV, C' and C. The desired precision level throughout is $\pm 5\%$ at the 1 standard error probability level (Forest Service Standard). Table I.1 below summarizes the results of these calculations. Final sample size was selected as n' = 400 and n = 55.

Table I.1 Sample Size/Allocation Summary (n/n')

	C'=1, C=10		C'=1, C=15		C'=1, C=18	
CV	ρ=.8(λ=.2372)	ρ=.9(λ=.1532)	ρ=.8(λ=.1936)	ρ=.9(λ=.1251)	ρ=.8(λ=.1768)	ρ=.9(λ=.1192)
.50	51/215	31/205	48/250	29/232	-	-
.55	62/261	38/248	59/305	35/282	-	-
.80	131/552	80/524	124/640	75/596	121/685	73/634
1.25	-	-	-	-	296/1673	177/1546

Appendix II: Detailed Costs of ERTS-Based Timber Resources Inventory System, Plumas National Forest, 1974

PRE-PHOTO/GROUNDWORK (Multidate Analysis: 3 dates)

Tape Acquisition	$ 1,080
Tape Reformatting	
Tape 3 tapes/date @ $7.75 ea	70
Computer Time 1 hr/date @ $40/hr.	120
Operator 1½ hrs/date @ $5/hr	23
Test Area Extraction	
Tape 3 tapes/date @ $7.75 ea	70
Computer 1 hr/date @ $40/hr	120
Operator 1½ hrs/date @ $5/hr	8
Delineation/Extraction of Stratification (initial)	
Photo Reduction of Map	16
Digitizer with Operator 2 hrs @ $43/hr	86
LSR Fit of Co-ordinates: computer 6 runs/date @ $1.80/run	65
operator 8 hrs/date @ $3/hr	72
Computer Mask Generation: computer	38
operator 3 hrs/date @ $5/hr	45
Delineation/Extraction of Administrative Boundaries	
Photo Reduction of Map	16
Digitizer with Operator 8 hrs @ $43/hr	344
LSR Fit of Co-ordinates: computer 9 runs/date @ $1.80/run	50
operator 10 hrs/date @ $3/hr	90
Computer Mask Generation: computer	13
operator 3 hrs @ $5/hr	15
Training of Classifier (~60 classes/strip; 3 strips/base date)	
Computer Display terminal 24 hrs @ $40/hr	960
Image Analysts 50 hrs @ $6/hr	300
Statistical Analysis: computer (LBL)	75
operator 30 hrs @ $3/hr	90
Selection of Channels & Classes 20 hrs @ $5/hr	100

Discriminant Analysis Run	
Multidate: computer 9 runs	$1,920
operator/analyst 50 hrs @ $7.60/hr	380
Generation and Selection of PSU's	
Computer 3 hrs @ $40/hr	120
Analyst 4 hrs @ $3.40/hr	14
Location of PSU's (for aerial photography)	
Computer 10 hrs @ $40/hr	400
Analyst 80 hrs @ $5/hr	400
	$7,100

AERIAL PHOTOGRAPHY/INTERPRETATION (74 ground plots)

Photo Acquisition		
Aircraft	25 hrs @ $32/hr	$ 800
Pilot	32 hrs @ $ 6/hr	192
Photographer	32 hrs @ $3.40/hr	109
Film	60 rolls @ $3.60/roll	216
Processing	60 rolls @ $1.90/roll	114
Printing	ave 30 images/roll @ $.63/5" X 7" print (1800 prints)	1,134
Photo Interpretation		
Image Analyst 360 hrs @ $3.40/hr		1,650
		$4,215

GROUND DATA COLLECTION (74 Ground Plots)

Travel	
Mileage 6,180 @ $.15/mile	$ 930
Crew	
Wages 1,980 hrs @ $3.86/hr (62 days; 4 men)	7,650
Per Diem	5,100
	$13,680

DATA SUMMARY AND MAP GENERATION

Computer Analysis, Ground and Photo Data	$ 280
Combining ERTS and Ground Data 8 hrs @ $5/hr	40
Generation of Summary Statistics 16 hrs @ $5/hr	80
Generation of Maps 90 township maps @ $90 ea	8,100
Report Preparation and Reproduction	650
Computer Time	250
	$ 9,400

Subtotal		$34,395
ADMINISTRATION	(27%)	9,287
OVERHEAD	(30.2%)	10,387
Total Cost		$54,069

CHAPTER 9

SPECIAL STUDIES

No. 1: Atmospheric Effects in Image Transfer

<u>Co-Investigators</u>: K. L. Coulson and R. L. Walraven, Davis Campus

No. 2: The Potential Usefulness of Earth Resources Technology Satellites in Relation to the Management of Earth Resources and the Preservation of Man's Environment

<u>Co-Investigator</u>: Robert N. Colwell, Berkeley Campus

No. 3: Statement Before the Subcommittee on Space Science and Applications of the Committee on Science and Astronautics, U.S. House of Representatives, Ninety-third Congress, Second Session

<u>Co-Investigator</u>: Robert N. Colwell, Berkeley Campus

No. 4: Input Quality Encoding of Multispectral Data

<u>Co-Investigator</u>: V. Ralph Algazi, Davis and Berkeley Campuses

CHAPTER 9

SPECIAL STUDIES

<u>Special Study No. 1:</u> <u>Atmospheric Effects in Image Transfer</u>

<u>Co-Investigators:</u> K. L. Coulson and R. L. Walraven, Davis Campus

I. Introduction

Evidence is being accumulated that the polarization of the light reflected from natural surfaces can be used to good advantage for characterization of the surfaces and for discriminating among the different types of surfaces of most interest in remote sensing applications. For instance, the small number of measurements available show that broadleaf plants polarize more strongly than do members of the grass family. Similarly, the degree of polarization of the reflected light is affected by the amount of wax on the leaf surface, the roughness of the leaf, any small hair-like structures of the leaf, and the general structure of the canopy. These are all parameters which are useful in discriminating among different types of vegetation.

The most convenient method of investigating the polarization characteristics of a scene is probably by the use of a television display. The advantages of this type of presentation over the photographic method is that, being essentially instantaneous, the television system is not subject to the delays necessary in developing negatives or prints, the signals are readily deciphered in terms of the physical quantities involved, and they can be introduced directly into a computer for digital enhancement or other manipulation of the data. This last factor is of particular value for polarization sensing, as the degree of polarization and orientation of the plane of polarization of the light are both derived from computations based on two or more images of the same scene. Electronic storage of the images, which is most conveniently accomplished for the sequential type signals of a television system, permits the type of computer manipulation necessary for deriving the state of polarization of the light from the scene of interest.

Another method of obtaining polarization measurements from natural surfaces is by the use of a polarizing radiometer. This is the most satisfactory method of investigating the reflection properties in detail, and it has already been extensively used on this project to yield valuable data on surface properties. The method is, however, not well adapted to determining the polarization properties of the type of image most useful in remote sensing applications. The radiometric method is slow, giving data at only one resolution point at each instrument setting, and it would take an inordinate amount of time to build up the image of a scene, element by element. In addition, the equipment is expensive, somewhat complicated, and not readily portable. The television-computer combination, on the other hand, makes use of the tremendous technology which has been built up by the electronics industry to avoid the main deficiencies of both the photographic and radiometric methods. Thus, it is most adaptable to the demanding task of extracting from an instrument response signal all of the intensity and polarization information contained in an image received at a remotely located sensor.

This is not to say, of course, that the television-computer combination is without difficulties for the purpose. The response of television tubes is non-linear with intensity, a fact which requires careful calibration and correctional procedures, and fatigue effects of the tube may be serious in some cases. In addition, digital processing of the signals is demanding in both computer capability and computer time. This latter factor is not particularly serious in the present study, however, as a relatively sophisticated computer system is readily available on the project.

II. Preliminary Results

In order to check out the concept of a video polarizer system for use in remote sensing, a somewhat primitive system has been built up and used for obtaining some low resolution images in which polarization effects are demonstrated. The preliminary nature of the results should be emphasized. Not only is the resolution low, but also some of the electronic components introduced sufficient noise into the signal to further degrade the image. These deficiencies can be eliminated, however, by improved electronic components and signal processing, and indeed these improvements are the major objective of the final phase of the project. As will be seen below, the basic concept of the video polarizer system is a sound one, the results obtained already show that the combined polarization and intensity fields carry much more information than does the intensity field alone, and the low level of effort anticipated for our part of this integrated study during the next year (as we conclude our "phasing out" stage), is expected to result in an operable system for remote sensing applications.

The final design of the system has been modified somewhat from that shown in a previous report to that shown in Fig. 1. The polarizer is set at different orientations in front of the television camera, an image being taken at each setting. At least three different polarizer settings are necessary to derive all of the polarization information, but four settings will provide some redundancy in the data and is the number used so far. The scan from the television camera is processed through various electronic modules, and is eventually presented to the

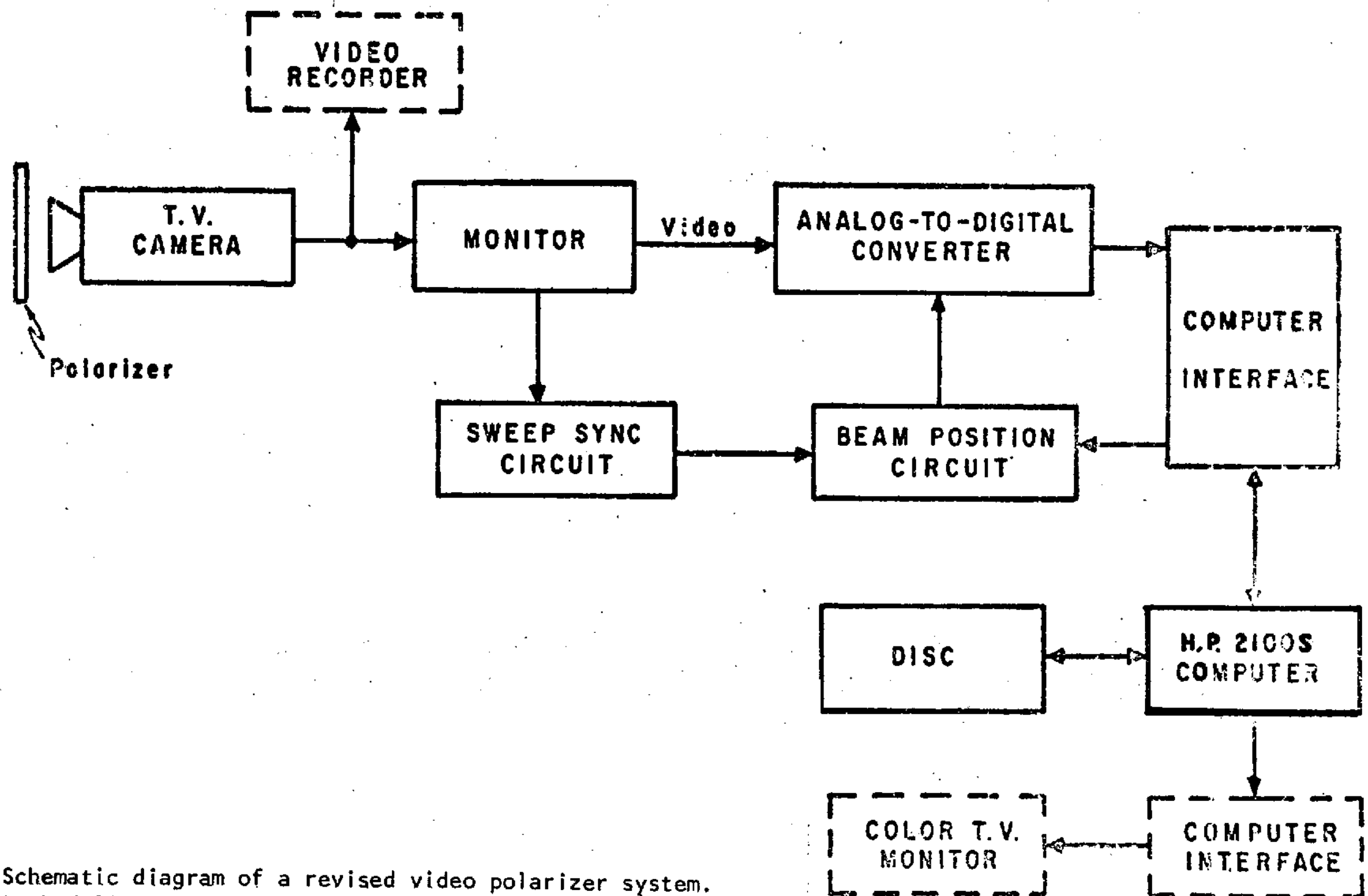


Fig. 1 Schematic diagram of a revised video polarizer system. Dashed lines indicate components that will be included during the next reporting period in order to display the polarized images by means of a color television monitor.

Hewlett-Packard 2100S computer and stored on the magnetic disc. Then the data for each of the images is retrieved from the disc for each resolution element and computer-processed to yield the three parameters intensity, degree of polarization, and angle of the plane of polarization. Once this is done for all of the resolution elements, an image for each of these parameters can be constructed. It is possible, of course, to further process the results for enhanced contrast, if such is desirable.

Once the intensity, polarization, and angle images are available in digital form, there are several options for the method of display. The most primitive of these is that of using an ordinary line printer with different symbols to obtain the half-tone shading required for building up the image. For instance, a comma, being small in area (and thus using a small amount of ink), will give a light tone, while a W, M, B, or any of several other letters (using a larger amount of ink) will give a much darker tone. In addition, it is possible, with some ingenuity, to use several overprints of letters to get a reasonably satisfactory shading within the image. This is the method which was used for some of the images shown below. The results are similar to those available with perhaps sixteen shades of gray, but of course the method is slow and primitive in general. An even slower and much more laborious method of sticking tiny pieces of either gray or colored paper over each resolution element was used for the other two images shown below (Figures 2 and 6). Several hours were required in this case to build up a single image, and even then the overall quality of the images is low. Obviously, a better method is required.

Perhaps the most satisfactory method of display of the images is by means of a television monitor. It is anticipated that this method will be implemented during the next period. The additional system components required are shown as dashed entries in Figure 1. The color television monitor is amenable to two different modes of operation. First, the image in any one of the three parameters, intensity, polarization, or angle, can be impressed as a black-and-white image on the television screen. This certainly has some usefulness, as certain features in one of the three images may be different from those of another, and thereby provide additional useful information. For instance, it is known that the degree of polarization is a function of the type of reflecting surface, so the polarization image can delineate the different types of surfaces perhaps better than can the intensity image. Likewise, the image in angle of the plane of polarization may show features that neither of the other parameters show.

The second mode of operation of the color monitor is to impress the signals for all three parameters on the tube at the same time, thereby yielding a single color image containing the information for all three parameters. The choice of color characteristic versus parameter is entirely arbitrary, but one possibility is to have the brightness controlled by intensity of the scene, color hue controlled by polarization of the scene, and color saturation controlled by the angle of the plane of polarization of the scene. Perhaps experience will show that some other combination is preferable for interpretation of various features of the scene, but since all of the signals are of the same digital form, there would be complete flexibility in the choice of presentation.

As mentioned above, some very preliminary results obtained from a primitive system are shown in the following low resolution images. The choice of an ordinary telephone as the subject was motivated by the fact that black plastic is a good polarizer, that the contoured surface of a telephone provides many different angles of the plane of polarization, and that the telephone is a familiar object.

A different rendition of the intensity image, in which the shading is obtained by gluing tiny pieces of paper made of eight different shades of gray on the resolution elements is shown in Fig. 2. In spite of the large amount of effort expended in constructing this image, the shading is not very uniform and the resolution is still low. The contrast, however, is better in this case than in those shown below.

The images of Figures 3, 4, and 5 were obtained from the parameters intensity, degree of polarization, and angle of the plane of polarization, respectively. They were made by judicious selection of the alpha-numeric symbols of a line printer to give the shading necessary. Although the resolution is low and the signal was somewhat noisy, there is no difficulty of recognizing the object as a telephone, at least in the intensity and polarization images of Figures 3 and 4. The image in angle of Fig. 5 is not quite so distinct, although even there the general outlines are evident. A careful look at the images reveals that not all of the images show the same features, a fact which emphasizes the basic value of the method. For instance, the telephone cord is more evident in the intensity image of Fig. 3; many more details of the dial section of the telephone are shown in the polarization image of Fig. 4; and details in or near the transmitter section (and also in the lower right section of the base) are best seen in the plane of polarization image of Fig. 5, even though the latter image suffers from noise. It should be realized in this context that in ordinary remote sensing methods, only the intensity image would be available.

An attempt to display all of the polarization information (Figures 4 and 5) in a single composite is shown in Figure 6. Here the structure was built up by gluing tiny pieces of colored plastic on the resolution elements. The degree of polarization is represented by the saturation of the colors and the angle of the plane of polarization by the hue. For instance, the light colored area to the right of the telephone represents the low polarization of the background, whereas the saturated color (deep red) of the earpiece represents a high degree of polarization. The change of color from red, yellow, green, blue, violet shows a rotation of the plane of polarization from 0 to 180° with respect to the vertical direction. This angle is dependent mainly on aspect angle of the surface.

Fig. 2 A low resolution image obtained by computer processing of the intensity component of the signal from the video polarizer.

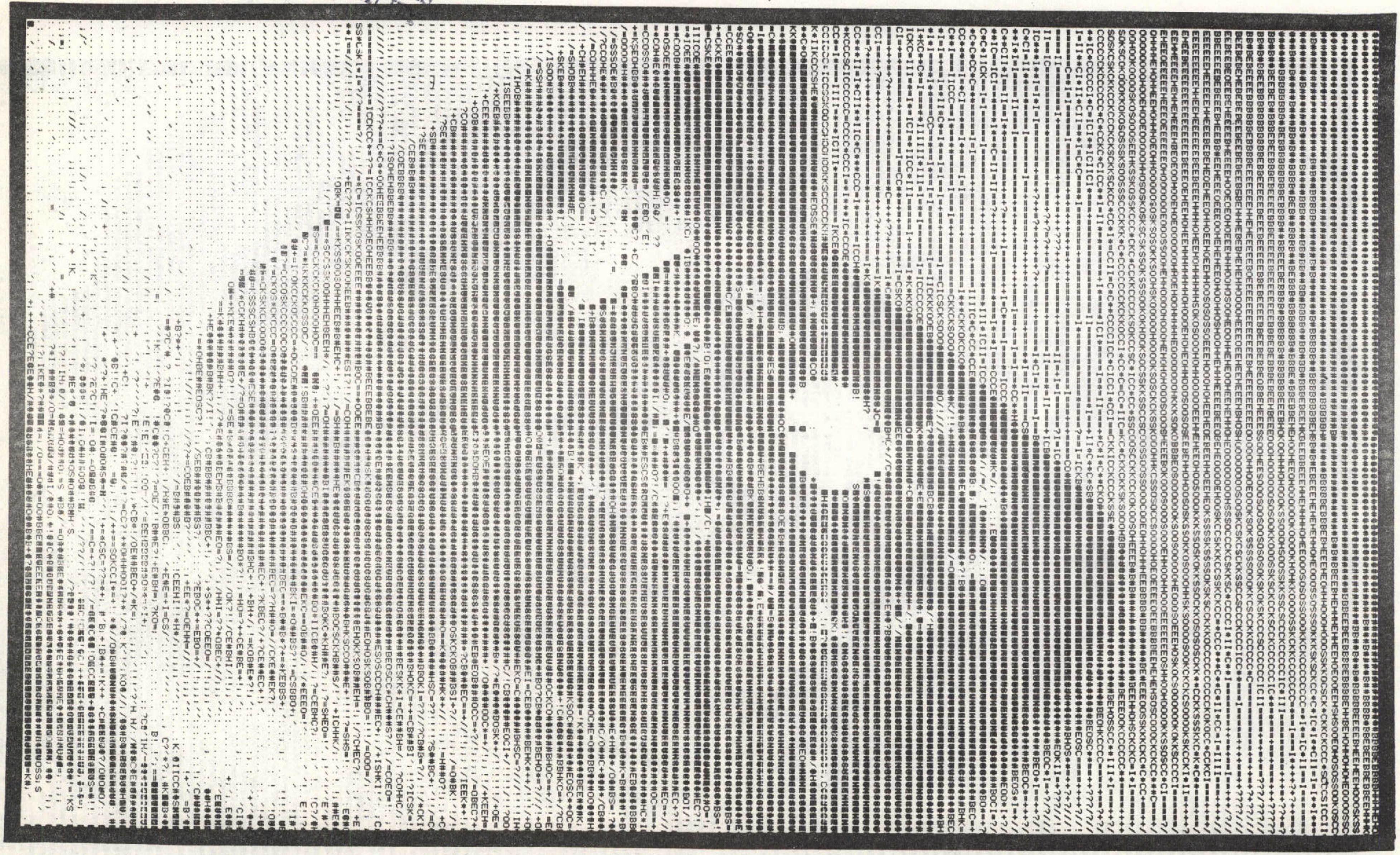


Fig. 3 A low resolution image obtained by a line printer readout of the intensity component of the signal from the video polarizer.

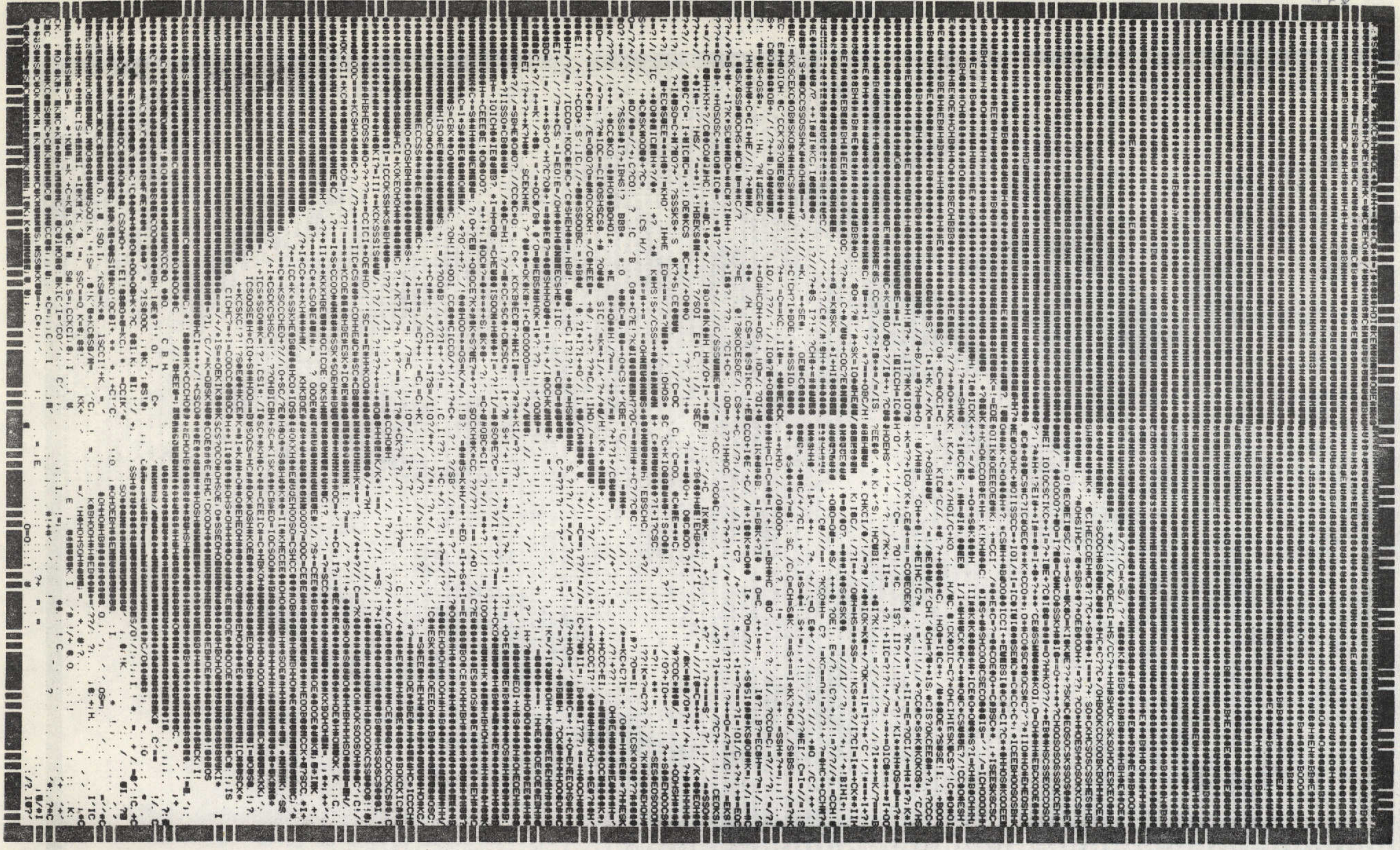


Fig. 4 A low resolution image obtained by a line printer readout of the <u>polarization component</u> of the signal from the video polarizer. (Only the polarization contributes to this image.)

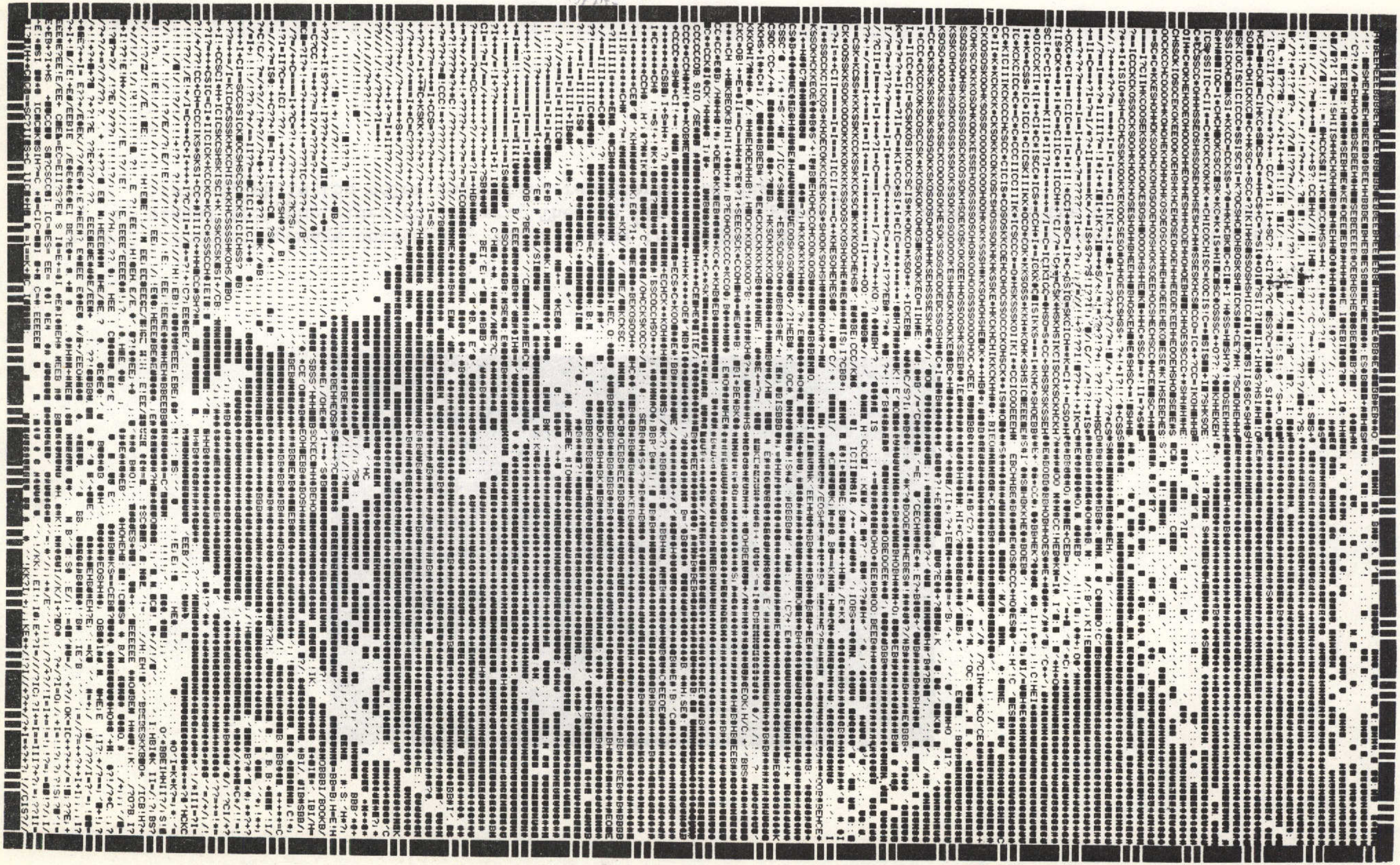


Fig. 5 A low resolution image obtained by a line printer readout of the plane of polarization component of the signal from the video polarizer. (Only the orientation of the plane of polarization contributes to this image.)

Fig. 6 A composite image obtained by color coding the degree and plane of polarization components of the signal from the video polarizer. The hue (red, blue, green, etc.) represents the plane of polarization, while the color saturation represents the degree of polarization.

The colored image suffers from the resolution and noise problems mentioned above, plus some additional ones of its own. Over the area of the telephone dial, for instance, the polarization field is so packed full of information, due to small elements which polarize highly, that a low resolution image becomes somewhat broken up. This is true also in other areas as well. Another practical difficulty is that it was impossible to get as many colors and shades of plastic as needed to represent all of the variations of hue and saturation. In spite of these difficulties, however, a careful analysis of Fig. 6 shows many subtle differences which can be interpreted in terms of the reflection characteristics and aspect of the various surfaces of the telephone and background. We emphasize again that this is strictly a polarization image, and is independent of intensity.

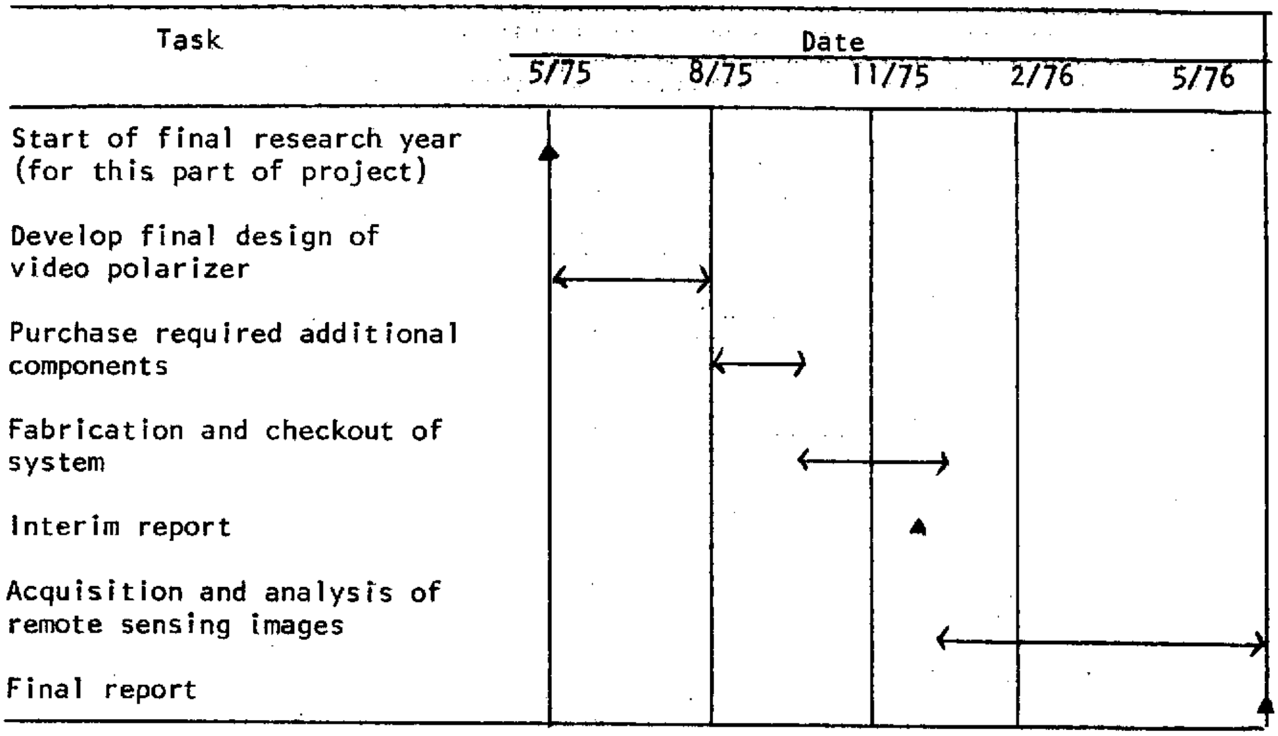
III. Future Plans

In order to further develop the method of introducing polarization effects into remote sensing applications, practically all of the effort in this final and low effort phase of the investigation will be put on the video polarizer system. The provision of a color television monitor, properly interfaced to the computer system, will greatly minimize the resolution problem which plagues the images shown above, and density gradients will be smooth and uniform. All three of the parameters can be displayed as intensity, hue, and saturation of the colors on the face of the tube, thereby presenting a tremendous amount of information in a form which is readily transferred to the human brain. All of the laborious and time consuming effort which went into building up the images shown above will be eliminated, and the images can be conveniently manipulated as required. A hard copy of any desired image can be obtained by photographing the face of the television tube.

The main hardware items which we still need in order to develop the video polarizer system to an operational status are a color television monitor (together with the necessary interfacing electronics), and the video recorder shown in the schematic diagram of Fig. 1. In addition, a considerable amount of effort will have to be put into the design, fabrication, and interfacing of the electronic modifications necessary to make the system truly operational. Both of these items are outlined in the proposed budget. At the end of the project period, it is anticipated that the system will have been used in an operational mode to collect data in realistic remote sensing applications to demonstrate its usefulness in a convincing manner.

IV Proposed Schedule

The following are the principal events anticipated for the final period of this part of the research grant:


Task
Date
5/75
8/75
11/75
2/76
5/76
Start of final research year
(for this part of project)
Develop final design of
video polarizer
Purchase required additional
components
Fabrication and checkout of
system
Interim report
Acquisition and analysis of
remote sensing images
Final report

SPECIAL STUDY NO. 2

THE POTENTIAL USEFULNESS OF EARTH RESOURCES TECHNOLOGY SATELLITES IN RELATION TO THE MANAGEMENT OF EARTH RESOURCES AND THE PRESERVATION OF MAN'S ENVIRONMENT

Robert N. Colwell

INTRODUCTION

The following is a report submitted to the Committee on Aeronautics and Space Sciences of the United States Senate in which many of the pertinent findings to date by research workers of the University of California, funded under the present grant, are summarized. The report was submitted to the Senate Committee at the request of the American Society of Photogrammetry.

The report begins with a tabulation of the unique combination of remote sensing capabilities to be found in ERTS-1. The value of this combination of capabilities is then considered in the light of five specific case studies which grant-funded University of California investigators have made, using ERTS-1 data.

The report concludes with the reproduction of a letter to Senator Moss which accompanied this report to him, dated August 1, 1974.

TABLE I
VALUABLE CHARACTERISTICS OF
ERTS DATA IN RELATION TO
THE INVENTORY AND MONITORING
OF EARTH RESOURCES

(NO OTHER VEHICLE PROVIDES THIS IMPORTANT COMBINATION OF CHARACTERISTICS)

1. MULTISPECTRAL CAPABILITY

   A. SENSES FOR THE OPTIMUM WAVELENGTH BANDS FOR USE IN THE INVENTORY AND MONITORING OF MOST TYPES OF EARTH RESOURCES (TIMBER, FORAGE, AGRICULTURAL CROPS, MINERALS, WATER, ATMOSPHERIC AND OCEANOGRAPHIC RESOURCES)
   B. PROVIDES HIGH SPECTRAL FIDELITY WITHIN EACH OF THESE BANDS

2. MULTI-TEMPORAL CAPABILITY (PROVIDES MULTIPLE "LOOKS" FOR MONITORING SEASONAL CHANGES IN VEGETATION, RATE AND DIRECTION OF PLANT SUCCESSION AND THE ACCUMULATION OR RECEDING OF SNOW OR FLOOD WATERS)

3. CONSTANT REPETITIVE OBSERVATION POINT (FACILITATES CHANGE DETECTION BY MATCHING OF MULTI-TEMPORAL IMAGES)

4. SUN SYNCHRONOUS (NEARLY CONSTANT SUN ANGLE) ENSURES NEARLY UNIFORM LIGHTING AND UNIFORM IMAGE TONE OR COLOR CHARACTERISTICS FOR USE IN FEATURE IDENTIFICATION

5. NARROW ANGULAR FIELD OF SENSORS (570 MILE ALTITUDE AND ONLY 115 MILE SWATH WIDTH AVOIDS TONE OR COLOR "FALL OFF" AT EDGES OF SWATH AND THUS INCREASES STILL FURTHER THE UNIFORMITY OF IMAGE TONE OR COLOR CHARACTERISTICS)

6. PROVIDES COMPUTER-COMPATIBLE PRODUCTS DIRECTLY (FACILITATES AUTOMATIC DATA PROCESSING)

7. POTENTIAL MINIMUM DELAY IN DATA AVAILABILITY TO USER (PERMITS "REAL-TIME" ANALYSIS AND FACILITATES MAKING GLOBALLY UNIFORM RESOURCE INVENTORIES, WHEN APPROPRIATE, OR ANALYZING TROUBLED AREAS SUCH AS SAHEL, IN AFRICA)

8. SYSTEMATIC COVERAGE OF ENTIRE EARTH EXCEPT FOR NEAR-POLAR REGIONS

9. CAPABILITY FOR RECEIVING DATA FROM GROUND-BASED DATA PLATFORMS (FACILITATES USE OF "GROUND TRUTH" DATA IN THE INVENTORY AND MONITORING OF EARTH RESOURCES)

10. SPATIAL RESOLUTION IS OPTIMUM FOR "FIRST STAGE" LOOK AND IS POLITICALLY PALATABLE, BOTH DOMESTICALLY AND INTERNATIONALLY

11. DATA ROUTINELY PLACED IN PUBLIC DOMAIN FOR BENEFIT OF ALL MANKIND

TABLE II

SUMMARY TABLE SHOWING VALUABLE CHARACTERISTICS OF ERTS WHICH FACILITATE THE SUCCESSFUL COMPLETION OF CASE EXAMPLES I THROUGH V, AS DESCRIBED IN SUCCEEDING PAGES* ("X" INDICATES SIGNIFICANT VALUE FOR CASE EXAMPLE IN QUESTION)

CHARACTERISTICS OF ERTS**	CASE EXAMPLES (SEE TEXT) I AGR	II FORESTRY	III RANGE	IV HYDROL	V HYDROL
1.	X	X	X		X
2.	X		X	X	X
3.	X		X	X	X
4.	X		X		X
5.	X	X	X		X
6.	X	X	X		X
7.	X		X		X
8.	X	X	X	X	X
9.			X		X
10.	X	X	X		X
11.		X	X	X	X

*TO COMPLETE THE ANALYSIS, SUB-SAMPLES OF DETAILED DATA INPUTS ARE NEEDED WHICH ARE ACQUIRED ON THE GROUND AND/OR FROM ULTRA-HIGH RESOLUTION AIRCRAFT OR SPACECRAFT IMAGERY

**FOR DESCRIPTION OF EACH ERTS CHARACTERISTIC SEE CORRESPONDING NUMBER IN TABLE I

CASE EXAMPLE NO. I

DISCIPLINE: AGRICULTURE

APPLICATION: CROP INVENTORY

INFORMATION REQUIREMENTS: ACREAGE OF MAJOR CROPS BY COUNTY AND IRRIGATION DISTRICT WITHIN LARGE AGRICULTURAL REGIONS. USER AGENCIES INCLUDE U.S. DEPARTMENT OF AGRICULTURE; STATE AGRICULTURAL AGENCIES; U.S. AGRICULTURAL STABILIZATION AND CONSERVATION SERVICE; CROP GROWERS ASSOCIATIONS; MANUFACTURERS OF AGRICULTURAL RELATED PRODUCTS; STATE AND COUNTY WATER RESOURCE DEPARTMENTS; AND LOCAL IRRIGATION DISTRICTS

STEP-WISE PROCEDURE:

A. OBTAIN ERTS COVERAGE OF ENTIRE REGION ON REPETITIVE BASIS ON 3-5 SELECTED DATES DURING GROWING SEASON

B. INTERPRETERS STRATIFY AREA INTO HOMOGENEOUS TYPES ON HARD COPY IMAGERY. COMPUTER PROCESSING (UNSUPERVISED CLASSIFICATION) OF DIGITAL DATA PROCEEDS IMMEDIATELY

C. BASED ON INITIAL PROCESSING, FIELD VISITS ARE MADE WITHIN ONE WEEK

D. USING GROUND DATA, SUPERVISED CLASSIFICATION BY STRATUM IS PERFORMED. AS SEASON PROGRESSES, MULTIDATE ANALYSIS IS USED IN ADDITION TO MULTIBAND ANALYSIS

E. COMPUTER CLASSIFICATION IS CORRECTED AND ADJUSTED, USING GROUND DATA, AND SUMMARY STATISTICS ARE COMPILED

END PRODUCTS: SUMMARY STATISTICS OF CROP ACREAGES BY STRATA, COUNTY, REGION; ALSO MAPS OF CROP LOCATION IF NEEDED

IMPORTANT ERTS CHARACTERISTICS (SEE TABLE I): 1, 2, 3, 4, 5, 6, 7, 8, 10

COMMENTS: THE ABILITY OF ERTS TO PROVIDE COMPUTER-COMPATIBLE DATA WITH HIGH SPECTRAL RESOLUTION, AND THE ABILITY TO ACCURATELY OVERLAY MULTIDATE DATA AND TO OBTAIN A RAPID TURN-AROUND OF DATA TO THE USER ARE CRITICAL. INFORMATION IS INDISPENSIBLE TO RATIONAL PLANNING OF AGRICULTURAL POLICY, BOTH AT A NATIONAL AND INTERNATIONAL LEVEL, AND FOR FORECASTING MARKET CONDITIONS.

CASE EXAMPLE NO. II

DISCIPLINE: FORESTRY

APPLICATION: FOREST RESOURCES INVENTORY

INFORMATION REQUIREMENTS:

A. A STRATIFICATION BY TYPE (SPECIES COMPOSITION) AND/OR CONDITION CLASS (THE PHYSICAL STATE) AS FOLLOWS:

TRUE FIR	OVER MATURE, DECADENT	CONDITION CLASSES
	POORLY STOCKED	
MIXED CONIFER	MATURE STANDS	
	IMMATURE STANDS	
EAST SIDE PINE	REGENERATION	
HARDWOODS		

NON FOREST-(CUTOVER), CROP, RANGE, BRUSH, WATER, ROADS, ETC.
NON COMMERCIAL-DERIVED FROM MANAGEMENT CONSTRAINTS:
 WITHDRAWN (WILDERNESS, AREAS UNDER STUDY, ETC)
 SENSITIVE AREAS
 LOW SITE (PRODUCTIVITY) AREAS
 CHRISTMAS TREE LANDS

B. AREAS AND BOUNDARY DELINEATIONS FOR EACH TYPE-CONDITION CLASS
C. YIELDS-VOLUME BY TYPE CONDITION CLASSES; QUALITY ASPECTS OF YIELD: TREE CLASS, SIZE, DEFECT
D. GROWTH-COMPONENTS: SURVIVAL, MORTALITY, INGROWTH
E. PROGNOSIS-FUTURE YIELDS (DERIVED)
F. LAND USE CONSTRAINT CLASSIFICATION
   I. NON-FOREST
   II. FOREST
      A. UNPRODUCTIVE (<20 CUBIC FT/YR GROWTH)
      B. PRODUCTIVE (>20 CUBIC FT/YR GROWTH)
         1. RESERVED (WILDERNESS, ETC.)
         2. DEFERRED (PENDING CLASSIFICATION AS RESERVED)
         3. COMMERCIAL
            a. UNREGULATED (NOT SUITABLE OR DESIRABLE FOR SUSTAINED YIELDS, E.G., ADMINISTRATIVE, CHRISTMAS TREES, AND RECREATIONAL LANDS)
            b. REGULATED
               (1) STANDARD (INTENSIVE MANAGEMENT)
               (2) SPECIAL (MANAGEMENT RESTRICTED BY OTHER VALUES)
               (3) MARGINAL (CAPABLE BUT NOT CURRENTLY PRODUCING OR VALUED)

STEP-WISE PROCEDURE:

A. HUMAN DELINEATION OF BROAD ENVIRONMENTAL STRATA USING HARD COPY PRODUCT
B. DISCRIMINANT ANALYSIS OF DIGITAL TAPE DATA FOR TYPE AND CONDITIONAL CLASS
C. SUB SAMPLING OF DISCRIMINANT ANALYSIS RESULTS PROPORTIONAL TO AREA OF TIMBER FOR VERY LARGE SCALE PHOTOGRAPHY TO OBTAIN SECOND STAGE ESTIMATES OF PARAMETERS
D. SUB SAMPLING OF LARGE SCALE PHOTOGRAPHY FOR GROUND MEASUREMENTS OF INVENTORY PARAMETERS
E. ERTS ESTIMATES ARE ADJUSTED TO REFLECT THE INFORMATION GAINED THROUGH THE SUBSAMPLING

END PRODUCTS:

A. STATISTICAL SUMMARY OF EACH PARAMETER OF INTEREST
B. MAPS OF PHYSICAL CONDITIONS OF THE AREA
C. CONFIDENCE ESTIMATE FOR MAPPED AND STATISTICAL DATA
D. COMPUTER DATA BASE FOR DIRECT USE IN RESOURCE ALLOCATION MODEL

IMPORTANT ERTS CHARACTERISTICS (SEE TABLE I): 1, 5, 6, 8, 10, 11

COMMENTS: THE APPLICATION OF THE ERTS DATA TO THE FORESTRY PROBLEM REQUIRES HUMAN AND COMPUTER PROCESSING OF BOTH HARD COPY IMAGERY AND DIGITAL TAPES. MULTIDATE, MULTISTAGE APPROACH WITH COMPUTER ANALYSIS OF THE DIGITAL DATA HAS PROVEN VERY COST EFFECTIVE. THE RESULTS OF THE ANALYSIS PROVIDE NEARLY ALL THE INFORMATION NECESSARY FOR THE MANAGER.

CASE EXAMPLE NO. III

DISCIPLINE: RANGE MANAGEMENT

APPLICATION: MONITORING CHANGES IN RANGE CONDITION

INFORMATION REQUIREMENTS:

A. AVAILABILITY OF UTILIZABLE FORAGE
B. CONDITION AND DEVELOPMENT OF FORAGE IN RELATION TO QUALITY AND QUANTITY OF FORAGE
C. PHENOLOGICAL STAGE AT SPECIFIC TIME INTERVALS FOR COMPARISON OF CONDITION AND PRODUCTION BETWEEN AREAS WITHIN A REGION AND FOR COMPARISON OF CONDITION AND PRODUCTIVITY BETWEEN SEASONS FOR A PARTICULAR AREA.
D. ASSESSMENT OF FINE-FUEL FLAMMABILITY
E. ASSESSMENT OF AVAILABILITY OF SURFACE AND SOIL MOISTURE
F. ASSESSMENT OF DROUGHT STRICKEN AREAS
G. USER AGENCIES INCLUDE:
   STATE CROP AND LIVESTOCK REPORTING AGENCIES;
   FEEDLOT OWNERS AND CATTLE RANCHERS;
   BUREAU OF LAND MANAGEMENT;
   FEED SUPPLEMENT INDUSTRY; AND
   STATE FIRE CONTROL AGENCIES

STEP-WISE PROCEDURE (OR APPROACH):

A. UTILIZE MANUAL INTERPRETATION OF ERTS IMAGES, AND SPECTRAL DATA FROM ERTS TAPES COMBINED WITH SELECTIVE GROUND SAMPLING
B. REQUIRES ANALYSIS OF SEQUENTIAL ERTS IMAGES ACQUIRED DURING INITIAL, AND MID-TO-LATE MATURATION STAGE OF PLANT DEVELOPMENT
C. MULTIBAND/MULTIDATE ERTS IMAGES ARE REQUIRED TO RECONSTITUTE VISUAL COLOR IMAGES FOR DETERMINATION OF HEALTH, AVAILABILITY, AND DISTRIBUTION OF FORAGE VEGETATION
D. SYSTEMATIC, REPETITIVE COVERAGE IS REQUIRED TO MONITOR CHANGES IN DEVELOPMENT OVER TIME
E. TO BE OF MAXIMUM USE, SHORT TURN-AROUND TIME IS REQUIRED IN ORDER TO MAKE MANAGEMENT DECISIONS WHICH ARE RESPONSIVE TO CHANGES IN CONDITION OF FORAGE
F. SPECTRAL FIDELITY OF ERTS IS ESSENTIAL TO COMPARE DIFFERENT AREAS WITHIN LARGE AREA SCENE AND ALSO IS REQUIRED FOR CALIBRATION PURPOSES WITHIN AND BETWEEN SCENES
G. THE MULTI-SPECTRAL DATA FROM ERTS TAPES CAN BE EXTRACTED AND SPECTRAL REFLECTANCE RATIOS CALCULATED WHICH CORRELATE WITH CHANGES IN PHENOLOGICAL STAGE, FORAGE CONDITION AND AMOUNT OF GREEN BIOMASS
H. GROUND SAMPLING IS REQUIRED TO ESTABLISH CORRELATION BETWEEN AMOUNT OF BIOMASS, PHENOLOGY, AND ERTS SPECTRAL REFLECTANCE RATIOS

IMPORTANT ERTS CHARACTERISTICS (SEE TABLE I): 1 THROUGH 11

END PRODUCTS:

1. A DETERMINATION OF THE TIME OF IMPORTANT PHENOLOGICAL EVENTS, E.G., SEED GERMINATION, PEAK FOLIAGE DEVELOPMENT, MATURATION

2. EVALUATION OF RATE OF CHANGE OF VEGETATION IN RELATION TO AVAILABLE MOISTURE

3. MAPS OF AREAL EXTENT OF AVAILABLE FORAGE BY FORAGE CONDITION CLASS, THROUGHOUT THE ENTIRE GRAZING REGION

4. QUANTITATIVE ASSESSMENT OF CHANGING PHENOLOGICAL STAGES

5. PERMANENT RECORD OF FORAGE CONDITION FOR COMPARISON WITH CONDITIONS IN SUBSEQUENT YEARS

DISCIPLINE: HYDROLOGY

APPLICATION: INVENTORY OF IRRIGATED LANDS

INFORMATION REQUIREMENTS: DETERMINE ACREAGE OF AGRICULTURAL LAND THAT IS UNDER IRRIGATION AT LEAST ONCE DURING THE COURSE OF EACH WATER YEAR. USER AGENCIES INCLUDE:
STATE AND COUNTY DEPARTMENT OF WATER RESOURCES;
U.S. BUREAU OF RECLAMATION; AND
LOCAL IRRIGATION DISTRICTS

STEP-WISE PROCEDURE:

A. OBTAIN QUARTERLY ERTS COVERAGE OF ENTIRE STATE OR REGION (REQUIRES RAPID SYNOPTIC COVERAGE OF LARGE AREAS ON REPETITIVE BASIS)
B. COLLECT GROUND DATA FOR SELECTED SAMPLE AREAS COINCIDENT WITH ERTS OVERPASS
C. USING POINT SAMPLING APPROACH, INTERPRETERS ENUMERATE POINTS UNDER IRRIGATION ON EACH OF THE IMAGE DATES (REQUIRES CONSTANT GEOMETRY OF IMAGERY ON SUCCESSIVE PASSES AND SUCCESSIVE 18-DAY CYCLES TO ALLOW EASY LOCATION OF SAME SAMPLE POINTS ON THE IMAGERY ON EACH OF SEVERAL DATES)
D. BASED ON POINT SAMPLE PERCENTAGES, ESTIMATE PERCENT OF TOTAL AREA BY COUNTY UNDER IRRIGATION, AND CONVERT PERCENTAGES TO ACREAGE ESTIMATES

END PRODUCTS: ACREAGE ESTIMATES OF IRRIGATED LANDS BY REGION, STATE, COUNTY, AND/OR IRRIGATION DISTRICT EACH YEAR

IMPORTANT ERTS CHARACTERISTICS (SEE TABLE I): 2,3,8,11

COMMENTS: THE COMBINATION OF LARGE AREAL EXTENT OF SURVEY AREA, TRANSIENT NATURE OF THE PHENOMENON, AND NEED FOR REPETITIVE OBSERVATIONS MAKES THIS TASK PROHIBITIVELY EXPENSIVE USING CONVENTIONAL TECHNOLOGY. INFORMATION IS VERY IMPORTANT TO THE OPTIMUM PLANNING OF WATER DISTRIBUTION FACILITIES AND ALLOCATION STRATEGIES.

CASE EXAMPLE NO. V

DISCIPLINE: HYDROLOGY

APPLICATION: SNOW SURVEY

INFORMATION REQUIREMENTS: PREDICTION OF WATER YIELD; SPECIFICALLY, THE ESTIMATION OF SNOW AREAL EXTENT, A FACTOR RELATED TO WATER YIELD. USER AGENCIES INCLUDE:

JOINT FEDERAL-STATE RIVER FORECAST CENTERS;
COOPERATIVE SNOW SURVEY ORGANIZATIONS;
MAJOR PUBLIC UTILITIES;
IRRIGATION AND WATER DISTRICTS;
CITY AND COUNTY AGENCIES

STEP-WISE PROCEDURE:

A. USING A STANDARD MIRROR STEREOSCOPE, AN OBSERVER VIEWS TWO MULTIBAND COLOR ERTS-1 ENHANCEMENTS SIMULTANEOUSLY--ONE TAKEN DURING THE SUMMER SEASON SHOWING VEGETATION DENSITY AND TERRAIN CONDITIONS, AND ONE TAKEN DURING THE SNOW SEASON SHOWING SNOW CONDITIONS. MULTITEMPORAL ERTS-1 IMAGERY GIVES RELATIVELY FREQUENT VIEWS OF THE WATERSHED DURING SNOW ACCUMULATION AND MELT.

B. 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 ANALYST APPEAR TO BE SUPERIMPOSED ONE ON THE OTHER. (WITH ERTS, THE RELATIVE CONSTANT IMAGE CENTER LOCATION ALLOWS SUPERPOSITION OF IMAGES FROM DIFFERENT DATES.)

C. A GRID OF KNOWN DIMENSIONS IS PLACED OVER THE SNOW SEASON IMAGE AND THE TOTAL PERCENT AREA WITHIN EACH GRID CELL THAT IS COVERED BY SNOW IS ESTIMATED AND RECORDED AS FALLING WITHIN A GIVEN PERCENTAGE COVER CLASS RANGE. ESTIMATION PROCEEDS ACCORDING TO AN ALTERNATE VIEWING OF SUPERIMPOSED IMAGES AND CONSEQUENT DECISIONS AS TO SNOW APPEARANCE BY COMPARISON WITH VEGETATION/TERRAIN TYPE KEYS, PREPARED IN ADVANCE. THE EXCELLENT SPECTRAL FIDELITY OF ERTS-1 IMAGERY ALLOWS UNIFORM INTERPRETATIONS TO BE MADE OF SNOW PRESENCE OVER THE ENTIRE AREA OF VIEW.

D. AREAL EXTENT OF SNOW IS DETERMINED FOR ANY GIVEN WATERSHED FOR ANY GIVEN DATE BY CALCULATING THE TOTAL ACREAGE IN EACH SNOW COVER CLASS (NUMBER OF CELLS IN EACH CLASS X AVERAGE NUMBER OF ACRES PER CELL), AND MULTIPLYING THE ACREAGE VALUE IN EACH CLASS BY THE PERCENTAGE MIDPOINT OF THE RESPECTIVE CLASS. IF DESIRED, THE OVERALL NEW ACREAGE ESTIMATE MAY THEN BE CALIBRATED BY USE OF AN INEXPENSIVE SAMPLE OF LARGE SCALE PHOTOGRAPHS OF BASIN SNOW CONDITIONS FOR THAT ERTS-1 SNOW DATE WITHIN THE WATERSHED OF INTEREST.

END PRODUCTS: ACREAGE ESTIMATES OF AREAL EXTENT OF SNOW BY WATERSHED, OR MANAGEMENT UNIT DURING THE PERIODS OF PEAK ACCUMULATION AND MELTING, WHICH MAY THEN BE USED AS ONE VARIABLE IN WATER YIELD PREDICTION EQUATIONS.

IMPORTANT ERTS CHARACTERISTICS (SEE TABLE I): 1 THROUGH 11

C-6

COMMENTS: THE DIRECT TELEMETERING OF ERTS-1 DATA TO THE GROUND IS VITAL FOR TIMELY, INEXPENSIVE DETERMINATION OF SNOW AREAL EXTENT OVER MANY LARGE WATERSHEDS. THE RELATIVELY LOW SPATIAL RESOLUTION OF ERTS-1 DATA ALLOWS ACCURATE ESTIMATES OF SNOW COVER TO BE MADE WITHOUT UNDULY HIGH AND THUS EXPENSIVE DATA LOADS. LASTLY, THE EXPERIENCE FACTOR GENERATED BY PERIODIC, UNIFORM, ADEQUATELY RESOLVED VIEWS FROM ERTS-1, MAY ALLOW CHARACTERIZATION OF THE AVERAGE SNOW EXTENT DYNAMICS RESULTING IN MORE COST-EFFECTIVE SAMPLING PROCEDURES.

UNIVERSITY OF CALIFORNIA, BERKELEY

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SPACE SCIENCES LABORATORY BERKELEY, CALIFORNIA 94720

APPENDIX I TO SPECIAL STUDY NO. 2

August 2, 1974

The Honorable Senator F. E. Moss
United States Senate
Committee on Aeronautics and Space Sciences
231 Russell Senate Office Building
Washington, D.C. 20510

Dear Senator Moss:

The American Society of Photogrammetry, which is this country's leading professional (non-profit) society concerned with achieving the intelligent use of aerial photography, space photography and other forms of remote sensing data, has asked me to convey to your committee my evaluation of Earth Resources Technology Satellites, such as ERTS-1, in terms of their potential benefit to mankind. Presumably I have been asked to respond because (1) For more than 30 years I have been making inventories from conventional aerial photos of various earth resources (timber, forage, soils, water, minerals, agricultural crops, etc.); (2) For the past several years I have been making similar inventories both of an operational nature and of a research nature with the aid of space photography in my capacity as Professor of Forestry and Associate Director of the Space Sciences Laboratory of the University of California and also as Director of the Berkeley Office of a private industrial concern known as Earth Satellite Corporation; and (3) As an honorary life member of the American Society of Photogrammetry and frequent office holder within that organization, I am among those who are often called upon to comment on matters, such as this, which are of primary concern to that Society.

At the outset I should emphasize that the two-fold objective of virtually all the work I have been engaged in has been (a) better management of the various earth resources for which inventories were being made, and (b) better preservation of the environmental complex associated with those resources. Hence, my comments will pertain primarily to the usefulness of ERTS-type data in relation to these objectives. As your committee members well know, the achieving of these objectives is a matter of increased concern to mankind because of his increased awareness in recent years of two related facts:

(1) the human <u>demand for</u> most kinds of earth resources, whether on a local, national or global level, is rapidly increasing, due to both the increased population and the increased <u>per capita</u> demand for these resources, and

(2) the <u>supply of</u> some of the most important of these resources is rapidly dwindling and the quality of certain others is rapidly deteriorating.

In January, 1972, at a joint meeting of the Committee on Science and Astronautics of the U.S. House of Representatives and its associated Panel on Science and Technology, I presented a paper which still serves as an adequate statement of my views on most of the points about which I have now been asked to comment. That paper was entitled "The Future for Remote Sensing of Agricultural, Forest and Range Resources." It included major sections dealing with such topics as (1) Potential Users of Remote Sensing Data and their Informational Requirements, (2) Who Needs Information on Crop Losses and Why?, (3) Future Prospects for the Use of Remote Sensing in the Management of Renewable Natural Resources, and (4) Some Factors to be Considered in Developing Operational Plans for the Remote Sensing of Renewable Natural Resources. Since you, of course, have access to that document, I will simply invite your attention to the fact that it dwells at length on the benefits to be achieved through the making of better resource inventories <u>within the continental limits of the United States</u> and then directs attention to the potential benefits derivable from <u>global</u> resource inventories. In this latter regard I should like to repeat here the quotes which were included in my paper from a speech given by the President of the United States to the United Nations General Assembly on September 18, 1969 and entitled "Toward an Open World":

> ...We are just beginning to comprehend the benefits that space technology can yield here on earth, and the potential is enormous. For example, we now are developing earth resource survey satellites, with the first experimental satellite to be launched sometime in the decade of the seventies. Present indications are that these satellites should be capable of yielding data which could assist in as widely varied tasks as these: the location of schools of fish in the oceans, the location of mineral deposits on land, and the health of agricultural crops. I feel it is only right that we should share both the adventures and the benefits of space. As an example of our plans, we have determined to take actions with regard to earth resource satellites as this program proceeds and fulfills its promise. The purpose of those actions is that this program will be dedicated to produce information not only for the United States but also for the world community...[such an adventure] belongs not to one nation but to all mankind and should be marked not by rivalry but by the same spirit of fraternal cooperation that has long been the hallmark of the international community of science.

Elsewhere in his presentation, the President asserted that within the next decade, "We can make significant gains in food production," spoke of "the urgent need for international cooperation in spurring economic development," and pointed out the need for "a fuller enlistment not only of government resources and private enterprise resources but also of the dedication and skills of those thousands of people all over the world who are ready to volunteer in human achievement."

Consistent with the thoughts quoted above, the work done to date by various agencies and individuals has demonstrated that ERTS-1 data properly analyzed often can facilitate the making of regional, national or even global resource inventories of certain kinds of earth resources, thereby facilitating resource management and environmental protection.

The President's comments notwithstanding, many authorities in this country consider that ERTS should be evaluated primarily in terms of its domestic benefits, i.e., its usefulness directly within the United States. Hence, in the accompanying short document I have attempted to report, first, on a few of the experiences we have had to date within the United States relative to the usefulness of ERTS-type imagery. Thereafter, the report briefly considers examples of information obtainable (by means of ERTS data) in other parts of the globe. The examples chosen are considered to be representative ones in that they are of concern to the United States for humanitarian reasons and/or because the United States, like many other nations, is becoming increasingly dependent upon earth resources beyond those produced within their national boundaries. It follows that global inventories, if sufficiently timely and accurate, can do much to alleviate local imbalances between the production and consumption of earth resources with consequent benefit to people throughout the United States and the rest of the world.

The report which I am submitting as an enclosure to this letter reflects the rationale expressed in the foregoing paragraphs. As previously indicated, it draws heavily on findings which my colleagues and I have arrived at.

It will be apparent from a reading of this report that I am among those within the American Society of Photogrammetry who hold the following firm beliefs: (1) this country should continue, without interruption, to build upon the very substantial progress which it has made in recent years toward the development of an operational satellite for use in the making of earth resource inventories, and (2) such progress can only be ensured through the early launching of ERTS-B and authority to proceed with ERTS-C.

If your committee desires additional information from me I shall be most happy to provide it.

Respectfully yours,

Robert N. Colwell

Robert N. Colwell
Associate Director

SPECIAL STUDY NO. 3

STATEMENT BEFORE THE
SUBCOMMITTEE ON SPACE SCIENCE AND APPLICATIONS
OF THE
COMMITTEE ON SCIENCE AND ASTRONAUTICS,
U.S. HOUSE OF REPRESENTATIVES

NINETY-THIRD CONGRESS

SECOND SESSION

by

Robert N. Colwell
Associate Director, Space Sciences Laboratory
University of California

Mr. Chairman and Members of the Subcommittee:

It is both a pleasure and an honor to appear before this Committee to present my views on the present status and potential future usefulness of earth resources survey programs in general and of earth resources technology satellites in particular.

At the outset and in the interest of avoiding redundancy, I must mention two previous statements of mine which overlap somewhat the one which I have been asked to give today. The first of these (Colwell, 1972a) was presented before your Committee nearly 3 years ago and dealt with the future for remote sensing of agricultural, forest and range resources. That presentation was given on the eve of what I referred to as "the most important photographic experiment in history," - - the one which would begin with the launching of the world's first Earth Resources Technology Satellite, ERTS-A.

The second of these earlier statements of mine (American Society of Photogrammetry, 1974) was presented only a short time ago to the Senate Committee on Aeronautical and Space Sciences. Since my second statement was prepared after ERTS-A (ERTS-1) had been in operation for a full two years, it provided me with an opportunity to summarize briefly how things had been going in that highly heralded experiment.

My basically optimistic evaluation, as given on that second occasion, was in marked contrast to the following pessimistic evaluations quoted to that same Committee by a distinguished representative of the Office of Management and Budget (Zarb, 1974).

1. The Statistical Reporting Service of the Department of Agriculture has asserted that "without significantly improved resolution and dependability there is no possible way the ERTS system can achieve any improvements over the existing crop

forecasting system"

2. The Forest Service has stated that "there is as yet no demonstrable need in forest inventory, the major area of benefit in forestry, for frequent acquisition of the relatively low resolution produced by ERTS" and

3. The Environmental Protection Agency, in commenting on ERTS, has similarly stated that "while some benefit may be derived from the examination of low resolution imagery, the great bulk of the essential elements of information required to produce a piece of finished environmental information lies well below 30 feet resolution" (as compared with the 10-fold poorer resolution, approximately, that is provided by ERTS).

Comments such as these prompted Dr. Zarb to testify with a fourth, and summarizing statement, as follows:

4. "the present ERTS technology is not yet good enough to justify a commitment to an operational system". Pointing to the need "to achieve significantly better resolution" he concluded that "any additional launch, beyond ERTS-B, of a remote sensing satellite should be carried out only when such a launch can be shown to be the most cost-effective way to achieve a significant advance in the state of the art".

There is a remarkably good consensus among the 4 viewpoints which I have just quoted. Furthermore they come from some of the most authoritative offices in this country. Therefore, there would seem to be no justification for me to occupy the time of your busy committee if it were merely so that you could hear additional testimony that was basically in agreement with these assertions. Such is not the case, however. Therefore, I will now proceed to indicate why I disagree with them. However, I will do so not because of any inherent belligerence that causes me to enjoy disagreeing with the experts, even to the point of questioning whether they know how to run their own business. Having worked closely for many years with such officials from the agencies quoted, I have great admiration and respect for their abilities, despite a few honest disagreements. Instead the rationale for my perilous course of action is simply as follows: your Committee obviously needs to know whether there are any valid challenges to the 4 assertions which I have just quoted as it seeks to decide whether it should favor the commitment of this country to the launching of ERTS-C in the near future and thus to the sustaining of a long-term and continuous ERTS-type of operational remote sensing system.

1. <u>Can ERTS-Type Data Help Improve Crop Forecasting Systems?</u>

Crop forecasting systems that presently are in use are able to acquire quite accurate information periodically on crop type and probable crop yield in selected sample areas or "segments". Two possibilities for sizable errors exist, however, under these systems: (1) The selected sample areas may not be adequately representative of the entire area to which such sample data are applied, and (2) The total agricultural acreage (a factor which is of great importance in developing "expansion factors" for the sample data) may not be known with sufficient accuracy.

If a crop forecasting system were to be based on ERTS derived data, the fact that the entire agricultural area could be viewed would reduce the potential for errors due either to unrepresentative sampling or to uncertainty as to the total agricultural acreage. Two possibilities for sizable errors would exist, however, if only the ERTS-system were to be used:

(1) those due to the misidentification of crop types, and

(2) those due to inaccurate forecasts of crop yields.

Experience with ERTS in California and elsewhere has shown that the multidate coverage of agricultural areas which it provides (at 18-day intervals, weather permitting, throughout the growing season) permits one to identify the more important crops in many instances to an accuracy of greater than 90 per cent. Furthermore there is reason to believe that two factors could greatly improve the accuracy with which crop yields, field-by-field, could be forecasted from ERTS-data.

(1) The use of pertinent data readily available from meteorological satellites, on temperature, precipitation and light intensity conditions existing in various parts of the agricultural area and at various critical times during the crop growing season and (2) the compilation, over a period of several years, of aids to crop yield estimation known as "photo interpretation keys". The value of such keys for similarly difficult photo interpretation problems already has been demonstrated on numerous occasions. In this instance the keys would consist of two components: (a) ERTS image examples of fields that had been monitored on the ground so that both crop type and crop yield were accurately known, field-by-field, and (b) word descriptions which would set forth in concise terms the photo image characteristics which were of greatest diagnostic value both for the identification of crop types and the forecasting of crop yields.

In summary of this section, 3 points seem worthy of emphasis: (1) It is quite unlikely that a crop forecasting system based entirely on ERTS data would ever provide sufficient accuracy to satisfy the needs of those using such forecasts; (2) Even at the present time, however, ERTS could be of great value as a supplement to the on-the-ground crop forecaster by permitting him better to select representative "segments" and better to determine the expansion factors to which data collected from such segments should be applied. (It is at this point that I find myself in substantial disagreement with the previously quoted statement that "there is no possible way that the (present) ERTS system can achieve any improvements over the existing crop forecasting system", and (3) If we were to be given a continuous period of several years during which to develop photo interpretation keys and to derive empirical relationships between crop yield and the data provided by both ERTS and meterological satellites, we would make great progress, indeed, toward improving present crop forecasting methods. With the ever-increasing demand for food and fiber and the ever-dwindling amount of arable land, the importance of developing such a capability in order to help ensure adequate crop production (whether regionally, nationally or globally) can scarcely be overemphasized.

2. Can ERTS-Type Data Help Improve Forest Inventories?

Forest inventory techniques that presently are employed make effective use of aerial photographs, but rarely do they make use of space photography such as that which ERTS can provide. Some of the most knowledgeable experts in the field of forest inventory have stated that a system, such as ERTS, which cannot resolve individual trees offers nothing of value to them. Others soften this viewpoint by asserting that the frequent acquisition of such imagery is not as yet a demonstrable need.

Although the second of these assertions is significantly different than the first, and although even the first does not address itself to all potential forestry uses, the net impact on many decision makers appears to be essentially the same, viz. that, at least from the forestry stand point, "present ERTS technology is not good enough to justify a commitment to an operational system".

My colleagues and I at the University of California have been conducting studies during the past year to determine the potential usefulness of ERTS-1 data as an aid to the making of timber inventories. Our test area has been a representative portion of the mixed confier forest of California's Sierra Nevada Mountains. In this work we have maintained close contact with local personnel of the U.S. forest and with numerous representatives of the forest industry the better to ensure that our research would be truly meaningful.

In one such test we investigated the usefulness of ERTS-1 data as an aid to determining timber volume only since this is perhaps the simplest kind of forest inventory worthy of testing. A basic premise in this study was that timber stand density (i.e. the proportion of the ground that is obscured by trees when the forest is viewed from overhead, as on ERTS-1 imagery) is a very useful, though admittedly rough indicator of timber volume. Based on this criterion a rough timber-volume classification was made from the ERTS-1 data of every resolution cell. Since each such cell is slightly greater than 200 feet on a side the result was essentially an acre-by-acre classification).

Using sampling techniques based on probability in proportion to volume, (ppv), sites were selected within which to obtain large scale aerial Ektachrome photography through use of a 35mm camera mounted in a light aircraft. On this photography tree heights and crown diameters were measured thereby providing much more refined estimates of timber volumes.

From the results thus obtained, and again using "p.p.v." sampling techniques, still smaller subsamples were selected. Ground survey crews visited these few sites and accurately measured the volume of each merchantable tree with the aid of an optical dendrometer.

Once this three-stage ERTS-based sampling scheme had been completed, the proper expansion factors were developed and applied, thereby providing a timber volume estimate for each portion of the test area and for the property as a whole.

Results of this test indicated that an acceptable order of accuracy could be achieved more quickly and at less than half the cost through use of the ERTS-based method as compared with conventional methods for timber volume assessments.

While some skeptics might raise the question of whether a "random success" was achieved in this instance, Forest Service personnel at both the local and national level are far more appreciative than they previously were of the value of ERTS-type data as an aid to forest inventory.

In most parts of the United States a timber inventory deals not merely with the estimation of timber volumes, but also with an appraisal of timber stand conditions and growth rates. Consequently our group has been conducting additional tests along these lines and appears to be achieving similar success, although final results will not be available until about 2 months from now.

Still another sense in which the term "forest inventory" is used by some is with respect to the entire "resource complex" of a forested area, including the timber, forage, soils, water minerals, fish, wildlife and recreational potential. Under sponsorship of the Bureau of Land Management our group is nearing completion of such an inventory for a 2-million acre area in north-eastern California. Based on results achieved to date there is little doubt among either the investigators or their sponsors that the most cost-effective way currently available for making such a survey involves the use of ERTS-type data as the first stage in a multistage sampling scheme.

3. Can ERTS-Type Data Help Improve Environmental Analyses?

As previously indicated the Environmental Protection Agency considers that ERTS-type data can be of only limited interest because of the limited spatial resolution which it provides. This may be true as applied to the making of traditional "environmental impact" studies of local areas and especially when the concern is primarily with respect to the immediate or short-term environmental effects. However, there is increasing evidence that environmental concerns and in consequence that environmental analyses should be macroscopic as well as microscopic (even to the point of providing broad regional or even global analyses) and that these concerns should also consider long term as well as short term environmental impacts. To the extent that these broader considerations become important, so does the potential usefulness of ERTS-type data. A century ago man's appreciation of his environment was essentially limited to what he could acquire while observing it from the ground,--a vantage point which offered him little better than the "worm's eye view". With the advent of the aircraft he was provided with the "bird's-eye" view that greatly broadened his environmental perspective. And since the dawning of the space age he has been provided with what some enthusiasts refer to as the "God's eye view". I hasten to state that it does not follow that man is thus able to acquire God's full perspective of what is happening to the earth's environment. There are numerous instances, however, in which the broad perspective and limited resolution of space-acquired ERTS-type data can elucidate environmental relationships that man previously was unable to discern. This is true not only because of the more limited perspective of earlier systems, based on aerial photography but also because the resolution of such systems provided such a large amount of detail that he couldn't appreciate the true nature of a forest (for example) because of the high-resolution noise from the individual trees.

And as for the short time-span that often is used as the frame-of-reference of the environmentalist as he makes detailed environmental impact studies, it often is too short, I believe, and certainly too short to achieve maximum benefit from ERTS data. In this regard, it is my flat prediction that the greatest value of all of the data acquired to date by ERTS-1 will emerge some 50 to 100 years from now when environmentalists of that day can go back to the first adequately detailed look that man ever obtained of this globe, viz. the look that was obtained and faithfully recorded by ERTS-1 in the early 1970's -- shortly before man irreversibly ruined major portions of it. By thus discerning clearly what environmental tragedies occurred on a grand scale, and thus by better understanding why they occurred, man hopefully will then be able to learn in the nick of time how to avert similar environmental tragedies in such parts of the globe as he has not by then got around to ruining.

4. Is Present ERTS Technology Good Enough to Justify Commitment to an Operational System Now?

Dr. Zarb seemingly answered this question with great finality when he said, "Any additional launch, beyond ERTS-B, of a remote sensing satellite should be carried out only when such a launch can be shown to be the most cost effective. . ."

The time when that will come seems to be related more to the development of faith than technology. The faith to which I refer is one that needs to be developed between budgetary officials and the potential users of ERTS data.

On the one hand, it appears that even now budgetary officials would approve the timely launch of ERTS-C if they had faith that enough potential users of its data would, indeed, do so.

On the other hand, it appears that a major deterrent to the receiving of such declarations from potential users is their lack of faith that budgetary officials will appropriate the funds required to insure the availability of ERTS data on a continuing basis.

For example, many of the resource managers with whom my associates and I work, (particularly those who seek to manage such renewable natural resources as agricultural crops, timber, forage and water) and also many of the environmentalists with whom we work, are convinced that ERTS technology already is good enough to justify abandonment of their old data basis and their switching to new ones which would use ERTS as the primary initial data input. They have no intention of making such a dramatic, and perhaps traumatić switch, however, until they have more faith than at present in the continuing availability of ERTS data. Because of the dynamic nature of these renewable natural resources, any system designed for use in monitoring them must provide updating information at suitably frequent intervals. The ERTS system has that capability, but obviously if ERTS vehicles do not continue to fly the required capability is lost. Quite understandably faith in the continuity of such a system is difficult for the potential users of ERTS data to develop under present circumstances. This is especially true when those officials who would need to authorize the funds for such a continuing effort make assertions such as the one which I previously quoted, VIZ. that "the present ERTS technology is not good enough to justify an operational system."

In the presence of this dilemma it is perhaps essential that I cite one or two specific instances in which potential users of ERTS data are, even now, on the threshold of switching to an information system which would make cost-effective use of ERTS data. In so doing I will continue to confine myself primarily to potential users and uses of ERTS data in the geographic area with which I am most familiar, VIZ. the state of California.

A. <u>Preplanning in Relation to the Suppression of Fires in Wildland Areas</u>

More than half of California's 100 million acres is classified as "wildland". Much of this vast area contains either highly flammable brush and herbaceous vegetation or highly valuable timber. Furthermore, these vegetation types in many instances clothe steep and highly erodible slopes and often they are intermingled with expensive summer homes and recreational developments.

Because of this combination of circumstances, several federal agencies including the U.S. Forest Service, the Bureau of Land Management and even the Department of Housing and Urban Development have expressed great interest in minimizing the damage inflicted in these areas by wildland fires.

One step that has long been recognized as an aid in reducing these losses is known as "Pre-planning" by means of which a strategy is developed in advance for use in combatting wildland fires wherever they may develop. The effectiveness of this strategy is greatly improved if a detailed knowledge of fuel types, area-by-area, is available. Preliminary research results obtained by my research group working in concert with the interested agencies, have demonstrated the value of ERTS data as the basis for mapping fuel types to uniform standards throughout California. From such information fire-fighting officials and agencies can intelligently engage in various pre-suppression activities, including the locating and building of fuel-breaks, helicopter landing sites and water storage tanks.

The value of this information would be enhanced if, in addition, accurate and current information were to be available at all times relative to fuel flammability and fire danger ratings, area-by-area, throughout this vast acreage. There is reason to believe that the thermal infrared scanner proposed for inclusion on ERTS-C, together with timely information provided at frequent intervals by meteorological satellites, would do much to provide this additional information.

B. Post-Burn Damage Assessment and the Planning of Rehabilitation Measures.

Large sums currently are expended each year in California in attempting promptly to rehabilitate wildland areas following burning.

Fire officials within the California Division of Forestry are among those who have developed a healthy respect for ERTS data as a means to that end. For example, less than 72 hours after ERTS had been launched it photographed a recently burned area in California with sufficient clarity to permit ERTS data analysts to estimate its areal extent 25 per cent more accurately than was done by conventional aerial and ground surveillance techniques. Such an increase in informational accuracy is of interest to many groups including those who must pay their pro-rated share (on an acreage burned basis) of the fire suppression costs and those who must develop a prompt and effective post-burn rehabilitation program.

In my oral presentation of this paper I will cite other examples with the aid of lantern slides. Those examples will serve to emphasize the essentiality of our having a continuity of ERTS-type data over a period of several years, the better to develop empirical correlations between ERTS data and ground truth and the better to determine the amount of year-to-year variability that can be expected with respect to this nation's renewable natural resources. It will be obvious from my discussion of those examples that I strongly favor a commitment being made now to an ERTS-type of operational system and, axiomatically, to the launch of ERTS-C at the propitious time for ensuring a continuity of ERTS data.

I would say finally -- we can have the lights on as I conclude -- that several of the groups that we work with, i.e., the user agencies, indicate that they would be prepared to use ERTS type data right now, expect for the following dilemma: On the one hand they are reluctant to switch away from their present resources inventory techniques, until they can be assured that, having gone through this traumatic experience, they will have a continuum of ERTS imagery in the future. On the other hand we have the other half of the dilemma in which OMB in effect says, "We don't want to Okay this continuum until we hear these people saying that they are ready to use ERTS data cost effectively now." So in contrast to the statement which Doctor Zarb made to the effect that we can't go further with this ERTS program until it has been proven cost effective, and until the ERTS technology has improved, it seems to me that it is not so much a question of technology, even at the present moment, as it is a matter of mutual faith among these two groups. And, if I were to point out the single key item that would rectify that difficulty, it would be some kind of assurance from OMB, certainly beyond what we have at the present time, that there would be a continuity of ERTS type data, at least for several years, as would be assured with the launching of ERTS-C, for example. These resource managers and user agencies would then feel that it would be cost effective to start switching to these techniques now.

Thank you very much.

Mr. Symington. Doctor Colwell, thank you for your as usual splendid, if not spectacular statement of the case.

I don't know whether you were here during the statement by OMB's representative?

Dr. Colwell. I heard the last half of one of their statements.

Mr. Symington. Of course you had obviously read it, because you prepared your presentation with it in mind. I think that has proven very helpful to the Committee.

Of course, the date and the context of the statements that you quoted are crucial. Those attitudes could well be modified by now. We have had a presentation today by General Electric on the digital analysis of crop forecasting and things of that sort, which I think none of us has seen and I doubt that OMB's witness had seen yet. It is a thing that happens almost daily.

Doctor Colwell. In this regard might I cite an analogy which is credited to one of my associates, Doctor Levin. Although perhaps it was not part of his testimony to Senator Moss' Committee, Ben Levin gave me a couple of days ago the following analogy which I think is well worth considering. "At the present time we are asked to evaluate the usefulness of ERTS, much as though we had been asked, through detailed anthropomorphic measurements of a 7-year-old child, to estimate whether this child will become a great heavyweight boxer. We just can't make an accurate estimate from measurements made that early in the child's development." I would submit then, with reference to the comments you have just made, Mr. Symington, that even in the interim during which the potential of ERTS has been debated in the last few months, researchers have progressed to where we are now, (to use the same analogy), able to measure a teenager instead of a seven-year-old and we are about to say "yes," this will be a good heavyweight boxer, something we would not have not been able to say with any certainty a few months or a few years ago. I think it is a very useful analogy.

Mr. Symington. I wonder if you would accept an appointment as Director of the OMB as soon as we can arrange it.

Doctor Colwell. I am distressed by the fact that people of OMB who need to see images as well as hear words missed my lantern slide presentation today. Without the slides, my paper is just some more words. I can hardly talk about the real capability of ERTS, however, without getting tears in my eyes. I wish OMB could get that kind of tears once in a while by seeing this kind of testimony.

Mr. Symington. They have sort of a fog which takes the place of tears.

Mr. Bergland?

Mr. Bergland. Mr. Chairman, I want to congratulate Doctor Colwell for his very splendid presentation and I am curious to know, Doctor, have representatives of OMB seen your work?

Doctor Colwell. I am fairly sure they have not. California is pretty far west compared to Missouri and some of these other places from which reports on the usefulness of ERTS have been submitted.

Mr. Bergland. They have not had the benefit of first hand exposure to the kind of thing that you are doing and the enormous potential that many of us see within your efforts?

Doctor Colwell. Well, I think they have not seen or heard my particular report. However, I am highly respectful of the very valuable research done, primarily under NASA funding, by a whole host of groups, so while I wish they could have seen this presentation, if they have not yet been convinced, I am among those that are inclined to despair that they ever will be. If OMB rejects ERTS-C on the grounds that presents ERTS resolution is no good, and that ERTS-1 must be proven cost-effective before OMB can approve ERTS-C, then I consider them wrong on both counts and these are essentially the arguments which I am rebutting here. But everyone else that has worked with this imagery instead of merely philosophizing about it arrives at essentially the same conclusions as I do. I doubt that OMB is going to do a 180° turnabout just because I get up and show my slides and do a little arm waving. I would welcome a chance of trying to persuade them, but I think it would be discourteous to my fellow researchers across the country if I implied that there is something so unique about my aspect of ERTS research that therefore OMB has to hear my story.

Mr. Symington. You project rather well. You are very persuasive, Doctor.

Doctor Colwell. Thank you, sir.

Mr. Symington. Thank you.

Your statement, Doctor Colwell, will be made a part of the record, the written statement as well as, of course, your verbal one.

I wish that the OMB representatives or at least one of them might have stayed behind. I don't think any did. At least, nobody is holding up their hand to that effect. So, we will just try in some fashion to bring them to an awareness of the approach you have taken and ask them for their comments.

I think without the sort of integrity and fire such as yours, we wouldn't be able to get this Committee to move the Congress in the direction I think we ought to go, or the country. So we are extremely grateful to you for visiting with us again today. We hope we can count on you in the future.

(Whereupon, the prepared written and oral statements of Doctor Colwell were entered into the record.)

Doctor Colwell. Yes Sir. Finally my apologies for the in-and-out appearance I had to make here. It happened that this is a pretty busy day for me. I am pleased that you adapted yourself to this schedule. Thank you sir.

Mr. Symington. Very happy to do so. Thank you very much.

The Subcommittee will meet again tomorrow at ten o'clock in this room.

Today we are adjourned.

(Whereupon, the Subcommittee adjourned at 12 o'clock noon, to reconvene on Friday, October 4, 1974 at 10:00 a.m.)

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SPECIAL STUDY NO. 4

INPUT QUALITY ENCODING OF MULTISPECTRAL DATA*

V. Ralph Algazi

Presented at the 1974 Picture Coding Symposium,
August 1974, Goslar, West Germany

1. INTRODUCTION AND OBJECTIVES

In the efficient representation and encoding of data, the engineer will generally exploit the statistical redundancy present in the data and try to accomodate the fidelity requirements specified by the user. In the case of multispectral data, in which many users are involved, it is difficult to specify a data quality which will accomodate all users. For error free analog data it is well known that an infinite bit rate is needed to represent the data exactly. Assuming digitized data, Spencer and May [1] have examined error free encoding techniques which use differential encoders. However, a more general statement as to the quality acceptable in the encoding of multispectral data is that encoding should preserve data quality as determined by image sensors and input quantization. Thus we can use data correlation for quantization noise reduction as well as for encoding with some errors, as long as the total error in the digital data is not larger than the total error in the original data. We have used linear transformation techniques and some theoretical results of others and ours to study this problem [2,3,4].

2. THEORETICAL BASIS

The steps in the optimum encoding of noise source are shown below:

$$\xrightarrow{\underline{s}} \boxed{\text{QUANTIZER}} \xrightarrow{\underline{x} = \underline{s} + \underline{n}} \boxed{\text{FILTER}} \xrightarrow{\hat{\underline{s}}} \boxed{\text{ENCODER}} \xrightarrow{\tilde{\hat{\underline{s}}}} \qquad (1)$$

In the mean-square sense the optimum filter is followed by the optimum encoder

D_{est} = Residual estimation M.S. error

D_{cod} = Encoding M.S. error

then the encoding preserves the input quality of the data.

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* Work supported in part by NSF Grant GK-37282

In filtering and encoding use Karhunen-Loeve transformation for optimum results for finite block size. Recursive techniques can be used in encoding and/or filtering in suboptimum schemes. When using transforms we schematically have the following

$$\xrightarrow{\underline{x}} \boxed{T} \xrightarrow{\underline{y}} \boxed{\text{SCALAR FILTER}} \xrightarrow{\hat{\underline{y}}_s} \boxed{\text{ENCODER}} \xrightarrow{\tilde{\underline{y}}_s} \boxed{T^{-1}} \xrightarrow{\tilde{\underline{s}}} \qquad (2)$$

in which T is the Karhunen-Loeve or a fast unitary linear transformation.

3. THEORETICAL RESULTS BASED ON ACTUAL DATA

In the theoretical analysis of this approach to encoding we have assumed the following models:

a. Quantization Error: $\sigma_n^2 = \frac{Q^2}{12}$, σ_n^2 quantization error variance we assume L quantization levels, $Q = \frac{6\sigma_s}{L} = \frac{6\sigma_s}{2^b}$, in which there are b bits quantizer between $\pm 3\sigma_s$.

b. Image Statistics: Gaussian, zero mean

Spatial: Separable first order Markov

$$E[s_{ij}s_{k\ell}] = e^{-\alpha[|i - k| + |j - \ell|]}$$

$$.05 \leq \alpha \leq .15$$

which fit ERTS-1 data quite well.

Spectral: We use ERTS-1 multispectral scanner statistics. We verified that spectral-spatial statistics are separable.

We have examined the results achievable using most of the transforms of interest: Karhunen-Loeve (KL), Discrete cosine (DC), Fourier (FR), Hadamard (HD), Haar (HA), slant Hadamard (SLD), Slant Haar (5) (SLHA), and the effects of encoding one dimension, two dimension spatially, on a spectral-spatial encoder.

We illustrate the results obtained by two graphs. In Figure 1, we show the number of bits needed to represent the data, assuming the number of quantization levels shown in abcissa. The encoder uses a 4 x 4 x 4 block of data. We note that most fast transforms perform as well as the optimum Karhunen-Loeve.

In Figure 2, we illustrate the effect of data statistics, in particular, of the spatial correlation of the data. We note that a theoretical rate of 2 bits per pel is possible with data degradation, starting from 6 bit quantized data.

4. EXAMPLE OF IMPLEMENTATION

We used ERTS-1 data from Northern California

a. Noise Model: The small variances of the 3 dimension covariance maxtrix measures error variance. This is needed because we have to account for sensor noise as well as quantization noise.

b. Block Size: From theoretical results, a 4 x 4 x 4 block represents a compromise between performance and speed.

c. Local Means: on 4 x 4 blocks for each spectral bands are removed.

d. Block Diagram: A block diagram of the implement algorithm is shown below

$$\xrightarrow{\underline{x}} \boxed{T} \xrightarrow{\underline{y}} \boxed{\text{Scaling}} \xrightarrow{\hat{\underline{y}}_s} \boxed{\begin{array}{c}\text{Truncation}\\ \text{Quantization}\end{array}} \xrightarrow{\tilde{\underline{y}}_s} \quad (3)$$

Walsh-Hadamard Haar   Shift   Non-Ideal Trade Off

IMPLEMENTATION WITHOUT MULTIPLICATION

e. Typical Result:

Errors: We can only measure the error between reconstructed and input data and thus

$$E[||\tilde{\underline{s}} - \underline{x}||^2] = E[||\tilde{s}||^2] + e[||\underline{n}||^2].$$

We check that

$$E[||\tilde{\underline{s}} - \underline{x}||^2] \leq 2E[||n||^2]$$

so that we can claim input quality encoding.

Entropy: We obtain an encoder with a rate of 2.08 bit for 4 x 4 x 4 Walsh Hadamard, $\leq$ 2.45 including encoding for spectral means.

5. CONCLUSIONS

These are encouraging preliminary results and this work will be prepared for publication in the coming few months.

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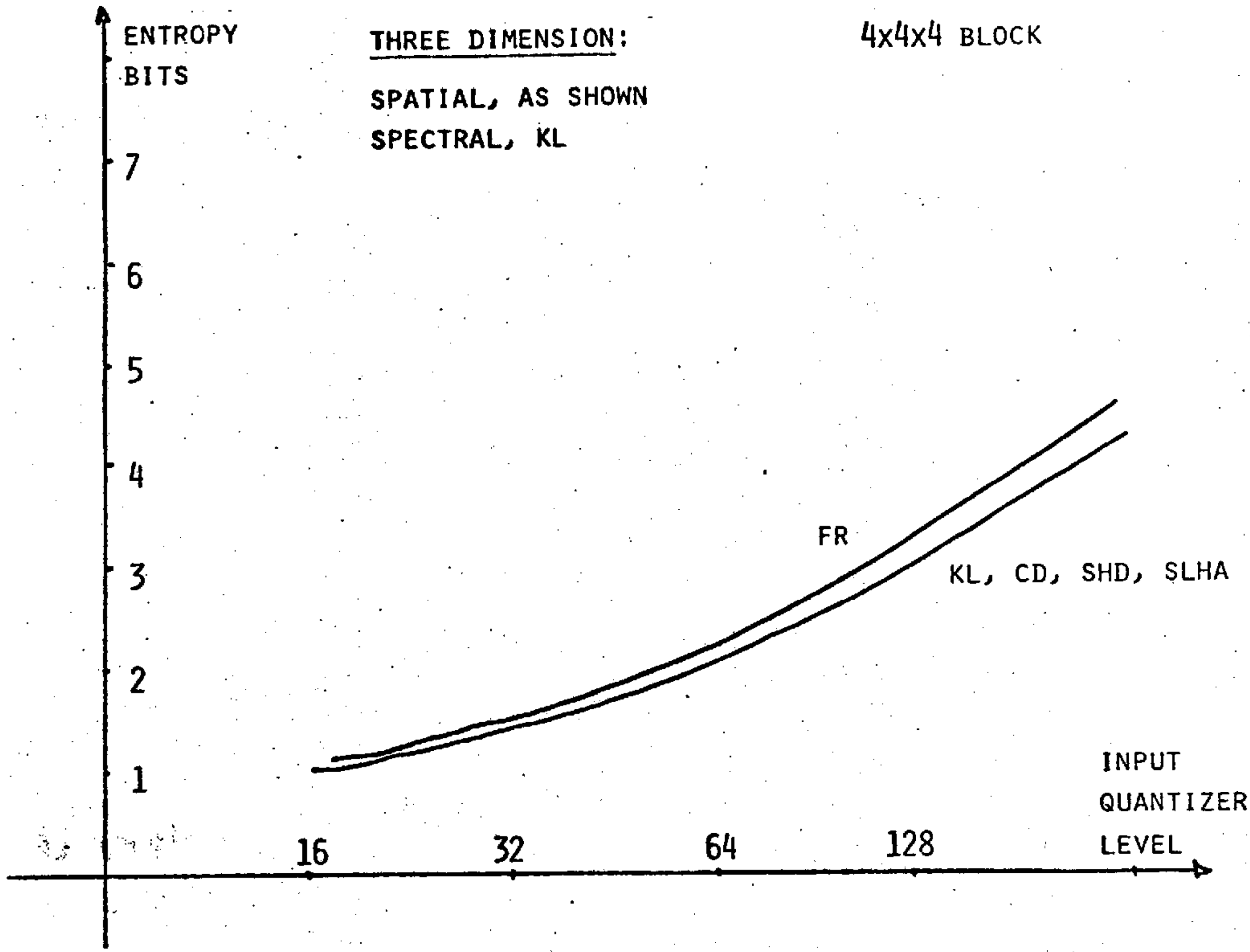
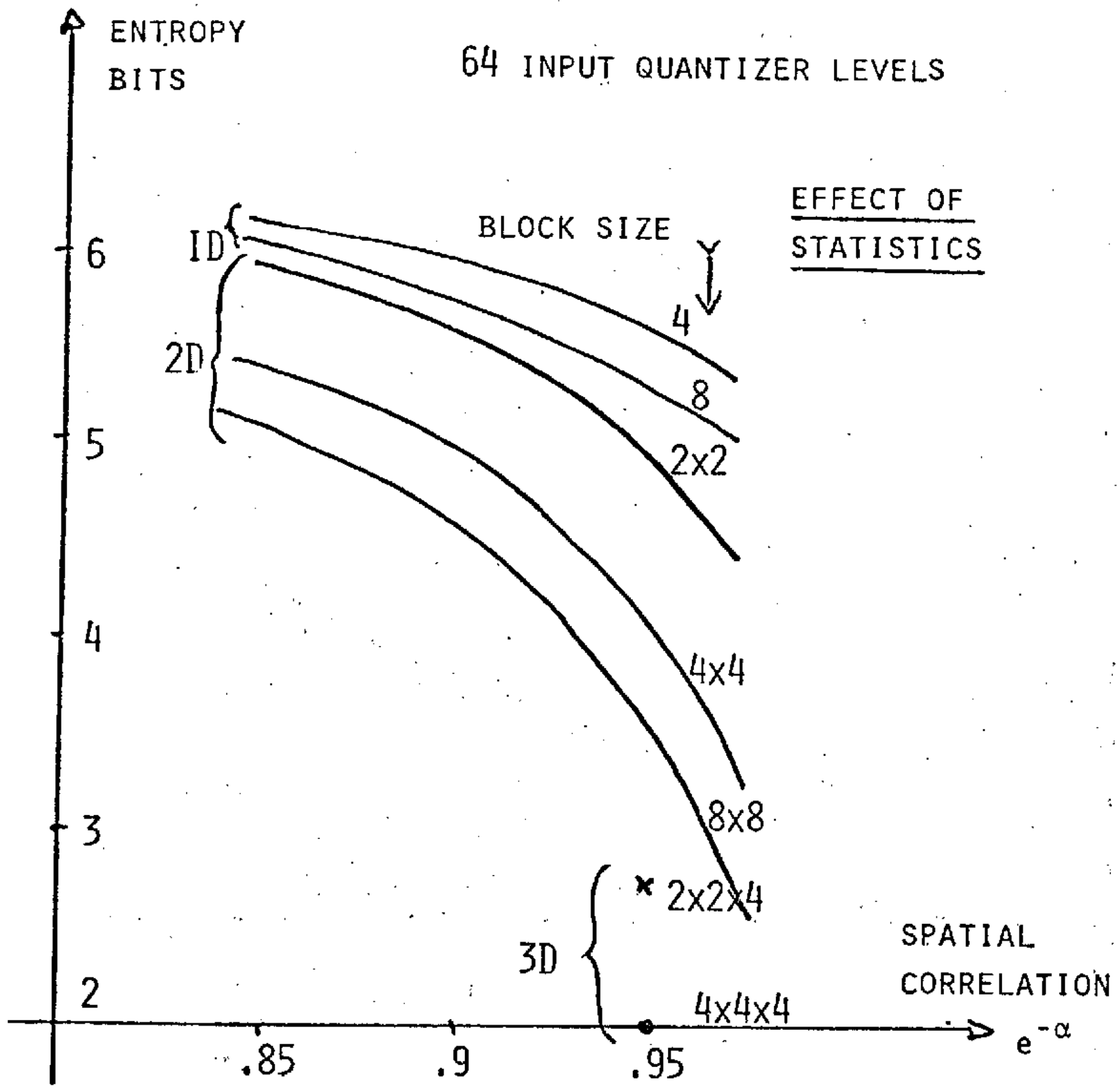

ENTROPY
BITS
THREE DIMENSION:
SPATIAL, AS SHOWN
SPECTRAL, KL
4x4x4 BLOCK
7
6
5
4
3
2
1
FR
KL, CD, SHD, SLHA
INPUT
QUANTIZER
LEVEL
16
32
64
128

Figure 1



ENTROPY
BITS
64 INPUT QUANTIZER LEVELS
BLOCK SIZE
EFFECT OF
STATISTICS
1D
2D
3D
6
5
4
3
2
4
8
2x2
4x4
8x8
2x2x4
4x4x4
SPATIAL
CORRELATION
$e^{-\alpha}$
.85
.9
.95

Figure 2

CHAPTER 10

SUMMARY

Principal Investigator: Robert N. Colwell

CHAPTER 10

SUMMARY

Robert N. Colwell

10.1.0 In Chapter 1 of this progress report the following facts are emphasized:

10.1.1 Research efforts under this integrated multi-campus study continue to be directed primarily toward developing remote sensing techniques for the inventory and management of California's water resources.

10.1.2 Studies pertaining to remote sensing in relation to water supply are concentrated on the Davis and Berkeley campuses in northern California. These campuses are nearest to the source of most of California's fresh water, viz., the northern Sierra Nevada Mountains.

10.1.3 Studies pertaining to remote sensing in relation to water demand are concentrated on the Santa Barbara and Riverside campuses in central and southern California; these campuses are nearest to the centers of demand for most of California's fresh water, viz., the San Joaquin Valley and the industrial and population centers of the Los Angeles basin.

10.1.4 The concepts embodied in this integrated remote sensing study of California's water resources, and the chronological plan being followed by each of the groups that are participating in it, will be found in Figures 1.1 and 1.2, respectively, of Chapter 1.

10.1.5 At the request of our NASA sponsors we have, in addition, made studies during the present reporting period relative to the cost-effectiveness of ERTS-1 data as an aid in the inventory of timber volume, timber stand condition class and timber growth rate.

10.1.6 To a greater extent than heretofore, the work of our Social Sciences group has been linked to that of our other remote sensing scientists to ascertain ways in which remote sensing data can cost-effectively enter into decision making processes relative to the management of California's earth resources.

10.2.0 Chapter 2 deals with certain aspects of our water supply studies that are being done in an integrated fashion by the Remote Sensing Research Program (Berkeley), the Algazi Group (Davis, Berkeley) and the Hoos-Churchman Social Sciences Group (Berkeley). The following summary statements apply to this chapter.

10.2.1 Continuing analysis of hydrologic model structure, inputs, and performance is being conducted by the former two groups.

10.2.2 Performance is being documented with respect to both "conventional" and "conventional-plus-remote sensing" data inputs.

10.2.3 Both the Remote Sensing Research Program (RSRP) and the Hoos-Churchman Group are quantifying costs and benefits associated with current and potential remote sensing-aided hydrological model applications.

10.2.4 Analysis of the California Water Project as a system continues from the standpoint of physical and economic phenomena.

10.2.5 Because water quality considerations are becoming increasingly important in California, integrated studies by the above named groups have begun to deal with various physical, economic, and social aspects of water quality as they relate to modern remote sensing capabilities.

10.2.6 The Algazi-Burgy group is undertaking an analysis of the manpower, time and cost factors that presently are involved in implementing both the Snow Surveys and the River Forecast Center water models currently being used in California. In relation to remote sensing possibilities, special attention is being given in these studies both to the critical periods when input data are needed and to a sensitivity analysis in relation to the "drivers."

10.2.7 The Algazi-Burgy group also is combining multispectral enhancement with ratioing (to reduce the effect of shadows in mountainous areas), masking of parts of the image, and the use of a likelihood ratio scheme in an effort to improve snow cover areal extent estimates. By such means the senstivity of the estimate to a change in decision threshold has been made quite small (4% variation in areal extent for a 20% change in threshold).

10.2.8 The Algazi-Burgy group also is continuing its work on:

a. application of remote sensing signal processing techniques to user oriented problems, and

b. basic studies on signal processing algorithms pertinent to remote sensing applications.

10.2.9 The portions of the RSRP work that are reported upon in Chapter 2 deal primarily with uses of remote sensing as an aid in estimating certain variables that are useful in predicting or measuring water supply. Specific activities and findings in this regard can be summarized as follows:

10.2.9.1 A multistage, multiphase sample design has been developed to estimate basin water loss to snow water content, evapotranspiration, and pervious surfaces. These estimates are designed to allow improved watershed water supply estimates.

10.2.9.2 Levels of data used are:

1. Digital and hardcopy satellite data
2. Large scale (1:1000) color photography
3. Ground data (several types)

10.2.9.3 Results to date with reference to the snow water content studies can be summarized as follows*:

a. A weighted stratified double sample design utilizing hardcopy ERTS-1 and ground data was utilized in developmental studies for snow water content estimation.

b. Results of this developmental study gave a correlation coefficient of 0.80 between ERTS sample unit estimates of snow water content and ground subsamples.

c. The preliminary study gave a basin snow water content estimate allowable error of 4 percent at the 95 percent confidence level with the same budget level utilized in conventional snow surveys.

d. The snow water content estimate precision ratio was found to be up to 7.2 to 1 in favor of the preliminary basin snow water content estimation procedure over current estimation systems.

e. The preliminary snow water content estimation system could reduce watershed snow water content estimation costs by 50 percent for the basin examined.

f. Formulation of linear probabilistic (e.g. analysis of covariance) and physically realistic deterministic snow water content estimation models designed to refine estimates is proceeding.

g. Techniques to refine sample unit specific ERTS-aided snow areal extent estimates utilized in snow water content estimation are proceeding. Present ERTS snow areal extent estimates, based on current RSRP methodologies, can be made with an allowable error of 5 percent at the 95 percent confidence level in April at the middle of the snow season for the Feather River Watershed. Direct

* The work reported in this section is considered to be complementary to, and not duplicative of, work currently being performed by NASA Goddard personnel under the title "GSFC Snow Mapping ASVT".

correlation of basin snow areal extent estimates with water runoff are also being considered.

10.2.9.4 Results to date with reference to evapotranspiration studies can be summarized as follows:

a. Evapotranspiration estimation models currently in the literature have been evaluated for their utility in the multistage, multiphase sample design.

b. Several evapotranspiration estimation models have been selected for efficient application at each level of information to be sampled.

c. Techniques for developing data to check evapotranspiration estimates are being formulated.

10.2.9.5 Studies to date with reference to pervious surface water loss estimation have focused on estimation of impervious surface area estimation, which is related to pervious water loss by subtraction. Results to date can be summarized as follows:

a. A preliminary area estimation procedure for impervious surface types of differing impermeability adjacent to stream channels has been developed.

b. The preliminary technique employs a double sample of 1:125,000 color infrared highflight transparency data with ground or large scale photography.

c. Impervious surface area estimates (related to pervious surface water loss by subtraction) can be specific to given subbasin areas as in the case of snow water content or evapotranspiration water loss estimation.

d. A semi-automatic impervious surface estimation procedure to be employed in the context of the multistage, multiphase sample design has been outlined.

10.2.9.6 Continuing work involves:

a. Documentation/development of procedures and software for water loss estimation.

b. Tests of model performance including cost-effectiveness analysis.

c. Tests and evaluation of improvement in Department of Water Resources water yield prediction models when remote sensing data is input.

d. Development of basin water/energy input estimation procedures including precipitation and temperature quantification based in part on ERTS and meteorological satellite data.

e. Interaction with California Department of Water Resources personnel concerning remote sensing-aided basin water loss quantification.

10.2.10 Cost-effectiveness methodologies relative to the use of these variables also are analyzed in Chapter 2.

10.2.11 Personnel of the RSRP are presently investigating the problems involved in integrating real-time meteorological satellite information into the water supply analysis. Work is presently proceeding to install a high quality phone line between the National Weather Service (NWS) Field Satellite Service Station in Redwood City, California and the RSRP Laboratory in the SSL Building at Berkeley. Twice daily reception of NOAA-4 very high resolution Radiometer (VHRR) data at the NWS station will be transmitted in an analog mode over the phone line to RSRP. Analog recorders will be automatically set to receive the transmitted data. After cataloguing, the NOAA-4 data for snow or evapotranspiration estimation dates of interest will be translated to digital form for merging with ERTS and other data.

10.2.12 A one month test of the system described above is scheduled for late winter or early spring, 1975. Signal quality as received at Berkeley will be compared with signals recorded directly from the NWS transmitting devices at Redwood City. In addition, analog data will be compared with copies of direct satellite reception data in digital form.

10.2.13 In order to understand the applicability of various types of evapotranspiration estimation equations to a remote sensing-aided system, a baseline definition and discussion of those equations is considered necessary at the outset. Consequently the information appearing in Appendix I of Chapter 2 has been compiled and analyzed by RSRP personnel in order to provide a comprehensive review and understanding of current evapotranspiration methodologies. For efficiency, however, the review focuses on those aspects of each approach which are either relevant to a remote sensing-aided multistage estimation procedure or which are important in understanding the appropriateness of such applicable techniques.

10.2.14 Similarly, with reference to Appendix II ("The Evaluation of Current Models for Evapotranspiration Estimation"), virtually all such models presume that only ground-based data will be available. Hence, the use of remote sensing techniques in cost-effective combination with a limited number of ground sensors is a possibility which RSRP is investigating. The evaluation of current models will help provide a baseline against which to judge the applicability of the various model types to each information resolution level of our proposed remote sensing-aided evapotranspiration estimation system.

10.3.0 Chapter 3 deals with the activities and findings of personnel within the Geography Remote Sensing Unit (GRSU) of the Santa Barbara Campus during the period covered by this report. These can be summarized as follows:

10.3.1 GRSU has demonstrated that the mapping of agricultural croplands can be done more cost-effectively in the San Joaquin Valley of California through the use of highflight photography and/or ERTS-1 imagery than by the various conventional techniques currently in use (viz., techniques used, respectively, in the surveys conducted by the California Department of Water Resources, in the yearly crop reports of the California Department of Agriculture, and in the crop reports compiled by individual water districts - 15 in Kern County alone).

10.3.2 Not only are the conventionally-produced reports more expensive and more time consuming than ones compiled by means of remote sensing, but collectively they also represent a large amount of duplicated effort by those preparing them. Such duplication could in large measure be avoided if crop land surveys based on remote sensing were to be implemented. All of the above three groups are much interested in this possibility. Quantitative data compiled by GRSU personnel in support of the conclusions cited above will be found in Chapter 3.

10.3.3 A sizable test, involving 4 water districts in Kern County, was undertaken by GRSU personnel to estimate the relative accuracies of cropland data derived from field observation, highflight photography and ERTS-1 imagery. Although some of the comparative data needed in order to complete this analysis are not yet available, it appears that agreement among the 3 methods to within 2 percent usually can be expected and that discrepancies greater than 3 percent will rarely be obtained, whether the remote sensing estimates are based on highflight photography, ERTS-1 imagery, or both.

10.3.4 It is anticipated that the best remote sensing based system for croplands mapping will be one that employs a multistage system involving ERTS-1, highflight photography, and very limited ground observation. The GRSU is currently in the process of devising and testing such a system.

10.3.5 The GRSU is also seeking to develop a procedure capable of cost-effectively utilizing remote sensing techniques to generate crop type data, on a nodal basis, as input to the hydrologic model currently being used by the Kern County Water Association (KCWA). The temporal nature of this task is such that multidate imagery of the type provided by ERTS-1 is highly desirable, and perhaps even essential.

10.3.6 The KCWA model pertains to an area of nearly 1 million acres (nearly 400,000 hectares), within which many different kinds of crops are grown. Consequently the area has been subdivided into "nodes" and efforts are being concentrated on achieving an acceptably high level of accuracy <u>at the nodal level</u> with respect to the informational requirements <u>of the hydrologic</u> model.

10.3.7 The Kern County area has salinity problems that are common to many arid environments. Because arid lands require a large amount of irrigation (up to 5 feet per year in Kern County) and because the irrigation waters contain soluble salts, the irrigation of such lands adds further to this problem, contributing as much as 25 tons of salt per acre per year. Unlike in humid climates these salts in the Kern County area are not leached downward into the ground water and eventually transported by streams into the oceans. The GRSU is investigating the usefulness of remote sensing techniques for the inventory and analysis of salinity problems in Kern County.

10.3.8 Additionally, in Kern County the ground basin transfer of salt-bearing waters away from higher lands raises the ground water level on the lower lands, often resulting in the perching of water tables or the temporary flooding of an area, especially if a subsurface impervious layer of soil known as an "aquaclude" is present. A major responsibility of the KCWA is to leach and drain these areas, as necessary, to improve productivity of the soil. In order to do this they must locate such problem areas as early as possible. One goal of the GRSU is to help KCWA accomplish this task.

10.3.9 In proceeding toward the above-mentioned goal, the GRSU has, during the period covered by this report, interpreted multidate Infrared Ektachrome highflight photography (scale 1/125,000) in selected areas as designated by KCWA. In so doing they have used the type and the vigor of both the native vegetation and the agricultural crops, area-by-area, as clues to the presence of troublesome salinity and perched water table conditions. Although quantitative comparisons of ground truth with these photo interpretations are not yet adequate, the GRSU concludes that it is "approaching an acceptable standard of accuracy in making such classifications from remote sensing imagery."

10.3.10 The GRSU is simultaneously conducting a study similar to the above but with the objective of detecting areas in which perched water is interfering with agricultural production. This entails comparing photo interpretation estimates with actual water table measurements made at 152 wells throughout the study area. In the coming months a determination will thus be made of the accuracies of interpreted delineations of perched water areas, based on such checking.

10.3.11 During recent months, GRSU participants in this integrated water resource study, have been working closely with farmers and with personnel of the Kern County Water Agency, in an effort to demonstrate that multidate remote sensing can be used cost-effectively to map areas in which crop production is being affected adversely by the above mentioned factors, (viz. (1) high soil salinity, (2) a perched water table, and (3) adverse seepage of water from one field to another). This effort is now being expanded with the result that interested individuals and agencies are assuming a major role in mapping such problem areas throughout the San Joaquin Valley.

10.4.0 In Chapter 4 investigations by personnel on the Riverside campus are reported. Based on studies which they have conducted during the period covered by this report, the following summary statements can be made:

10.4.1 The use of highflight photography to determine long-term water demand based on present and projected land use is proving to be cost-effective. Preliminary findings show that a single highflight image, when used for this purpose, can replace many low altitude images and yield far less distortion while permitting much faster data reduction to determine water demands. Quantitative data in support of this conclusion will be found in Chapter 4.

10.4.2 For any improved Water Demand Model that might be used in Southern California, it is apparent that land use would be the driving parameter. This, in turn, means that non-permeable areas (such as paved roads, parking lots, and areas occupied by roofed-over structures) would need to be deducted from the gross area. Consequently an evaluation of highflight photography currently is being made by the Riverside group to determine the usefulness of such photography for improving on methods currently being used by the California Department of Water Resources in calculating what they term the "Net Reduction Land Use Factor." Results to date support the conclusion that human and machine analysis of remote sensing data can provide a much more cost-effective means of obtaining the necessary information.

10.4.3 Because agriculture represents one third of the land use in Southern California's Upper Santa Ana River Drainage Basin, the accuracy with which the length of the fallow season (period of minimal water use) can be determined for crops, field-by-field, in this basin becomes an important consideration when annual water demand estimates are being made. Hence the Riverside group is seeking to determine the extent to which aerial or space photography might improve such estimates. Results to date have demonstrated that multidate highflight photography can cost-effectively achieve this objective.

10.4.4 With respect to land use mapping, machine drafting techniques are being investigated by the Riverside group. Digital encoding can be profitably accomplished of all of the vertices within each field or other "polygon" having a specified land use category, judging from their work to date. Each polygon is readily encoded on the digitizer with all data (polygon number, land use type and location of each vertex) punched automatically from the digitizer console. The digitizer then measures each vertex in both X and Y direction from an arbitrarily selected origin with an accuracy of 0.25mm. This new procedure, in addition to eliminating 80 man hours per map, has reduced the number of coding errors caused by mistakes in numbering or in reading the formerly pre-encoded numbers.

10.4.5 Once a polygon has had its vertices identified and encoded, the acreage of each polygon is readily calculated by the machine. Summaries by land use type, hydrologic sub-unit or any other defined subdivision are then obtainable in less than one minute of computer time for each map sheet.

10.4.6 The primary advantage of using the method just described is in the time efficiency which it provides. Although there may be a larger margin of error in individual area measurements, this is offset by the taking of a larger and more representative sample (since remote sensing provides a view of the entire area) and also by the greater number of categories that can be recognized. The total process has been found to yield more accurate and more current reduction factors than had previously been available, thereby permitting more accurate demand estimates to be made.

10.4.7 Many of the vineyards in Southern California have become non-profitable operations due to high taxes, high labor costs and decreased demand for certain kinds of wine grapes. Since grapes grown in this area require approximately 0.26 hectare-meters (2.1 acre-feet) of water per season, the large scale abandonment of vineyards currently taking place in this area is having a significant effect on water demand. Hence the Riverside group is developing remote sensing-based methods for monitoring vineyard abandonment. It now appears that the season of photography will be a very important consideration in relation to this problem.

10.4.8 There is a need to use highflight photography to monitor water consumption, waste production and polluting effects on surface and subsurface water quality of the tremendous number of drylot dairies in the Chino Valley area of Southern California. Specifically, in this area there are 426 such dairies having a total cow population of 176,077 head. All of these areas have now been identified on highflight photography.

10.4.9 The California Water Quality Control Board is cooperating in this dairy study by furnishing information supplied by the dairymen on their individual operations (number and type of livestock, water use, waste production, waste disposal). Because of potential pollution problems, surface runoff from these dairies now is prohibited by the Santa Ana Regional Water Quality Control Board. Consequently dairymen must construct settling ponds, readily seen on the highflight photography.

10.4.10 It now appears that monitoring of these many dairy areas for compliance with the Board's directives can best be done with the aid of remote sensing. Investigations relative to this possibility are continuing with emphasis on measuring the cost-effectivenss of various remote sensing techniques.

10.4.11 As a result of the various efforts described above, participants in this integrated water resource study from the Riverside campus have convinced resource managers in Riverside and San Bernardino counties of the great value of remote sensing from ERTS-1 and U-2 aircraft for mapping (1) areas devoted to multi-cropping with consequent high water use; (2) areas devoted to dairying with special kinds of water use and associated nitrogen pollution of the soil; (3) fallow areas and areas of dryland agriculture having little or no water use; and (4) areas which, because they either are paved (e.g. streets and parking lots) or covered with buildings, contribute excessively high runoff during storms. The next step is to convert such convictions on the part of potential users into technology acceptance that will make them actual users. Progress of this type is being made as indicated below.

10.4.12 The California Department of Water Resources has announced that working with our Riverside group, it will base its forthcoming decennial inventory of the Santa Ana River watershed on these techniques. In addition, these techniques will be employed in the next few months by a private industrial group in mapping water resource factors in the western half of Riverside County.

10.5.0 Chapter 5 contains an account of work done by the Social Sciences Group. Activities of that group during the period covered by this report, and the rationale for those activities are summarized in the following sub-paragraphs.

10.5.1 The Social Sciences Group considers that its primary function is to ascertain the ways in which remote sensing-derived information can enter into decision-making processes, their costs and effectiveness, and their potential impact.

10.5.2 Within the California Water Project the focus of the Social Sciences Group has been to develop insights into the very complicated web of factors impinging on the management of water in order to understand how the new sources of information can be intelligently accomodated. Involved here are not only the official agencies at state, regional, county, and local levels, but also the relationships with federal bodies. All of these are part of an intricate combination of legal, cultural, historical, social, economic, and political events and trends.

10.5.3 Consistent with the above, the Social Sciences Group is in the process of trying to achieve two basic objectives:

10.5.3.1 to develop an understanding of the relevant social, political, and economic considerations that must be taken into account in the larger context of technological assessment, itself a matter of no small concern to agencies at all levels of government;

10.5.3.2 to ascertain the ways in which remote sensing-derived data can be put to beneficial use, specifically and primarily but not exclusively, in relation to California water.

10.5.4 The first of the above objectives (10.5.3.1) is a long-range matter. It is clear that technological advance is not achieved in a social, economic, and political vacuum; it is equally clear that decisions regarding public works must take into account the full dimensions of their impact. Hence the task of the Social Sciences Group is, in a sense, to "map the social landscape." This it has done in preparation for the next major step in the history of California water, viz., the Peripheral Canal. What can be said of this Group's ongoing work so far is that it represents an almost unique effort to accomplish something that is now just becoming recognized as essential -- the social assessment of public works.

10.5.5 With respect to the second objective (10.5.3.2) the Social Sciences Group has been working in close cooperation with our project's remote sensing specialists. In so doing, it has been (a) participating in a study to determine whether remote sensing can be cost-effectively integrated with data used at present in the California Cooperative Snow Surveys model, and has been (b) conducting a study to determine what environmental consequences will result from construction of the last remaining element of the California Water Project, viz., the Peripheral Canal. The potential significance of these studies lies in the application of a methodology for comparing different information-gathering technologies, an approach that could have more generalized applicability with respect to data acquisition for other natural resources.

10.5.6 During the period from July to November, 1974, the Social Sciences Group, in addition, made a number of advances to government agencies and agri-business groups to prepare the way for more applications or remote sensing techniques.

10.5.7 During the next several months the Social Sciences Group expects to complete its present study on the cost-effectiveness of various methods of snow surveying and initiate similar studies, some related to water, others to specific crops, and to examine the possible uses of the data in the various decision-making contexts.

10.5.8 With the greatly aroused interest of State legislative committees in scarce foods and resources in view of California's global role, the Social Sciences Group is finding that new sources of reliable data are taking on considerable significance in the eyes of California's resource managers. The Social Sciences Group has been able to establish excellent rapport with these managers and their associated agencies and expects to play an active role in these new relationships.

10.5.9 With the Peripheral Canal now the prime focus in the California water picture, environmental impacts in all their ramifications become ever more important. Through our numerous contacts with both advocates and adversaries, we have learned how urgent indeed is the need for constant monitoring of adverse effects that might result from construction of that canal. In this respect, remote sensing almost certainly will be found to be very useful. This being the case, the Social Sciences Group is now in an excellent position to ascertain the potential impact of such techniques on the decision-making processes.

10.5.10 Although reported in a separate chapter (Chapter 6), participation in the RSRP conducted work dealing with "Snow Survey Cost-Effectiveness Analysis" represents a continuing activity of the Social Sciences Group. Like other activities in which this group is involved, the Snow Survey study seeks (1) to provide resource managers with useful research results and (2) to assess remote sensing technology in its wider applications.

10.6.0 Chapter 6 consists primarily of a comparative cost-effectiveness analysis of existing and ERTS-aided snow water content systems. Highlights of that analysis can be summarized as follows:

10.6.1 Cost Savings: Total estimated costs of the two production systems were compared at many levels of effectiveness. Figure 6.3 showed the CCSS system producing at a direct cost budget level of \$4,200 per snow survey month; point P_o identified one production possibility at that budget. Point P_1, representing an output of equivalent precision and accuracy on the ERTS-aided system's production schedule, showed a \$3,200 cost savings. Extrapolated over the full range of survey months, this would imply a savings of around 50 percent (~\$14,000) over the existing annual snow survey budget for the Feather River Basin.

10.6.2 Increased Precision:

10.6.2.1 Advantages of the ERTS-aided system are also apparent on the capability of effectiveness side. At a given budget level, the proposed remote sensing-aided snow water content estimation system produced results 25 times more precise than the existing system when stratum weighting option number 2 (W02) was applied. Under a different weighting option (W01), the ERTS-aided system was more than 10 times more precise than the current CCSS system when existing snow courses were stratified into snow water content strata based on ERTS data. Without this stratification, the ERTS-aided system (under W01) was 43 times more precise than the conventional approach. A comparison of weighting options showed that the ERTS-aided system under W01 estimated overall watershed snow water content with approximately 1.0 to 1.7 times the precision of the same system using W02.

10.6.2.2 The ERTS-aided system with weighting option 1 yielded the most precise estimates of total watershed snow water content. For a \$5,000 monthly budget, this approach estimated true basin snow water content to within $\pm$ 0.69% ninety-five times out of a hundred. The precision of basin water content estimates could be improved still further by using techniques that increase the correlation of orbital-to-ground snow water content estimates. Smaller image sample units, more environment-specific snow class interpretations, and automatic processing of satellite digital data are some of the more promising of these techniques.

10.6.2.3 The choice between weighting options is dependent upon the researcher's objectives. W02 will give more precise estimates for fringe snow zone areas. If fringe areas are important during some periods of flood forecasting, then W02 with the ERTS-aided system will produce the better results. However, if overall basin snow water content is highly correlated with either short- or long-term water yield, then W01 is more appropriate.

10.6.3 Additional Abilities:

10.6.3.1 The ERTS snow areal extent-snow water content transform* presented here is only a first case model. Yet it yields correlations with ground sample data on the order of .80. More sophisticated stochastic and physical transform models now being developed should push this correlation significantly higher. The result will be greater snow water content estimation precision at the same level of budget.

10.6.3.2 The ERTS-to-ground correlation coefficient of .80 was achieved using satellite imagery specific to two ground survey dates plus minimal information from a third date. In an operational situation, however, detailed early-season and/or previous-snow-season ERTS data would be available in combination with the snow date of interest, this additional information should further increase the correlation coefficient and produce an even more cost-effective snow water content estimation.

10.6.3.3 An ERTS-aided snow water content estimation system offers several additional possibilities for future snow survey work:

- One biproduct of the ERTS-derived sample unit data is an in-place mapping of snow water content with respect to known melting environments and stream channels. Such time- and place-specific snow melt records could be used to aid in the selection of new snow course sites or in the placement of automatic snow sensors. Snow pack and stream channel juxtaposition data could also be used in refined models of runoff timing.

- Human and automatic analysis of daily meteorological satellite data, when correlated with less frequent ERTS and ground data, offers the possiblity of extremely frequent watershed snow water content updating.

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* The work reported in this section is considered to be complementary to, and not duplicative of, work currently being performed by NASA Goddard personnel under the title "GSFC Snow Mapping ASVT".

- Hydrologic models of the future will conceivably integrate remote-sensing and meteorological data with automatic ground-based snow sensing equipment. Real-time information eventually could be generated for entire watersheds or subbasins, depending on the need to assess the impact of a major storm or a minor subdivision. The continued refinement of remote sensing-aided snow water runoff estimation procedures is likely to be a necessary input into future water resource management practices.

10.7.0 In Chapter 7 an analysis is made of ERTS-type data as an aid in the making of a timber volume inventory. By way of summarizing that analysis, the following statements can be made:

10.7.1 A quasi-operational study demonstrated that timber inventories based on manual and automated analysis of ERTS-1 and supporting aircraft data could be made using multistage sampling.*

10.7.2 This inventory, using ERTS-1 imagery for the first stage, proved to be a timely, cost-effective alternative to conventional timber inventory techniques in obtaining gross timber volume. The volume on the Quincy Ranger District (215,000 acres) of the Plumas National Forest was estimated to be 2.44 billion board feet with a sampling error of 8.2 percent. Costs per acre for the inventory procedure at 1.1 cent/acre compared favorably with the costs of a conventional inventory at 25 cents/acre. A point-by-point comparison of CALSCAN-classified ERTS data with human-interpreted low altitude photo plots indicated no significant differences in the overall classification accuracies.

10.7.3 The ERTS model was found to be a more efficient system of inventorying and therefore could replace the conventional design. As indicated in the text, the estimated cost-effectiveness ratio increased as the allowable error diminished. At a 10% AE the benefit was 3.08:1 and at a 5% AE it was 3.56:1. This gain in efficiences was largely the result of the following two main cost differences: (1) first stage procedures and (2) map generation. As to the first, in the conventional model the initial stratification of the area was done mainly by human interpreters using resource photography whereas in the ERTS model, operating on ERTS data, CALSCAN provided a point by point classification of the area at a lower cost and with greater precision. With this higher level of precision, coupled with the work done on large scale stereo triplets, a less costly sampling scheme was obtainable.

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* Technique development and testing for the ERTS-aided timber volume inventory were performed under Remote Sensing Research Program ERTS-1 studies funded by NASA contract no. NAS 5-21827, Task III, Investigation #217C. Comparative cost-effectiveness analysis, along with all other material in chapter 7 not relating specifically to the ERTS-aided inventory procedure, was performed under this NASA grant's funding at the special request of the Office of Applications, NASA Headquarters.

As to the second difference, that of map generation, this study found that a WRIS black-and-white boundary map of a township at a scale of 4 inches to a mile could be processed by computer for approximately $200. Using the ERTS model system, on the other hand, a color-coded township map of the same scale could be processed for roughly $50.

10.8.0 Chapter 8 consists of a cost-effectiveness comparison of existing and ERTS-based "total timber resources" inventory systems. Highlights of that analysis and related RSRP analyses can be summarized as follows*:

10.8.1 Numerous manual image interpretation tests were performed which were designed to evaluate various components of the ERTS-1 system (see pages 4-16 to 4-36). Detection of wildland resource features and conditions was done acceptably well on single-band, single-date ERTS-1 imagery, but identification of the resources was more difficult. On a single-date color composite transparency, however, a skilled interpreter could detect and identify sixteen specific resource types 67 percent of the time and in broad types 73 percent of the time. In addition, tests showed that a three-band electronic enhancement and a two-band color composite were best among the image types tested for classifying commercial conifer forest.

10.8.2 A quasi-operational study was performed and demonstrated that ERTS-1 imagery is ideal for making vegetation/terrain type maps using manual interpretation techniques (see pages 4-36 to 4-47). In this demonstration project a vegetation/terrain map was prepared from ERTS-1 imagery for the entire 2.25 million acre Feather River watershed and required only 11.5 hours of interpretation time. The ERTS-1 map had an accuracy level of 81 percent. A similar map made using conventional methods -- compiled from both current and outdated data -- had an accuracy level of 68 percent. Furthermore, the ERTS-1 map was prepared at approximately one-third the cost of the conventional map.

10.8.3 Using ERTS-1 imagery for the first stage in the sample design proved cost-effective in obtaining timber resource information compatible with USFS information requirements. Detailed summaries of volume information are still to be determined but correlations between ground plot measurements and photo plot estimates indicate the effectiveness of ERTS-1 imagery in estimating acreages of timber within stand type and in locating and collecting subsequent samples

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* Technique development and testing for the ERTS-aided total timber resource inventory were performed under Remote Sensing Research Program ERTS-1 studies funded by NASA contract 5-21827, Task III, Investigation #317C. The comparative cost-effectivenss analysis, along with all other material in chapter 8 not relating specifically to the ERTS-aided inventory procedure, was performed under this NASA grant's funding.

based on timber acreages. CALSCAN-classified ERTS data efficiently separated timber from non-timber classes and many of the timber classes may prove to be related to stand conditions as well as type. Transformation of ERTS-1 imagery to ground coordinate systems (e.g. UTM) were possible to within ± a picture element when adequate control was provided. Costs per acre of the ERTS-based total timber resource inventory at 4.7¢/acre were slightly more than one-half the costs of a comparable USFS inventory system at 8.4¢/acre.

10.8.4 One of the greatest applications for analysis of ERTS-1 imagery is in the detection of changes in the resource base over time. For example, when using manual interpretation techniques, harvesting activities in the timbered regions of northern California could be monitored with ERTS-1 imagery. Also it was found that a determination of the location and an estimation of the size of a burned area could be made. ERTS-1 imagery provided the ability to accurately (1) map the perimeter of the burned area, (2) make an estimate of the acreage burned, and (3) determine the extent of damage within the fire perimeter. Other resource changes which can be monitored include: sediment plume size and direction, greening and drying of annual herbaceous vegetation, location and amount of irrigated crops, stage of development of marsh vegetation, and changes in the size of large ponds and lakes. For most of the changes that can be detected or monitored, supporting information from either aerial photographs or ground sampling is required in order to establish the significance of the change.

10.8.5 The primary usefulness of vegetation/terrain map information derived from the ERTS-1 imagery in the North Coast is in the display of land use types throughout large regions. The ERTS-1 imagery provides a regional perspective of resource types and management units and allows the resource types to be evaluated in terms of their relationship to each other and related to the different types of land management practices. The ERTS imagery can be rectified and enlarged to a workable map scale of 1:250,000 or 1:125,000 thus providing a map base for resource types upon which other sources of map information can be superimposed.

10.9.0 Chapter 9 consists of four special studies closely related to this integrated multi-campus project, but not relating to the specific remote sensing applications envisaged by any of the participating groups:

10.9.1 The first of these four studies is entitled "Atmospheric Effects in Image Transfer" and reports on the work of two of our co-investigators on the Davis Campus, K. L. Coulson and R. L. Walraven. Highlights of that report can be summarized as follows:

10.9.1.1 Polarization of light from surfaces is a physical property that can be detected by remote sensing and used as an aid to the identification of certain types of earth resource features.

10.9.1.2 The most convenient means of using remote sensing to investigate polarization pehnomena is through the use of a television display. By such means the signals are readily deciphered in terms of the physical quantities involved, and they can be introduced directly into a computer for digital enhancement or other manipulation of the data.

10.9.1.3 In order to check the concept of a video polarizer these members of our integrated team (viz. Coulson and Walraven) constructed a phototype system.

10.9.1.4 Despite the low resolution and excessive noise level of the system which they constructed these investigators found that it permitted both the intensity of polarization and the plane of polarization to be investigated either separately or in various combinations, including color displays (as seen on the television monitor's screen).

10.9.1.5 Results of this test have demonstrated that polarization adds a significant new element for potential use in discerning the unique "tone or color signatures" of various kinds of earth resource features, including those of significance in the inventory of water supply and demand factors.

10.9.1.6 In order to further develop the method of introducing polarization effects into remote sensing applications, improvements are greatly needed in the video polarizer system itself: The making of such improvements will constitute the principal efforts of these investigators during their concluding year of participation in our integrated study.

10.9.2 The second of the four special studies appearing in Chapter 9 is entitled "The Potential Usefulness of Earth Resources Technology Satellites in Relation to the Management of Earth Resources and the Preservation of Man's Environment." It consists of a report submitted by our project's Principal Investigator to the Committee on Aeronautics and Space Sciences on August 1, 1974. In it many of the pertinent findings of research workers involved in our integrated study are summarized including the following:

10.9.2.1 Our research findings have repeatedly demonstrated that the great value of an ERTS-mounted multispectral scanner is to be found, - not in any single attribute of such a remote sensing system, but in an unusually effective combination of attributes.

10.9.2.2 The eleven most important attributes of this remote sensing system, judging from work performed to date under our integrated study, are those listed in Table 1, on page 9-16 of this Progress Report.

10.8.2.3 This Special Study Report next presents a Table which summarizes the combination of characteristics of ERTS found to be most valuable in each of 5 "case studies" recently made by various participants in our integrated project.

10.9.2.4 The report continues with the presentation of details, in tabular form, relative to each of these 5 Case Studies.

10.9.2.5 The report concludes with a copy of the letter written to Senator Moss, (Chairman of the Committee on Aeronautics and Space Sciences) by our project's principal investigator inviting the attention of his committee to this important combination of ERTS-1 attributes, as documented in the fashion described above.

10.9.3 The third special study appearing in Chapter 9 consists of a statement made by our project's principal investigator before the Subcommittee on Space Science and Applications of the Congressional Committee on Science and Astronautics. Although this statement purposely avoids duplicating any significant part of the testimony given to the Senate Committee (Special Study No. 2) it nevertheless draws heavily upon the findings to date of research workers involved in our integrated study. Highlights of this statement can be summarized as follows:

10.9.3.1 The statement seeks to speak directly to certain specific questions as raised by personnel of the Office of Management and Budget, relative to the usefulness of ERTS.

10.9.3.2 Most of these questions, in turn, are based on adverse comments that were made only a short time after ERTS-1 had been launched, by each of three important potential users of ERTS-data, viz. the Statistical Reporting Service, the Forest Service and the Environmental Protection Agency.

10.9.3.3 Among these specific questions, addressed in the principal investigator's statement, are the following:

10.9.3.3.1 Can ERTS-type data help improve crop forecasting systems?

10.9.3.3.2 Can ERTS-type data help improve forest inventories?

10.9.3.3.3 Can ERTS-type data help improve environmental analyses?

10.9.3.3.4 Is present ERTS technology good enough to justify commitment to an operational system now?

10.9.3.4 As indicated by the concluding portions of this part of Chapter 9, reactions by Congressmen to the above-described presentation and to our Integrated Study (on which much of the testimony was based) proved to be quite favorable.

10.9.4. The fourth and concluding special study appearing in Chapter 9 is entitled "Input Quality Encoding of Multispectral Data." It consists of a report submitted by one of our project's co-investigators, Dr. Ralph Algazi, at the 1974 Picture Coding Symposium which was held in Goslar, West Germany. Highlights of that report can be summarized as follows:

10.9.4.1 The quality acceptable in the encoding of multispectral data should be commensurate with the quality of the remote sensing input data.

10.9.4.2 Steps involved in the optimum encoding of such data (involving the use of a quantizer, a filter and a coder) are described.

10.9.4.3 An example is then given of how these steps can be implemented. The example is based on ERTS-1 data of northern California currently under study by some of the participants in our integrated project.

10.9.4.4 The report concludes with an assessment of these results and a statement of plans for further work in this type of activity.

10.10 Overall summary

10.10.1 It will be apparent from the foregoing that work performed under our integrated study falls into 3 main categories.

10.10.1.1 Work designed to provide us with a better understanding of the factors at play, the premises involved, and "models" being used in the management of California's water resources.

10.10.1.2 Work designed to incorporate remote sensing technology cost-effectively either into the existing models or into modifications of them, the better to manage California's water resources (and also to manage certain other components of California's earth resources complex, such as timber).

10.10.1.3 Work designed to acquaint various federal, state and private resource managers and decision makers with our findings, so that they might better progress toward the acceptance of this new technology.

10.10.2 We believe that the balance which we are striving to achieve in conducting the three aspects of our study described above is a highly desirable one. Nevertheless, now that our study of the first of these aspects is nearing completion, it will be possible for the work which we propose to perform next year to be much more heavily oriented toward the second and third of these aspects, dealing respectively with determinations of cost effectiveness and with acceptance and adoption of the new technology by resource managers.