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AN INVENTORY OF IRRIGATED LANDS FOR SELECTED COUNTIES WITHIN THE STATE OF CALIFORNIA BASED ON LANDSAT AND SUPPORTING AIRCRAFT DATA

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16. Abstract The primary objective of the project was to develop an operationally feasible process by which the Calif. Dept of Water Resources (DWR) could use information derived from the analysis of Landsat imagery, together with supporting large scale aerial photography and ground data to obtain irrigated acreage statistics on a regional basis (i.e., statewide). The methods developed were demonstrated/tested in a survey of ten California counties (13,745,000 acres). Three dates of Landsat imagery were chosen for the estimation: June, August and September, 1975.

A three-phase sample design with cluster units was chosen for the study and involved Landsat interpretation (Phase I), large scale aerial photography interpretation (Phase II) and ground measurement (Phase III). The sample units at each phase were a sub-sample of the sample units at the previous phase. Since estimates were required on a county basis, a stratification by county was also used.

Manual interpretation techniques were developed and utilized to estimate the proportion of the final population (3,707,000 acres) that was irrigated. Of the final population interpreted, 80.17% was estimated to be irrigated (2,971,827 acres). The relative error of these estimates was 2.73%.

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Preface

The Irrigated Lands Project had three main objectives: (1) to develop an operationally feasible process whereby satellite imagery of the type procured from Landsat can be used to provide irrigated acreage statistics on a regional basis; (2) to develop a technique that would allow the California Department of Water Resources (DWR) to perform this inventory for the entire state of California in a one year period and have the data available for publication within six months following the end of the calendar year of the inventory; and (3) to achieve a level of accuracy for the test area and the state to within ± 3% at the 99% level of confidence.

In conjunction with DWR, ten counties representatative of much the agricultural diversity found in California were selected for investigation. The population of interest for sampling purposes was extracted from the total area (13,744,640 acres) of these ten counties. A number of land uses found in these counties were not subject to irrigation and therefore were excluded from consideration. Additionally, areas where information on irrigation practices was so good as to make sampling unnecessary were also excluded (e.g. established orchards, vineyards, wildlife refuges). After exclusion, the total population subject to sampling and interpretation was 3,706,726 acres.

The selected sampling strategy was a three phase sampling design based on a sampling frame of area units (clusters) with stratification by county. Therefore, within each county (stratum), of the N units in the sample area, n* Phase I sample units (SU) were chosen at random. Each of these n* units were interpreted on Landsat imagery to determine the proportion of its land that was irrigated. From the n* units, n' Phase II SU's were chosen at random. Interpretation of large scale aerial photography was performed on these n' units. Finally n Phase III sample units were randomly selected from the n' units for ground measurement. In total, 1292 Phase I, 90 Phase II and 18 Phase III sample units were used. A regression model link was used to relate the larger scale photo and Landsat variables, and an additional regression link was used to relate the LSP data to actual ground measurements.

From the outset, the advantages offered by the multidate capacity of Landsat for monitoring an agricultural growing season were obvious. Three time periods were selected for analysis: early June to monitor small grains and establish a base for multi-cropping; August when maximum canopy cover was expected for many irrigated crops in this area, and September, for further observations on multiple cropping. The three-phase, three-date measurement procedure called for large scale aerial photography to be acquired on three dates for each of the randomly selected Phase II sample units. A Twin Commanche aircraft, equipped with a vertical closed-circuit tv system and Nikon 35mm camera set-up was used. After enlargement (1:19,000 - 1:22,500) the photography was mosaiced into strips that covered each sample unit. Each SU was one mile wide and varied in length from four to nine miles. Ground data for a sample of the Phase II units was collected simultaneously or within several days of the acquisition of the large scale photography.

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Interpretation was done on multidate Landsat mosaics (enlarged to approximately 1:154,000) and the large scale aerial photography to estimate the proportion irrigated. The resulting information was tabulated and input to a fortran program (MPHASE) so that statistical correlations between the matched sample units at all three phases could be made. MPHASE was used to calculate the multiphase estimate, the variance, standard error and relative error, as well as the sample correlation coefficients for each county. Of the total land in the population (3,706,726 acres), 80.17% was estimated to be irrigated. The relative error of these estimates is 2.73%. Since the population sampled in this study represents less than hald the agricultural land in California, it would be assumed that a similar sample covering all the land would achieve a smaller error term. An error term on the order of the ± 3 percent at the 99% level of confidence desired by DWR would be expected if such a state-wide inventory was performed.

An evaluation as to the meaning of ILP's results led to three general conclusions: (1) as far as unit costs are concerned, ILP compared favorably with a hypothetical DWR-style survey of irrigated lands, (2) ILP results, when considered for the entire study area, closely approximate those of comparable surveys and they do so at relatively high accuracy, and (3) experience from ILP indicates that its design objectives concerning timeliness are still realistic.

One major recommendation suggested itselt in the course of the project; that of applying a detailed stratification for more optimum allocation of sample units. This stratification would be based on cropping practices/ environmental conditions as they affect both irrigation procedures and interpretation techniques.

The success of the project has depended greatly on the continuing growth of interest and participation by DWR. This strengthening cooperative interaction has led to follow-on project work in which we (DWR and the University of California) will implement the recommendations derived from this research on a larger regional demonstration and expand the research to include computer assisted analysis techniquees and crop identification procedures.

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Acknowledgments

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Grateful acknowledgment is also given to Mr. Barry Brown, Dr. William Draeger and Mr. David Huston who participated in the initiation of the project and to Mr. Steve Harui, Mr. Vincent Vesterby, Mr. David Larrabee, Ms. Hortencia VanGelder and Ms. Betsy Ringer who aided greatly in their capacity as colleagues at the Remote Sensing Research Program, University of California, Berkeley.

1.0 Introduction and Objectives

For more than 25 years the California Department of Water Resources (DWR) and its predecessor agencies have conducted surveys designed to monitor the development of the state's lands to assess the changing needs for water management. California receives an annual average of 200 million acre-feet of precipitation, most of the runoff (ammounting to approximately 35% of the total precipitation) occurs in areas with the lowest population densities. Because of this, the state has constructed large-scale systems to store and transport water from areas of "surplus" to areas of "scarcity".

California Water Code Section 10005 established the California Water Plan in 1957. It is a "comprehensive master plan to guide and coordinate the planning and construction of works required for the control, protection, conservation and distribution of the water of California to meet present and future needs for all beneficial uses and purposes in all areas of the State."[1] In addition to establishing the California Water Plan, Water Code Section 10005 assigns to DWR the responsibility for updating and supplementing the Plan.

"The Department carries out this responsibility through a statewide planning program, which guides the selection of the most favorable pattern for the use of the State's water resources, considering all reasonable alternative courses of action. Such alternatives are evaluated on the basis of technical feasibility and economic, social, and institutional factors. The program comprises:

- Periodic reassement of existing and future demands for water for all uses in the hydrologic study areas of California.
- Periodic reassessment of local water resources, water uses, and the magnitude and timing of the need for additional water supplies that cannot be provided locally.
- Appraisal of various alternative sources of water - ground water, surface water, reclaimed waste water, desalting, geothermal resources, etc. - to meet future demands in areas of water deficiency.
- Determination of the need for protection and preservation of water in keeping with protection and enhancement of the environment.
- Evaluation of water development plans."[2]

To meet these needs the DWR has long recognized the need for specific land use data as an aid to state water planning. Since the late 1940's the Department has been performing a continuing survey on a five to ten year cycle to monitor land use changes over the state. Because of the costs and

[1] Bulletin No. 160-74, "The California Water Plan Outlook in 1974," Department of Water Resources, November, 1974.

[2] Ibid

manpower efforts involved, only a portion of the state is surveyed during a given year. The Department has conducted two kinds of surveys, (1) land use surveys to record the nature and extent of present water-related land development, and (2) land classification surveys to determine the location and extent of lands with physical characteristics suited to specific kinds of development. Land use surveys, which are the most pertinent to the Irrigated Lands Project (ILP) described in this report, are compiled through the interpretation of current aerial photography (35 mm slides) supplemented with field inspections. The acreage of each specific category of land use or class is determined for each county portion of the survey area, for each quadrangle map, and for other area subdivisions such as water agencies, or hydrographic areas. Figures 1 and 2 show the land use legend and a completed land use map respectively, as compiled by DWR.

As can be seen from Figures 1 and 2, each parcel of agricultural land has as a prefix a symbol designating that parcel as either irrigated, "i" or non-irrigated "n". This condition is determined from the aerial photography acquired for each county on a single date basis (usually early July) and the supplementary field data. Due to the limitations of the one date survey, DWR is not able to determine the proportion of acreage devoted to multiple cropping or the acreage of small grains (these may be irrigated or dry farmed) which are often harvested by the date of the survey.

Because of the important need on the part of DWR for periodic tabulation of the statewide acreage of agricultural land receiving irrigation, the Remote Sensing Research Program (RSRP) of the University of California at Berkeley, working closely with personnel of DWR, engaged in an investigation of the feasibility of using Landsat imagery for the inventory and monitoring of irrigated agricultural lands in the state of California. Judging from the results of this investigation, information acquired from the analysis of satellite imagery, such as that to be collected by the ILP, can become a valuable supplement to the land use information presently collected by DWR. Satellite image analysis offers DWR the opportunity to collect data on several dates during the growing season and the opportunity to collect data over the entire state in one year. The ILP is designed to collect data for only one parameter, that of irrigated acreage and, therefore, is designed to enhance, not replace, the present DWR Land Use Surveys.

1.1 Objectives Several meetings between DWR and ILP personnel were held to determine how the ILP could best be structured to meet the needs of DWR. The major objectives, accuracy requirements, timeline requirements, and operational processes were outlined through this cooperative effort. The results of these meetings are as follows:

AGRICULTURE

Each parcel of agricultural land use is labeled with a notation consisting basically of three symbols. The first of these is a lower case "i" or "n" indicating whether the parcel is irrigated or nonirrigated. This is followed by a capital letter and number which denote the use group and specific use as shown below.

C SUBTROPICAL FRUITS
1 Grapefruit
2 Lemons
3 Oranges
4 Dates
5 Avocados
6 Olives
7 Miscellaneous subtropical fruits

D DECIDUOUS FRUITS AND NUTS
1 Apples
2 Apricots
3 Cherries
5 Peaches and Nectarines
6 Pears
7 Plums
8 Prunes
9 Figs
10 Miscellaneous or mixed deciduous
12 Almonds
13 Walnuts

G GRAIN AND HAY CROPS
1 Barley
2 Wheat
3 Oats
6 Miscellaneous and mixed hay and grain

F FIELD CROPS
1 Cotton
2 Safflower
3 Flax
4 Hops
5 Sugar beets
6 Corn (field or sweet)
7 Grain sorghums
8 Sudan
9 Castor beans
10 Beans (dry)
11 Miscellaneous field

T TRUCK AND BERRY CROPS
1 Artichokes
2 Asparagus
3 Beans (green)
4 Cole crops
6 Carrots
7 Celery
8 Lettuce (all types)
9 Melons, squash, and cucumbers (all kinds)
10 Onions and garlic
11 Peas
12 Potatoes
13 Sweet potatoes
14 Spinach
15 Tomatoes
16 Flowers and nursery
18 Miscellaneous truck
19 Bushberries
20 Strawberries
21 Peppers (all types)

P PASTURE
1 Alfalfa and alfalfa mixtures
2 Clover
3 Mixed pasture
4 Native pasture

V VINEYARDS

R RICE

I IDLE
1 Land cropped within the past three years but not tilled at time of survey
2 New lands being prepared for crop production

S SEMIAGRICULTURAL AND INCIDENTAL TO AGRICULTURE
1 Farmsteads
2 Feed lots (livestock and poultry)
3 Dairies
4 Lawn areas

Special conditions are indicated by the following additional symbols and combinations of symbols.

A ABANDONED ORCHARDS AND VINEYARDS
F FALLOW (tilled but not cropped at time of survey)
S SEED CROPS
Y YOUNG ORCHARDS AND VINEYARDS
X PARTIALLY IRRIGATED CROPS

INTERCROPPING (or interplanting) is indicated as follows: $i\frac{D13\text{-}y}{T9}$ = a melon crop planted between rows of young walnut trees

URBAN

UC - URBAN COMMERCIAL

UC 1 Miscellaneous establishments (offices and retailers)
UC 2 Hotels
UC 3 Motels
UC 4 Apartments, barracks (three family units and larger)
UC 5 Institutions (hospitals, prisons, reformatories, asylums, etc., having a reasonably stable 24-resident population)
UC 6 Schools (yards mapped separately if large enough)
UC 7 Municipal auditoriums, theaters, churches, buildings, and stands associated with race tracks, football stadiums, baseball parks, rodeo arenas, etc.
UC 8 Miscellaneous high water use (indicates a high water use not covered above)

UI - URBAN INDUSTRIAL

UI 1 Manufacturing, assembling, and general processing
UI 2 Extractive industries (oil fields, rock quarries, gravel pits, public dumps, rock and gravel processing plants, etc.)
UI 3 Storage and distribution (warehouses, substations, railroad marshalling yards, tank farms, etc.)
UI 6 Saw mills
UI 7 Oil refineries
UI 8 Paper mills
UI 9 Meat packing plants
UI 10 Steel and aluminum mills
UI 11 Fruit and vegetable canneries and general food processing
UI 12 Miscellaneous high water use (indicates a high water use not covered above)

UV - URBAN VACANT

UV 1 Miscellaneous unpaved areas
UV 4 Miscellaneous paved areas

UR - URBAN RESIDENTIAL

One and two family units, including trailer courts

RECREATION

RR RESIDENTIAL
Permanent and summer home tracts within a primarily recreational area. (The estimated number of houses per acre is indicated by a number in the symbol)

RC COMMERCIAL
Commercial areas within a primarily recreational area (includes motels, resorts, hotels, stores, etc.)

RT CAMP AND TRAILER SITES
Camp and trailer sites in a primarily recreational area

P PARKS

NATIVE

NV NATIVE VEGETATION
NR RIPARIAN VEGETATION
NR 1 Swamps and marshes
NR 2 Meadowland
NW WATER SURFACE
NC NATIVE CLASSES UNSEGREGATED

Figure 1. Legend developed by the California Department of Water Resources and employed in their land use surveys,

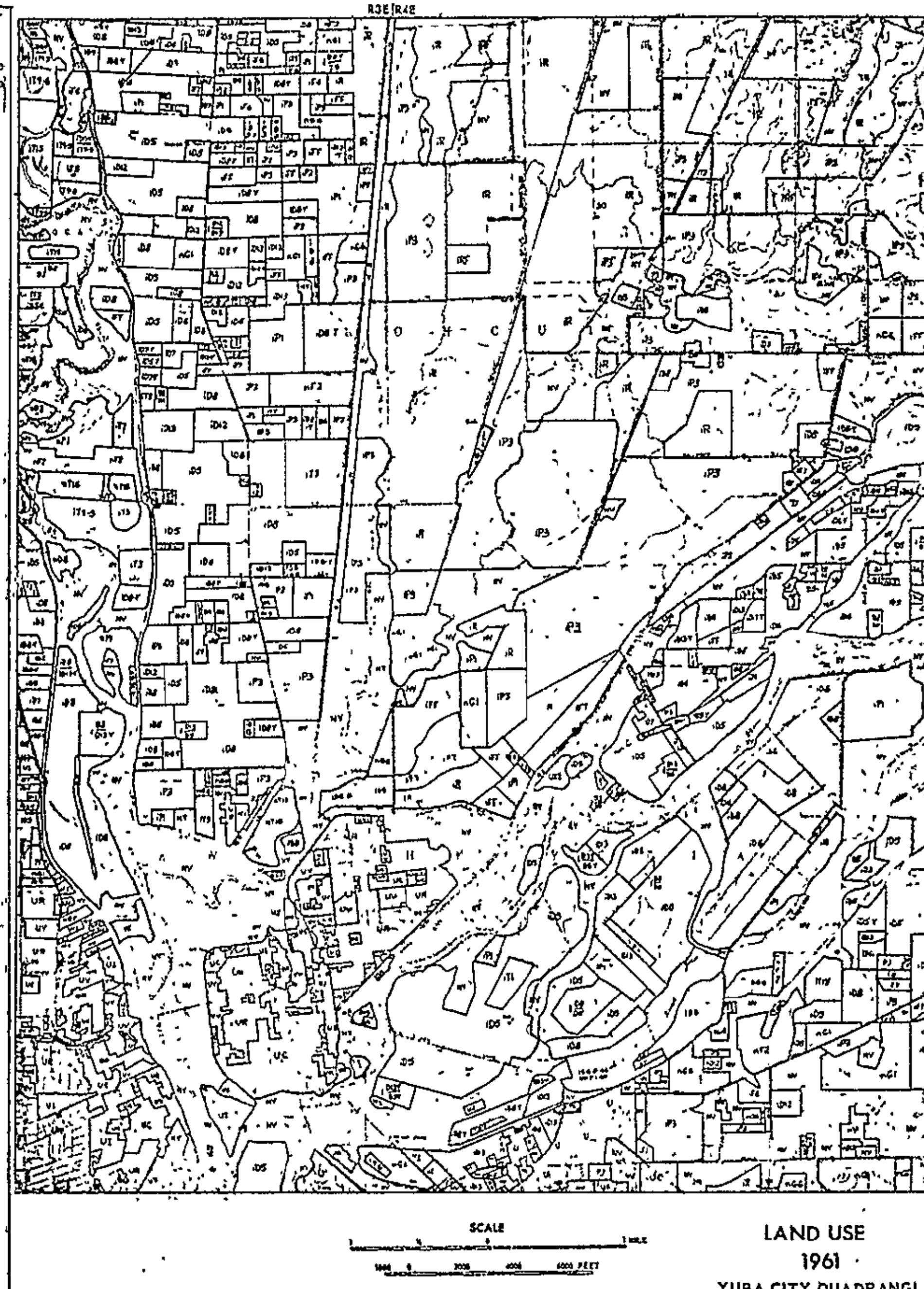

Figure 2. A representative example of a completed 7½ minute quadrangle land use map as prepared by DWR.

- The primary objective of this investigation is the development of an operationally feasible process whereby satellite imagery of the type to be obtained from Landsat can be used to provide irrigated land acreage statistics on a regional basis. The information required by DWR is the acreage of land, by county, that is irrigated at least once during the calendar year. For purposes of achieving this primary objective, the number of water applications need not be determined.

- The technique developed should be one that will enable DWR to perform such an inventory for the entire state of California, in a one year period and to do so every fourth year. The data collected should be available for publication within six months following the end of the calendar year of the inventory. The primary intended use of the satellite-based irrigated acreage is in aiding DWR to assess current and probable future water demands. Present Land Use Surveys alone do not enable DWR to directly establish any single given year as a base year for irrigated acreage statistics.

- The desired accuracy for the test area, and ultimately the entire state is to within ±3% at the 99% level of confidence.

2.0 Definition of Study Area and Sampling Design

2.1 Study Area. Although ultimately the universe of interest is the entire state, for the scope of this project and in conjunction with DWR, ten counties representative of much of the agricultural diversity found in California were selected for investigation (see Figure 3). Sites located in the Sacramento/San Joaquin River Delta, Sacramento Valley, San Joaquin Valley, Sierra Nevada Mountains and Pacific Coast provided the opportunity to test the procedures in a number of environmentally different areas. The counties found in each of the areas mentioned above are as follows:

Geographical Area	County
Sacramento/San Joaquin River Delta	Sacramento San Joaquin
Pacific Coast	Monterey
Sacramento Valley	Sacramento Sutter
San Joaquin Valley	
San Joaquin Basin (N)	San Joaquin Stanislaus Merced Madera
Tulare Basin (S)	Fresno
Sierra-Nevada Mountains	Sierra Plumas

Figure 3. The ten county study area within California that was selected for estimation of irrigated land.

The population of interest for sampling purposes was extracted from the total area of these ten counties. A number of land uses found in these counties were not subject to irrigation and therefore were excluded from consideration. The exclusion areas were primarly, (1) urban areas; (2) non-agricultural wildlands; and (3) hilly agricultural areas not subject to irrigation. Additionally, areas where information on irrigation practices was so good as to make sampling unnecessary were also excluded (e.g. established orchards, vineyards, wildlife refuges and military reservations). The exact mapped region of each county (the total area was stratified by county) which comprised the population of interest was specified jointly by DWR personnel and RSRP. An example of one of the counties with the final population delineated is shown in Figure 4.

2.2 Sampling Design With the parameter of interest defined and the sampling population specified, it was possible to consider alternative sampling systems. Feasible sampling strategies may be identified as combinations of the following factors: (1) sampling frame and sampling unit specifications; (2) stratification; and (3) the use of auxiliary variables. For geographic areas, sampling frames usually are constructed as either a point system referenced by coordinates, an arbitrary clustering of areas into some convenient size unit (e.g. rectangular areas), or a combination of point centered clusters which may overlap. In this investigation, three obvious geographic reference systems could be used to identify and locate sampling units: (1) The state plane coordinate system; (2) UTM coordinate system; or (3) the rectangular land survey system. Similarly, stratification could be based on political subdivisions (such as county boundaries), DWR planning units, or any number of physiographic/biological subdivisions (e.g. geologic, soil, agricultural field size). In this situation logical auxiliary variables which should relate closely to the actual variable (proportion irrigated) would be interpretations made of large scale aerial photography (LSP) and Landsat imagery. These auxiliary variables could then be utilized to construct selection probabilities, e.g. probability-proportional-to-size (PPS) sampling and/or they could be utilized in a ratio or regression predictive model.

The project objective (estimation of irrigated acreage) as well as statistical and implementation considerations all enter into decisions which lead to the "optimum" strategy for sampling the population. Given that photo related variables are a major part of the system, the sampling frame should allow maximum use of the photographic capabilities for a given expenditure of effort. For this reason, point systems are not practical; to photograph a large number of different points with a single or pair of images is very costly. A cluster system is more economical since larger units allow additional information to be obtained at little incremental cost. In this case a cluster system referenced to the rectangular land survey was deemed advantageous.

Stratification by counties was selected based on its importance to DWR personnel for estimates by this population subdivision. In addition, advance information on irrigation practices was available by county. This was useful in the process of determining appropriate sample sizes for the selected strategy. Further stratification, such as that based on field size, was not utilized since irrigation practices in this area did not seem to be related to this variable.

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Figure 4. Sutter County with the final population delineated. The final population consisted of the entire area of the county less exclusions. The exclusions, which were made up of orchard, urban and wildland areas, are marked as "X".

In surveys where a single parameter is to be estimated or where additional estimates are made for parameters of minor importance, variable selection probabilities based on auxiliary variables can lead to substantial gains in precision. This technique however, requires, measuring the auxiliary variable for each sampling unit in the population. With a manual system of this size, cost and the associated amount of effort required to implement a PPS system are substantial. A number of additional parameters also are of interest, at least from an experimental point of view. For these reasons variable probability sampling was not considered. Instead equal selection probabilities were used and the auxiliary variables were employed to generate ratio or regression type estimators. In particular, a regression model link was used to relate the large scale photo and Landsat variables, and an additional regression link was used to relate the LSP data to actual ground measurements.

Two final questions remained to be answered. First, with an area sampling unit (a cluster), should the auxiliary variable be measured for the entire population or for only a sample? As discussed above, costs for measuring every sampling unit would be great. However, if only the population proportion was desired, an estimate could be obtained without requiring a proportion for every sampling unit. It still would be desirable to use a sample, however, unless the sample size required approached the population size. Second, should the auxiliary variables be measured for the entire cluster or should subsampling be used to generate estimates of sampling unit values? Since the whole sampling unit was readily available for measurement, there was really no need to consider subsampling which would add an additional component of variability into the estimates.

In summary then, the selected sampling strategy was based on a sampling frame of area units (clusters) with stratification by county. Therefore, within each county (stratum), of the N units in the sample area, n^* Phase I sample units (SU) were chosen at random. Each of these n^* units was interpreted on Landsat imagery to determine the proportion of its land which was irrigated. From the n^* units, n' Phase II sample units were chosen at random. The interpretation of large scale photos was performed on these n' units to determine the proportion of irrigated acreage. In cases where the Phase I sample size was not much smaller than the number of units in the population, all Phase I units were measured. Finally n Phase III sample units were randomly selected from the n' units for ground measurement of proportion of area irrigated. This then was a three phase sampling design, since the n units were a subset of the n' units, which were in turn a subset of n^* units. A schematic of the sampling system is shown in Figure 5.

Optimization in sampling systems is difficult because there are so many unknown factors. A number of assumptions and approximations of unknown parameters must be made in an attempt to arrive at a reasonable and near optimal survey system. Two particular parts to this system need to be addressed: cluster size and sample allocation. With no information on variability associated with various sizes and shapes of cluster units, the decisions on size and shape were based largely on practical considerations. A one by five mile sampling unit size was selected because: (1) a one mile wide area is covered by a strip of 35 mm photography at a scale (1:62,500 negative scale) considered sufficient for interpreting irrigated acreage data (negatives or transparencies can be enlarged or projected to provide a good work base), and (2) a five mile length is easily located and accurately flown over several dates.

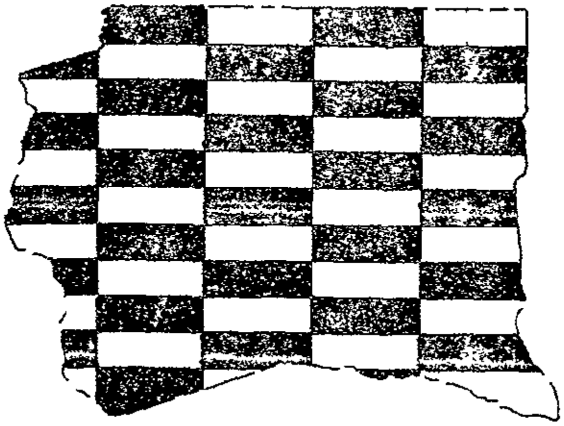
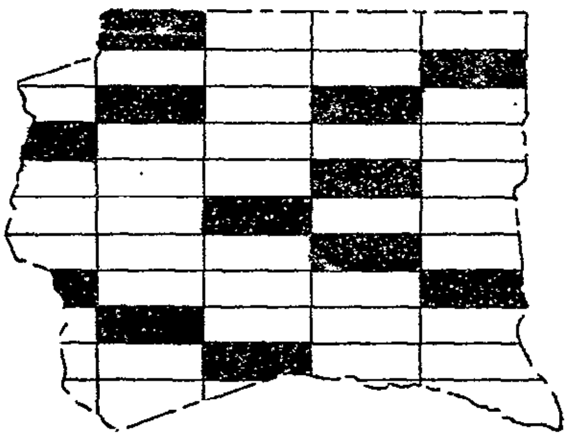
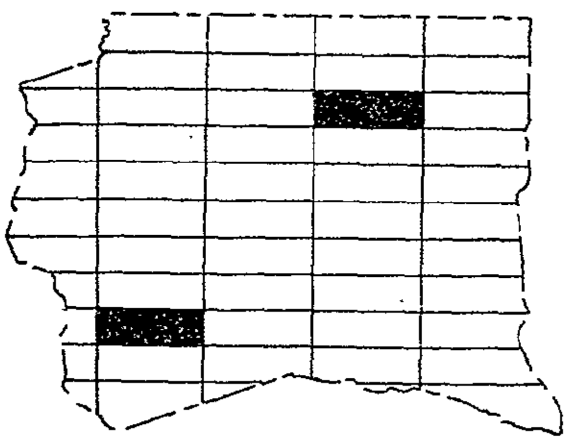
Phase	Schematic of County h	Stratification is by Counties
I		n* Phase I SU's (1 by 5 mile units), selected at random for LANDSAT measurement of proportion irrigated, (y*) are shown in black. In some cases rather than have a sample, the entire county was measured on LANDSAT.
II		n' Phase II SU's (a subset of Phase I SU's) selected at random for large scale photograph measurement of proportion irrigated (y')n'<<n*
III		n Phase III SU's (a subset of Phase II SU's) selected at random for ground measurement of proportion irrigated (y)n≥2

Figure 5. Schematic design describing the sampling system used in the Irrigated Lands Project.

For design purposes, a preliminary population model was constructed; sample sizes (number of sample units) and allocations were based on rough parameter estimates of proportion of area irrigated by county, rough cost ratios and a non-linear programming algorithm which minimizes cost, subject to constraints on variance. California Experiment Station Bulletin 847 and 1974 County Agricultural Commission reports provided most of the numerical data on irrigated acreage. Results of this analysis are shown in Table 1.

Following the formulation of the multiphase sampling scheme described above, a literature search was conducted to determine what had been published relative to this estimation procedure. There has been considerable work completed by many sources on double (two-phase) sampling, but comparatively little on multiphase sampling in general. However, a very detailed and thorough doctoral thesis and a later article by Bhagwan D. Tikkiwal covered the subject very well. The thesis was completed at North Carolina State College in 1955 and the article appeared in the, "Review of the International Statistical Institute," Volume 35:3, 1967. Both treat multiphase sampling on several occasions. Other helpful references were Cochran (1953) and Raj (1964).

The estimators are of the regression type. That is, the model assumes a linear relationship between certain variables and sample estimates of the model parameters are generated. The estimators are also iterative such that the Phase III (ground) estimator uses the Phase II (LSP) estimator which in turn uses the Phase I (Landsat) estimator. The parameters requiring estimation are the proportions of irrigated land within the sampling region of each county using all three phases together. In order to estimate these parameters it is necessary to obtain estimates based only on Phases I and II and estimates based only on Phase I. Therefore, for each county there will be a set of three population parameters: (1) irrigation proportion determined from Phase I, (Y^*); (2) irrigation proportion determined from Phases I and II, (Y'), and (3) irrigation proportion determined from all three phases, (Y). Their corresponding estimators are denoted $\hat{Y}^*$, $\hat{Y}'$ and $\hat{Y}$. The last of these is the end result; $\hat{Y}^*$ and $\hat{Y}'$ are only used as needed to obtain $\hat{Y}$.

The fact that the sample units are considered as clusters and that these clusters are of unequal size affects the estimators. It requires accurate measures of the sizes of the individual sample units. Weighted means may then be used in the estimators rather than unweighted means (unweighted means would increase the variance of the estimates).

The Phase I estimator is a simple weighted average (see Table 2 for an explanation of the following notation):

$$\hat{Y}^* = \frac{1}{n^*}\sum_{i=1}^{n^*} Y_i^*\left(\frac{M_i}{\bar{M}^*}\right) = \frac{1}{n^*}\sum_{i=1}^{n^*} \frac{a_i^*}{\bar{M}^*} = \frac{\sum_{i=1}^{n^*} a_i^*}{\sum_{i=1}^{n^*} M_i} \qquad (1)$$

Table 1. Preliminary sample size summary for the ten county study area (based on historical information).

Assumptions: Based on computer run of FCDPAK on 14 May 75 09:46:45

1. Desired error = 3% for the entire state (assuming 10 counties represents half of the agricultural land in California)

2. Probability level = 99%, t = 2.567

3. Correlation between Landsat and LSP = 0.90

4. Cost ratio (Landsat:LSP) = 1:10 (and LSP:Ground as well)

5. Correlation between LSP and ground = 0.95

6. Stratification data and sample sizes:

Strata (county)	N	P	W ($\sum wi=.5$)	Sample Sizes n* Landsat	n' LSP	n Ground
Fresno	350	.9146	.1585	215	25	2
Madera	79	.9870	.0355	28	7	2
Merced	149	.9463	.06725	68	9	2
Monterey	91	.9050	.0408	*72	7	2
Plumas	54	.5855	.0235	*49	6	2
Sacramento	82	.8597	.63705	*65	7	2
San Joaquin	187	.9101	.08435	86	14	2
Sierra	20	.6748	.0087	*14	4	2
Stanislaus	150	.—	——	*50	9	2
Sutter	98	.8663	.04435	*78	8	2
	1260		.5000	725+	96	20

*measure whole county

7. n* and n' were determined by NLP routine FCDPAK.[3] n is the minimum desired sample size considering the very high correlation that is expected between LSP and ground measurements.

[3] A nonlinear allocation algorithm developed by M. J. Best at the University of Waterloo, Canada. It has been adapted for use on the University of California CDC 6400 computer.

Table 2. Definitions of notation (for a particular stratum):

Symbol	Meaning
N	Population size of units to be sampled
n^*	Phase I (LANDSAT) sample size
n'	Phase II (Large-scale photo) sample size
n	Phase III (Ground) sample size
M_i	Size of sample unit i (any consistent unit of measure)
$\overline{M}^*$	Mean phase I sample unit size; $\overline{M}^* = \frac{1}{n^*} \sum^{n^*} M_i$
$\overline{M}'$	Mean phase II sample unit size; $\overline{M}' = \frac{1}{n'} \sum^{n'} M_i$
$\overline{M}$	Mean phase III sample unit size; $\overline{M} = \frac{1}{n} \sum^{n} M_i$
a_i^*	Irrigated area in sample unit i of phase I
a_i'	Irrigated area in sample unit i of phase II
a_i	Irrigated area in sample unit i of phase III
Y_i^*	Irrigation proportion in sample unit i of phase I; $Y_i^* = a_i^*/M_i$
Y_i'	Irrigation proportion in sample unit of phase II; $Y_i' = a_i'/M_i$
Y_i	Irrigation proportion in sample unit i of phase III; $Y_i = a_i/M_i$
$\hat{\sigma}_{Y^*}$	Sample standard deviation for weighted phase I observations
$\hat{\sigma}_{Y'}$	Sample standard deviation for weighted phase II observations
$\hat{\sigma}_{Y}$	Sample standard deviation for weighted phase III observations
$\hat{\rho}_{Y^*,Y'}$	Sample correlation between weighted phases I and II
$\hat{\rho}_{Y',Y}$	Sample correlation between weighted phases II and III

The Phase II estimator is:

$$\hat{Y}' = \frac{\sum^{n'} a_i'}{\sum^{n'} M_i} + \hat{\rho}_{Y^*;Y'} \left(\frac{\hat{\sigma}_{Y'}}{\hat{\sigma}_{Y^*}}\right)\left(\hat{Y}^* - \frac{\sum^{n'} a_i}{\sum^{n'} M_i}\right) \qquad (2)$$

Note that this (eq. 2) uses the Phase I estimator Y*. The first term is the weighted Phase II mean and the second is its regression correction. The regression coefficient is the term involving the correlation and the standard deviations. It may be seen from this that higher correlations between Phases I and II increase the effect of the correlation term (which may be either positive or negative). Also, the smaller the Phase II standard deviation is in relation to the Phase I standard deviation, the smaller the effect of the correction term becomes. These same remarks apply to the Phase III estimator, which is of exactly the same form:

$$\hat{Y} = \frac{\sum^{n'} a_{i'}}{\sum^{n} M_i} + \hat{\rho}_{Y';Y} \left(\frac{\hat{\sigma}_{Y}}{\hat{\sigma}_{Y'}}\right)\left(Y' - \frac{\sum^{n} a_i}{\sum^{n} M_i}\right) \qquad (3)$$

This final estimator introduces a difficulty because of the small Phase III sample sizes used in the ILP (n ranges from one to three). The sample standard deviations and correlations either are not defined (in the case of n=1) or there are not enough observations to produce reliable values (in the cases of n=2 or n=3). To avoid this difficulty, the standard deviations and correlations used in the Phase III estimator are computed from the combined observations of all the strata (counties). This insures enough degrees of freedom to get stable estimates at the cost of using observations from alien strata. The estimator $\hat{Y}$ is the end result needed. It is the "best" estimator in the sense that it has the minimum variance of any unbiased estimator of the given linear form.

The variance estimators are also computed in an iterative manner. The Phase I estimator is simply the variance of the weighted observations for simple random sampling with a finite population:

$$\widehat{VAR}\left(\hat{Y}^*\right) = \frac{\hat{\sigma}_{Y^*}^2}{n^*}\left(\frac{N-n^*}{N}\right) \qquad (4)$$

The second phase variance estimator is:

$$\widehat{VAR}\left(\hat{Y}'\right) = \hat{\sigma}_{Y'}^2 \left[\frac{1-\hat{\rho}^2_{Y^*;Y'}}{n'} + \hat{\rho}^2_{Y^*;Y'} \frac{\widehat{VAR}\left(\hat{Y}^*\right)}{\hat{\sigma}_{Y^*}^2} - \frac{1}{N}\right] \qquad (5)$$

This depends directly on the Phase II standard deviation and uses the Phase I variance estimate. The last term ($-\hat{\sigma}_{Y'}^2/N$) is the decrease in the variance caused by sampling from a finite population. The Phase III variance estimator is of the same form:

$$\hat{VAR}\left(\hat{Y}\right) = \hat{\sigma}_Y^2 \left[\frac{1-\hat{\rho}^2_{Y'Y}}{n} + \hat{\rho}^2_{Y'Y} \frac{\hat{VAR}\left(\hat{Y}'\right)}{\hat{\sigma}_{Y'}^2} - \frac{1}{N} \right] \quad (6)$$

A single FORTRAN program, named MPHASE, was written to compute three phase estimates and the associated variance estimates. It was designed to handle as many as seven variables of interest in a single run, so that variables other than irrigated proportion (i.e. small grain and multiple cropping proportions) can be estimated if desired. These variables need not be input directly. A special FORTRAN subroutine is used to transform the input variables into the variables of interest. This is convenient for this project because dot counts may be used as input and changed to proportions within the program. In the absence of a third level of information, MPHASE can be used for two phase estimates also. In either case, there is the option to combine the observations from different strata for the two phases with the least observations in order to obtain more stable standard deviation and correlation estimates. Modifications to the original MPHASE allow it to accept variable cluster sizes and to weight the proportions appropriately, as well.

2.3 Allocation of Sample Units The three phase sample design required sample unit selection at all three phases. A description of the total population from which the sample units were chosen is found in section 2.1. The appropriate county boundaries and exclusion areas were delineated on 1:1,000,000 scale Landsat color composite transparencies and 1:250,000 scale USGS quadrangles. The county boundaries were transfered from the USGS quads to the Landsat transparencies using a Bausch and Lomb Photogrammetric Rectifier, Bausch and Lomb Zoom Transferscope and visual location. The exclusion boundaries were delineated directly on 1:250,000 maps by DWR district personnel and were transfered to the satellite imagery using the same methods. Once the population had been accurately defined, selection of the SU's proceeded.

A grid of east-west oriented one by five mile units (as described in section 2.2) was superimposed on the population. County and stratification boundary irregularities caused a practical range of grid sizes from one-by-four miles to one-by-nine miles. Each unit was then numbered, and random number tables were used to select the Phase I (Landsat) SU's.

From this newly defined and smaller set, the appropriate number of Phase II (LSP) sample units was randomly selected for each county. Following this selection two SU's from each county were randomly chosen from the set of Phase II sample units to be the Phase III (ground data) SU's. Figure 6 shows Sutter County with the Phase I, II and III SU's delineated.

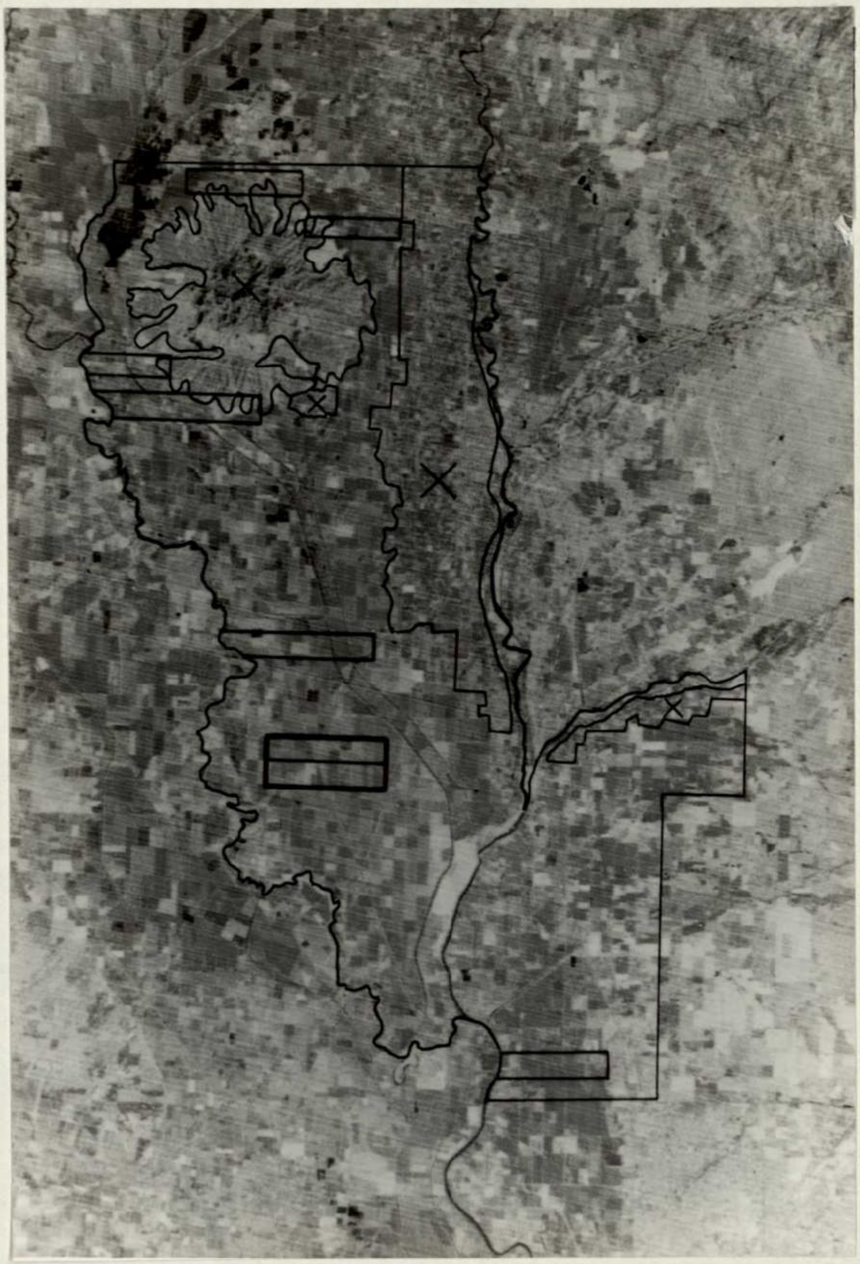


Figure 6. Sutter County with the three phase sample units illustrated. In Sutter County all the Phase I (Landsat) SU's were interpreted, therefore, the total county acreage less exclusions (X) was interpreted. The Phase II (large scale aeral photography) sample units are the eight rectangles delineated above. The two Phase II sample units outlined with the heavy line are the Phase III (ground data) sample units.

3.0 Acquisition of Imagery and Ground Data

3.1 The Selection of Phase I Landsat Photographic Data From the outset, the advantage offered by the multidate capability of Landsat for monitoring an agricultural growing season were obvious. To properly exploit this feature for an estimation of irrigated acreage a number of factors were considered before the selection of the optimum dates for interpretation: (1) expected crop calendar, (2) county cropping practices, (3) historical cropping trends, and (4) harvest dates (especially critical for crops that are in a multi-crop sequence). Based on these factors as well as prior experience in this geographic area and meetings with DWR district personnel and University Agricultural Extension officials, three time periods of Landsat imagery were selected for analysis. These periods were early June to monitor small grains and establish a base for multi-cropping; August when maximum canopy cover was expected for many irrigated crops in this area and September, for further observations on double cropping and its implication on the total irrigated acreage. Due to the orientation of Landsat's orbit with respect to the northwest-southeast trend of the Sacramento/San Joaquin Valley three passes of the satellite were needed to provide coverage in each time period.

Figure 7 illustrates the orientation of the orbital passes in relation to the ten county study area and the dates of imagery for each pass that were used in the study.

3.2 The Acquisition of Phase II Large Scale Aerial Photography The three-phase, three-date measurement procedure called for large scale aerial photography to be acquired on three dates for each of the randomly selected Phase II sample units. Each photo mission was to correspond with the Landsat overpasses used in the study. On the first date (June 2-6, 1975), the pilot located the one-by-five mile SU's (which had been delineated on county topographic maps) and obtained photography for all counties but Plumas and Sierra (these are the Sierra Nevada Mountain counties which were still snow covered). For this flight as well as the remaining flights a Twin Commanche aircraft, equipped with a vertical closed circuit TV system and Nikon 35 mm camera set-up, was used. After enlargement to the standard 3R size (scale 1:19,000), the June photography was mosaiced into strips that covered each sample unit. On the subsequent dates, the pilot was able to precisely locate the starting, ending and center line of the flight lines by using the June flight line photo mosaics and the vertical closed circuit TV system. Comparison of ground features on the TV screen with the photo mosaic enabled this precise location. To ensure coverage, the second and third dates of photography were flown at a slightly higher altitude with a resulting scale of 1:22,500 after enlargement.

The second flights, planned to correspond with the maximum canopy cover expected in August, took place on August 8, 13 and 15 for all counties but Monterey, Plumas and Sierra. Coverage of Monterey was obtained on August 29 and coverage of Plumas and Sierra counties on September 5, 1975. Final coverage for Fresno, Madera, Merced and Stanislaus counties was obtained on September 29 and October 2, 1975. Monterey, Plumas, Sacramento, San Joaquin, Sierra and Sutter counties were completed on October 14, 16 and 28, 1975. Poor weather conditions in September delayed the acquisition of the Phase II

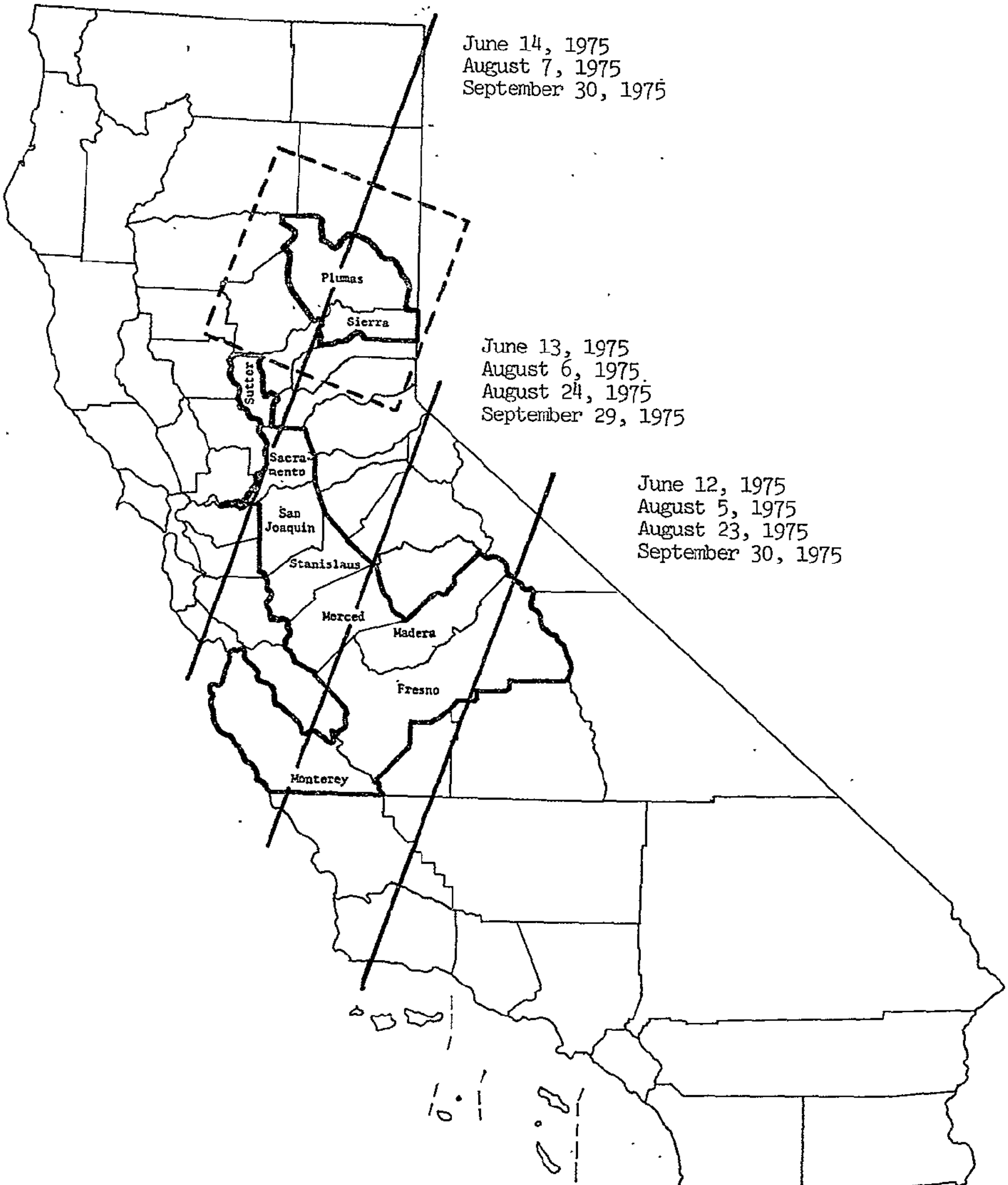


Figure 7. The Landsat orbital paths and dates of imagery used for the study. The square delineated on the most northern track illustrates the approximate area encompassed by one Landsat frame.

photography until after what was considered the optimum time frame.

For each date and for each sample unit, mosaics of the large scale photography were made. Each mosaic had the sample unit precisely delineated and was labeled by county, date, sample unit number and direction of flight. The mosaics were then stored in looseleaf binders for ease of removal and multidate comparison. Figure 8 shows a representative example of the Phase II multidate aerial photography used in the estimation of irrigated lands.

3.3. The Acquisition of Phase III Ground Data In order to correct the estimations made of irrigated acreage on the large scale aerial photography and Landsat imagery, samples of the Phase II SU's were visited on the ground. In each county two Phase II sample units were randomly selected for the collection of ground data. Field maps were prepared from the photography acquired on the June LSP missions. Crop type and irrigated/non-irrigated information for each field for each of the three dates was annotated on the field maps. The DWR land use code (Figures 1 and 2) was utilized for the ground data collection. Figure 9 shows the ground data collected to correspond with the three dates of LSP's seen on Figure 8. For the June collection of ground data, several days elapsed between the acquisition, processing and mosaicing of the LSP and actual collection of data. On the subsequent dates, the first date mosaics were used as ground maps and the field views collected ground data (Phase III) simultaneously with the acquisition of the Phase II large scale aerial photos.

4.0 Interpretation of Landsat and Aerial Imagery

4.1 Phase II Large Scale Aerial Photography Interpretation and Tabulation Procedures

Each Phase II sample unit was interpreted on the large scale aerial photography, (1) to obtain an estimate of the proportion of the agricultural area with the SU that was irrigated and (2) to obtain an estimate of the irrigated area within the entire SU. The estimations were made on mosaics of each SU constructed from the 35 mm aerial photography for each of the June, August and September/October dates. On each of these mosaics, the perimeter of the sample units was first delineated. A clear acetate overlay was placed over the fall date photography and registration and identification symbols and numbers were annotated.

Once the photos were prepared for interpretation, each SU was assigned to an appropriate field size class. Measurements were made on the most westerly one-square-mile area of the sample unit. The average field size within the one-square-mile area was determined and the area assigned to one of four field size classes; Class I <40 acres, 16 or more fields per square mile; Class II 41-80 acres, 8-15 fields per square mile; Class III 81-159 acres, 5-7 fields per square mile, and; Class IV >160 acres, 4 or fewer fields per square mile. The purpose of assigning field size categories was to determine if there was a positive correlation between field size and percent non-crop acreage. To further define the area of the SU into agriculture or non-agriculture classes, boundaries were drawn around urban area, major highways, large irrigation and drainage canals, large areas of riparian vegetation, swamps, marshes and meadowland. After these areas were excluded, the remaining area was the actual agricultural acreage that was to be analyzed.

An interpretation procedure was developed for the remaining agricultural acreage that utilized the benefits of a multi-date system to evaluate the use of each field in the sample unit. Looking at each field or group of fields in the SU on all three dates, the analyst interpreted the use of the field from the classification listed below and coded the use on the acetate overlay.

Table 3. Interpretation code for Phase II large scale aerial photography sample units.

Symbol[1]	Use of Field
NA	Non-agriculture
I	Irrigated[2]
NI	Not irrigated[3]
G	Small grain (barley, wheat, oats, miscellaneous and mixed hay and grain)
G/I	Small grain followed by an irrigated crop
MC	Multiple cropping

1. In practice, color-coded symbols were used.
2. Most crops actively growing in the Central Valley during the summer months are irrigated. Therefore, a signature which indicated the presence of an actively growing crop in August was called irrigated. Wet soil also indicated irrigation.
3. Non-irrigated areas included abandoned orchards and vineyards; fallow fields; non-irrigated, often native pasture and new land being prepared for crop production.

Following the interpretation of all the Phase II sample units from the eight major agricultural counties by DWR and RSRP, tabulation of the results for input to MPHASE was completed. Two methods of measurement were used to compile the results from this phase: (1) DWR tabulated the results of the Phase II SU interpretations using the standard cut-and-weigh method, and (2) RSRP's interpretations were measured using an electronic coordinate digitizer (GRAF/PEN) and an area computer routine (NINEBY). The GRAF/PEN system utilizes a tablet, pen and control box. The tablet has a grid of 2000 x 2000 points over a 14 x 14 inch area. When the pen is pressed against the tablet, the coordinates of the nearest grid intersection are sonically recorded. A field can be defined by recording the coordinates of its corners if it is regularly shaped or by tracing an irregular edge. The computer program (NINEBY) uses the coordinates to compute the area of the field, expressed as the number of grid points within the field. A simple scaling factor is then applied to the point count to convert to acres. Tabulation of the ground data results was also completed using the GRAF/PEN system.

Figure 8. Multidate large scale aerial photography used for the Phase II estimate of proportion irrigated. This sample unit, SU08, is the southern of the two units outlined by the heavy line on Figure 6. A comparison of the appearance of the fields seen above with their appearance on multidate Landsat imagery is possible by reference to Figure 10.

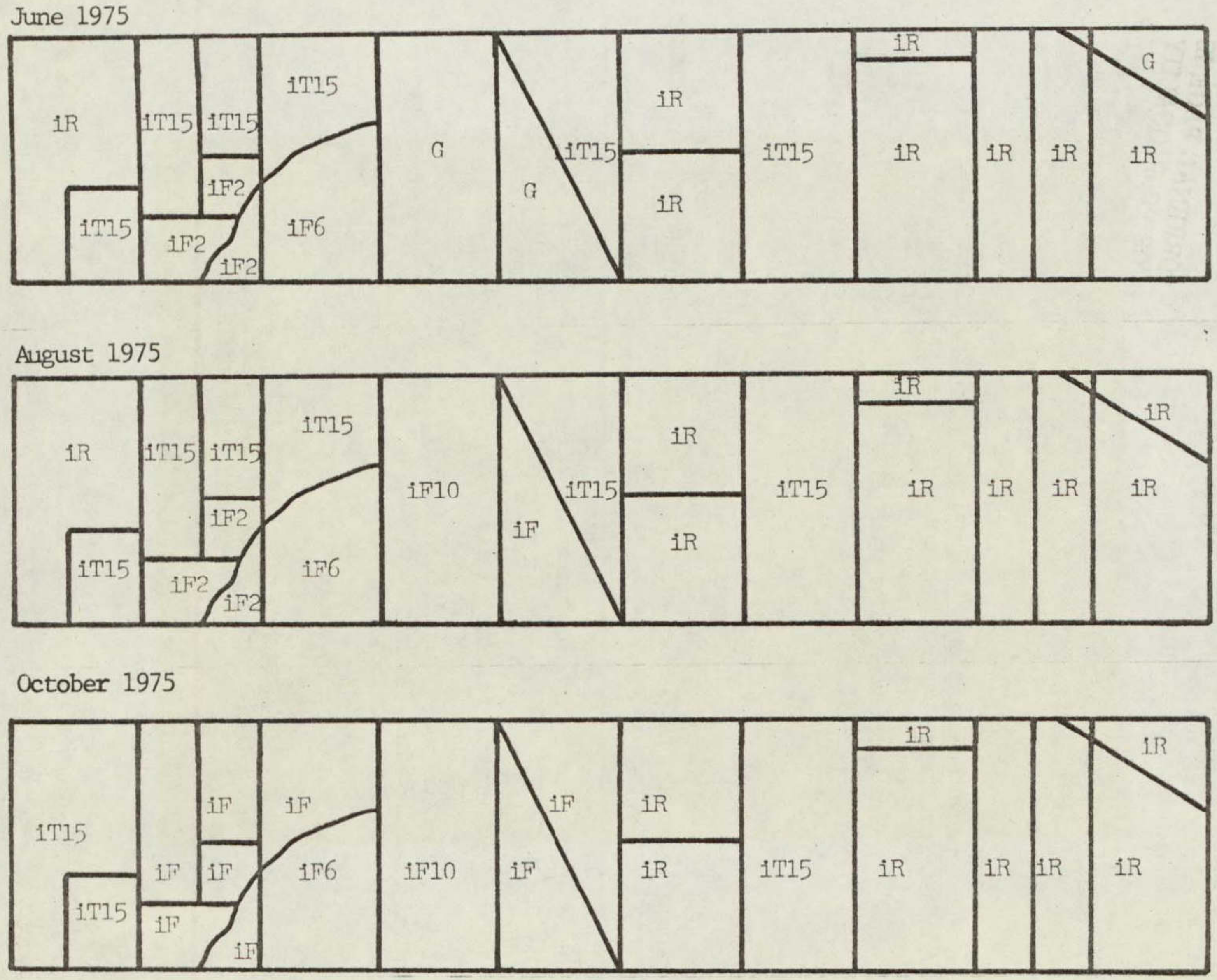


Figure 9. Ground data (Phase III) collected on sample unit SU08 seen as Figure 8. The land use code utilized is that which was developed by DWR and is employed in their current surveys (Figures 1 and 2). The "i" symbol indicates that the field was irrigated at least once during the growing season.

Using MPHASE with the measurements as described above, sample correlations between the large-scale photo (Phase II) interpretation and ground measurement (Phase III) were arrived at as follows:

Irrigation proportion	.874
Multiple crop proportion	.971
Small grain and safflower proportion	.850

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These values, (based on 14 observations from eight counties, (Sierra and Plumas were excluded from this preliminary test)), indicated that there was sufficiently high correlation between Phase II and Phase III observations for accurate three-phase estimation.

4.2 Phase I Landsat Analysis and Tabulation Procedures. The analysis of the Landsat test area was the last interpretation phase that needed to be completed. Color prints enlarged to a scale of approximately 1:154,000 were produced in-house from the transparencies. Extreme attention was paid to reproducing each county on each date of imagery at exactly the same scale. The enlargements were then carefully mosaiced together so that each county could be viewed in entirety on each date.

County boundaries taken from USGS 1:250,000 topographic sheets and exclusion areas provided by DWR were located on the August date mosaic. Location of all the boundaries was done with the aid of a Baush and Lomb Zoom Transferscope and reference to NASA-flown high altitude aerial photography when it was available. In most cases highflight photography of the area taken within the last six years was found in the RSRP film library. Although high flight photography was not an integral part of the design scheme, nor was it used in the interpretation phase of this study, it was very useful in the location of county and exclusion boundaries. Since NASA high flight photography is generally available for the agricultural areas of California it can be used to great advantage in a project such as this.

In order to develop a general technique for the interpretation of the Landsat imagery, the Phase III (ground data) sample units for each county were located on Landsat mosaics. A comparison between the appearance of each field on the satellite imagery and that same field on the Phase II large scale aerial photography could then be made. It is important to remember here that the Phase III ground data SU's were a sample of the Phase II large scale aerial photography. The ground data collected for each of these fields provided the training necessary for describing the tones and the multidate sequence of tones that allowed discrimination between irrigated and non-irrigated areas. Following this initial review with the three phases of information, a technique for the analysis of the Landsat imagery was established. This technique is as follows:

1. An acetate overlay, with appropriate registration marks, county boundaries and exclusion areas was placed on the August Landsat image. Non-irrigated acreage was then delineated. Any crop in a vigorous state of growth in the Central Valley of California in August, and thereby exhibiting a bright red color on Landsat imagery, was assumed to be irrigated. Since the vast majority of the acreage within the study area was assumed to be

irrigated, most of the area was interpreted as irrigated on this August date and hence was removed from further consideration on the June and/or October dates. Only fields not showing the bright red color were delineated.

2. The overlay, annotated with the delineations and interpretations, was transferred to the June date of Landsat imagery and the fields previously called non-irrigated were checked. Where necessary fields included in the non-irrigated population were added to the irrigated acreage.

3. The overlay was transferred to the September Landsat data and the remaining non-irrigated fields were rechecked.

4. A final check of the interpretations was made.

This use of the multidate imagery was central to the success of the project. The added information, made possible by being able to monitor the growing season and to inventory areas of multiple cropping, was critical to achieving the objectives of estimating total irrigated acreage and providing pertinent information for the classification of crop type as well.

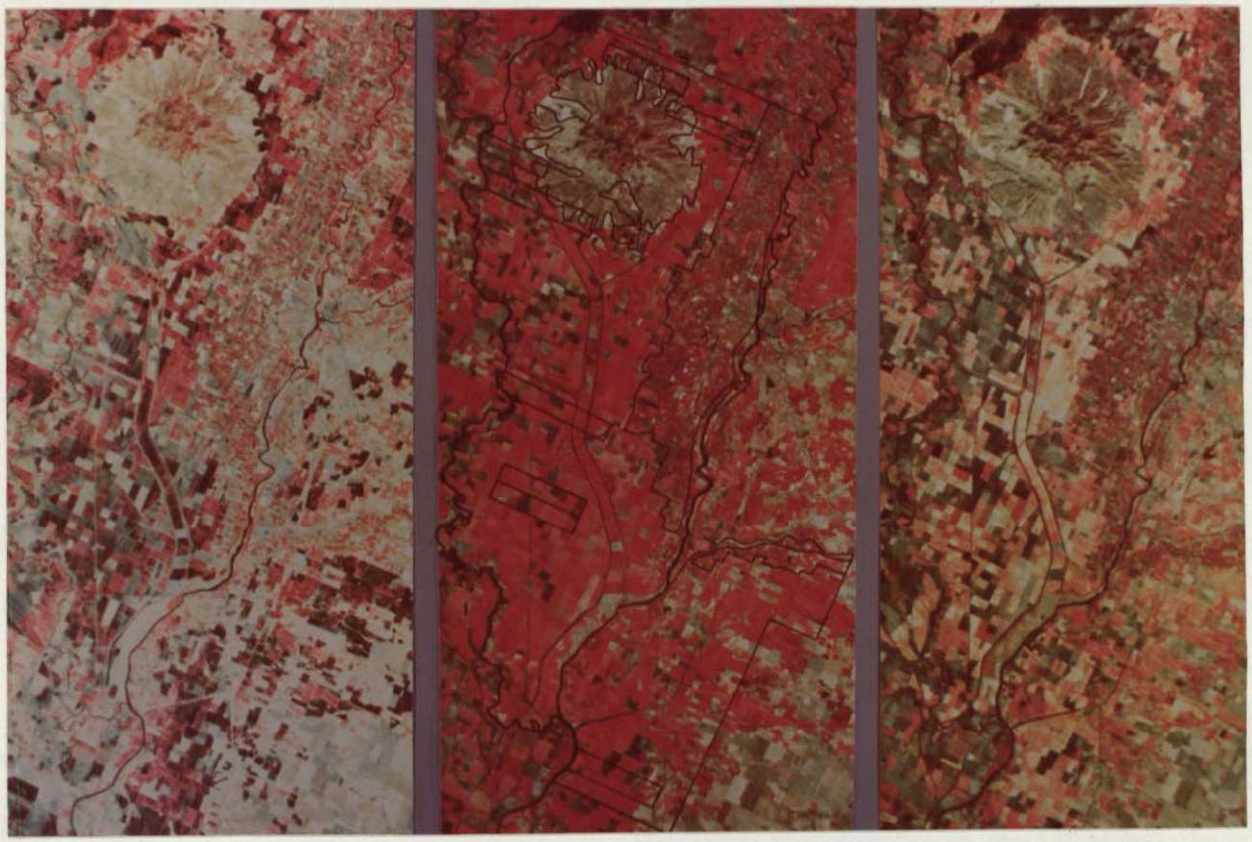
In order to test the operational use of the Phase I interpretation techniques and to obtain some preliminary figures on the correlation between the three phases, Sutter County was selected for a test case study. Through use of the training and interpretation techniques previously described, the Phase I interpretation was completed. Measurements of the entire county, the DWR exclusion areas, major canals and non-irrigated areas were extracted using the GRAF/PEN and were then utilized in the statistical analysis.

A three-phase estimate of the proportion of irrigated land within Sutter County was computed. The sample region was divided into 91 sample units, each of which was interpreted on the Landsat imagery for proportion of irrigated land. Phase II interpretation was performed on eight of these units and Phase III ground data collected for two of the eight Phase II units.

This combination option of MPHASE was used to obtain the relation between Phase II and Phase III. In total, nine Phase II - Phase III pairs were used from 5 counties. The correlation between these was .951. The correlation between Phases I and II was also high, .950. The high correlation meant that there was a possibility of a significant correction to the Phase III mean by the Phase II and Phase I information. The means were:

Phase I mean	.762
Phase II mean	.673
Phase III mean	.834

The three-phase estimate was .808 with a standard error of .058. The results of the Sutter County test case demonstrated that the training and interpretation techniques were providing reliable results and that further modifications to the techniques would not be necessary. Figure 10 shows the multidate Landsat enlargements used for the estimate of irrigated acreage in Sutter County.



June 1975 August 1975 September 1975

Figure 10. Multidate Landsat enlargements used for the estimate of irrigated acreage in Sutter County. The success of the project was based largely on being able to monitor crops through the growing season and inventory areas of multiple cropping. As can be seen, an estimate based solely on one of the dates shown above would not provide the comprehensive data desired by DWR.

On May 18 and 19, 1976, a training session was held at DWR's facilities in Sacramento. The main objective of this meeting was to transfer interpretation procedures to the DWR personnel who would be cooperating in the Phase I interpretation. The objective was met through the presentation of training exercises and materials, practical demonstrations and discussion. Following the training, multidate Landsat mosaics, with the final population delineated on them were distributed. In addition to the DWR analysts who would be participating in the interpretation of Madera, Monterey, Sacramento and Stanislaus counties, other DWR district personnel attended the session to become familiar with the project goals and procedures.

In all, DWR personnel interpreted 1,071,163 acres of the total 3,706,726 acres analyzed in the Phase I step. Interpreters at the RSRP completed the remaining 2,635,563 acres. In addition to this cooperative effort, DWR employees tabulated the acreages of irrigated and non-irrigated areas for 3,094,000 of the 3,706,726 acres. RSRP personnel tabulated the remaining acreages. The traditional cut-and-weigh technique was used for this measurement. In this method, paper prints are made of the interpreted area and then cut into segments of irrigated and non-irrigated areas. These segments are then weighed using a Mettler balance. Since the size of the total sample area had been determined, simple proportions of irrigated to non-irrigated acres were easily derived from the weighed segments. Either the proportions or the weight of each segment (in grams) could be input to the MPHASE program. Table 4 lists the weight in grams, proportions and acreages for each county as measured by DWR and RSRP. Weights and proportions for each of the Phase II and Phase III sample units as they were interpreted on the Landsat imagery were recorded separately as well. These individual measurements were needed as input to MPHASE so that statistical correlations between the matched sample units at all three phases could be made. For a table listing the proportion irrigated for all three phases, see Appendix A.

5.0 Statistical Analysis and Results

With the numerical data calculated by DWR and RSRP, the MPHASE program was run for each county. Section 2.2 of this report describes the sampling scheme used in detail. The main features are repeated here. The levels of information corresponding to the phases are: Landsat image interpretation (Phase I), large-scale aerial photo interpretation (Phase II), and ground measurement (Phase III). Multi-phase sampling is characterized by the sample units at each phase being a subsample of the sample units at the previous phase. The units then are the same size for each phase. An assumption of this design is that there are strongly positive correlations between adjacent phases. The units are considered as clusters because it is desired to find results about irrigation proportions per unit area rather than in terms of the particular sample units.

Since estimates are required on a county basis, a stratification by county was used. Within each county there were areas removed from the region whether because the area was known to be non-agricultural or because DWR already possessed reliable irrigation information about the area. A grid of 1 x 5 mile sample units oriented in an east-west direction was placed over each county. The size and shape was chosen for practical considerations involved in collecting and analyzing the data at all three phases. When a

Table 4. The weight in grams, proportion irrigated and acreage as interpreted on Landsat. These figures were then used to input to MPHASE to calculate the final estimate.

County	Total Interpreted as Irrigated Weight (grams) Proportion Acreage	Total Interpreted as Non-irrigated	Total Interpreted
Fresno	10.4425 .8935 1,034,936	1.2453 .1065 123,419	11.6878 1.00 1,158,355
Madera	1.7809 .6981 170,748	.7701 .3019 73,835	2.5510 1.00 244,583
Merced	4.2055 .8323 416,780	.8476 .1677 84,023	5.0531 1.00 500,803
Monterey	1.3333 .9072 124,028	.1364 .0928 12,688	1.4697 1.00 136,716
Plumas	.4911 .5355 34,279	.4260 .4645 29,201	.9171 1.00 63,480
Sacramento	2.2688 .5028 171,360	2.2431 .4972 169,418	4.5119 1.00 340,778
San Joaquin	4.9474 .8206 488,873	1.0813 .1794 106,848	6.0287 1.00 595,721
Sierra	.1926 .8059 17,321	.0464 .1941 4,172	.2390 1.000 21,493
Stanislaus	3.2845 .8961 312,810	.3809 .1039 36,276	3.6654 1.0000 349,086
Sutter	2.3336 .7619 225,302	.7294 .2383 70,409	3.0630 1.0000 295,711
TOTAL ACREAGE	2,996,437	710,289	3,706,726

boundary of the sample region fell within one of the rectangular units of the grid, a convention was used which allowed the sizes of the sample units to vary between 4 and 9 square miles. Once this was completed, the population of units to be sampled was well defined. The number of sample units to be allocated at each phase within each county was then determined, based on rough irrigation proportion estimates, cost ratios and desired accuracy. A non-linear programming routine which minimized cost subject to these constraints was used to do this. Simple random sampling was then used to select the sample units at each phase. In some counties the number of Phase I sample units was so close to the total number of sample units in the population that all the units in the population at the Phase I level were sampled (see Table 1). In performance of the Phase I interpretation, it was found to be much more convenient and time saving to interpret the entire population of sample units rather than having to select and precisely locate each of the randomly selected Phase I SU's. Therefore, for each county the total population (N) was interpreted at the Phase I level. The final sample size summary is shown in Table 5.

Table 5. Final sample size summary

Stratum - (County)	N_h n^* Population - Landsat	n' LSP	n Ground
Fresno	348	25	3
Madera	79	7	1
Merced	135	9	2
Monterey	233	7	2
Plumas	18	2	2
Sacramento	106	7	1
San Joaquin	166	14	1
Sierra	7	2	2
Stanislaus	109	9	2
Sutter	91	8	2
TOTAL	1292	90	18

MPHASE was used to calculate the multiphase estimate, the variance, standard error and relative error, as well as the sample correlation coefficients for each county. The final results are shown in Table 6. A detailed summary of the estimates by stratum or counties, is provided in Table 7. Table 7 shows: the total sample population area in acres, N_h; the proportion of the total ten-county population each county represented, W_h (e.g. Fresno County represented 31.25% of the total ten-county population); the estimate of proportion of the population that was irrigated, $\overline{Y}_h$, (e.g. 90.38% of the sample population in Fresno County was irrigated); the standard error of the estimate $\overline{Y}_h$, designated as $S_{\overline{Y}_h}$, (the standard error is an absolute estimate of the magnitude of variability in sample estimates which would occur if repeated samples were taken from the same population and this sampling technique was used); the stratum sample size, n'_h, (e.g. Fresno County had 25 Phase II samples); the estimated acreage of irrigated land (the product of the population area in acres, N_h, and the estimated proportion of the population that was irrigated, $\overline{Y}_h$. Using Fresno County as an example, 1,158,355 acres x .9038); the relative standard error, this calculation facilitates comparisons of the error associated with sampling between different counties. It is arrived at by dividing the standard error, $S_{\overline{Y}_h}$, by the estimate, $\overline{Y}_h$, therefore, for Fresno, .04308 ÷ .9038. In studying Table 7, it can be seen that Madera and Sacramento Counties show a much higher percentage error (12.8 and 13.7 percent respectively) than the other counties. If interpretation competence is assumed to be equal for all the counties, it may be inferred from this that in the future additional sampling effort would be required in these two counties. The table continues with the total county acreage, and finally, the proportion of the <u>total</u> county acreage that is irrigated. The estimates by county can be used in planning on a county basis as well as an indicator of the level of sampling which might be required in future surveys within these same counties.

Table 6. Final results of the multiphase estimate as calculated using MPHASE.

	Multiphase Estimates and Variances				Sample Correlation Coefficients			
County	Estimate	Variance	St. Deviation	Relative Error	Correlation between Phases I and II	Covariance between Phases I and II	Correlation between Phases II and III	Covariance between Phases II and III
Fresno	.9038	.0019	.0431	.0477	.7849	.0169	.9820	.0044
Madera	.5917	.0057	.0758	.1282	.8387	.0267	0	0
Merced	.7973	.0030	.0551	.0690	.8216	.0212	1.0000	.0071
Monterey	.8996	.0026	.0507	.0563	.9923	.1228	1.0000	.1907
Plumas	.5649	.0021	.0454	.0790	1.0000	.0101	1.0000	.1000
Plumas-Sierra	.6390	.0021	.0462	.0723	1.0000	.1009	1.0000	.0999
Sacramento	.5354	.0054	.0735	.1373	.9300	.0411	0	0
San Joaquin	.8163	.0048	.0692	.0847	.9821	.0736	0	0
Stanislaus	.8463	.0025	.0499	.0589	.9894	.0926	1.0000	.1070
Sutter	.8097	.0034	.0575	.0717	.9505	.0864	-1.0000	-.0018

Lumped Standard Deviation and Correlation

Lumped Phase II Standard Deviation matching Phase III samples

.2500

Lumped Phase III Standard Deviation

.2668

Lumped Correlation between Phases II and III

.9669

Table 7. Summary of stratified estimates of proportion irrigated.

h	County	Population Area (Acres) N_h	Population Proportion W_h	Estimated Proportion of Population Irrigated $\bar{Y}_h$	Standard Error of $\bar{Y}_h$ $S_{\bar{Y}_h}$	Stratum Sample Size n'_h	Estimated Irrigated Acreage	Relative Standard Error	Total County Area (Acres)	Estimated Proportion of total county area irrigated
1	Fresno	1,158,355	.3125	.9038	.04308	25	1,046,921	.04767	3,830,400	.27332
2	Madera	244,583	.0660	.5917	.07580	7	144,720	.12811	1,374,720	.10527
3	Merced	500,803	.1351	.7973	.05505	9	399,290	.06905	1,269,120	.31462
4	Monterey	136,716*	.0369	.8996	.05067	7	122,990	.05633	2,127,360	.05781
5	Plumas/ Sierra	84,973	.0229	.6390	.04620	2	54,298	.07230	2,257,920	.02405
6	Sacramento	340,778	.0919	.5354	.07351	7	182,453	.13730	630,400	.28942
7	San Joaquin	595,721	.1607	.8163	.06918	14	486,287	.08475	902,400	.53888
8	Stanislaus	349,086	.0942	.8463	.04986	9	295,431	.05892	963,840	.30651
9	Sutter	295,711	.0798	.8097	.05749	8	239,437	.07100	388,840	.61634
	TOTAL	3,706,726	1.0000	.8017	.02188	88	2,971,827	.02730	13,744,640	.21622

*For Monterey county only the Salinas Valley was included as a major agricultural area.

Table 8 summarizes the estimates of proportion irrigated (within the sample population), the estimated total acreage irrigated, and the relative error as calculated for the combined ten county area. Confidence statements are also given for various levels of confidence (e.g. the 95% of level of confidence, or $1 - \sigma = .95$). Of the total land area in the ten counties (13,744,640 acres), 2,971,827 acres or 21.6 percent of the total land area is estimated to be irrigated. The relative error of these estimates is 2.73 percent, assuming acreage measurements were without error. Since the population sampled in this study represented less than half the agricultural land in California, it would be assumed that a similar sample covering all the land would achieve a much smaller error term since the sampling portion of the state would be sampled at about the same rate. An error on the order of the ± 3 percent at the 99% level of confidence desired by DWR would be expected if such a state-wide inventory was performed.

An additional calculation was computed to determine the accuracy gains obtained by allocating the sample units by county. This stratification led to a 17.57% decrease in variance and thus represents a positive gain. It can be assumed that a more sophisticated stratification based on such environmental factors as field size or agricultural cropping practices as well as a county stratification would cause an even greater decrease in variance.

6.0 Evaluating accomplishments of the Irrigated Lands Project[3]

A well-designed project often will generate more questions than it sets out to answer. So far, this report has dealt with queries relating to the ends and means of the Irrigated Lands Project (ILP): What were we trying to do?; How did we go about it?; What happened? In contrast, this section deals with questions relating to ILP's meaning: i.e., So what?

The open-ended nature of this third line of inquiry should be apparent since the purpose of most evaluation exercises is to produce information that might be useful in guiding choices among alternative programs and policies. No guarantee is implied that the information actually will be useful. All evaluative techniques, regardless of how quantitative they appear, are deeply infused with human values. As a consequence, such techniques are prone to all the failings commonly associated with human judgement. Wise users thus will employ these techniques as exploratory tools for revealing assumptions, values, and judgements, for exposing uncertainties, and for formulating new questions.

Results from the Irrigated Lands Project are examined in this same spirit of inquiry. A framework for evaluation is created by assuming that ILP results are roughly comparable with portions of the land use survey conducted by California's Department of Water Resources (DWR). The following questions ensue: How do the two approaches compare in terms of their objectives, products, users, costs, accuracies, and timeliness?; How fair is the comparison?; What do these results imply? Answers to these questions are necessarily tentative and partial, pending further experimentation with more directly comparable data. Nevertheless, a thoughtful evaluation at this stage can help guide work to follow the Irrigated Lands Project.

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[3] This section was prepared by James M. Sharp, resource economist for the Social Sciences Group at the Space Sciences Laboratory.

Table 8. Summary of estimates for the 10 county area.

Parameter	Estimate	Standard Error	Relative STD Error	CONFIDENCE INTERVAL HALF WIDTH EXPRESSED as percent of the estimate i-α ± .68 t = 1.00	i-α ± .95 t = 1.98	1-α ± .99 t = 2.58
Overall Proportion I Irrigated within the sample population	.8017	.02188	.0273	2.73	5.41	7.04
Total irrigated land	2,971,.82 (acres)	77,119 (acres)	.0273	2.73	5.41	7.04

6.1 Objectives. An evaluation of ILP accomplishments cannot overlook the hierarchy of objectives that surrounds the project and related DWR activities. Objectives within the project itself are research-oriented, aimed at developing an operationally feasible process for producing irrigated acreage statistics with the help of satellite imagery. Similar statistics, though usually disaggregated by crop type, are routinely gathered as part of the DWR surveys of water-related land use. When they were initiated in the late 1940's, these surveys were intended "to identify the nature, location, and extent of present land use and lands suitable for various kinds of water-using development."[4]

In recent years, the Department has supported the land use surveys as part of their ongoing planning and management activities. The surveys presently serve a variety of purposes: as baseline information for statewide long-range forecasts of water and power needs, as a check on comparable U.S. Census of Agriculture statistics, as special inventories of agricultural water uses under exceptional conditions like the current drought, or as general information of use to non-DWR agencies and individuals.

The numerous objectives served by the DWR land use surveys, in combination with their greater statistical disaggregation, obviously complicate any attempt to subject ILP results to comparative evaluation. In addition, there is the problem of estimating the value of updated land use information against the full range of DWR objectives. What impact, for instance, would less costly, more accurate, or more timely irrigated acreage statistics actually have on DWR water demand forecasting activities? Could other agencies or organizations also benefit from the improved statistics? Are there alternatives other than improved land use information that would better achieve DWR objectives? It is clear an evaluation of ILP can easily lead past mere "apples and oranges" questions to a cornucopia of considerations beyond.

6.2. Products. The illusory nature of land use planning considerations is illustrated by DWR's land use quandrangles. As the most tangible representation of the Department's survey efforts, the maps are tempting surrogates for output products. More correctly, the maps are intermediate products to be used in forecasting and planning processes to follow. Nearly all the materials produced in the course of DWR's survey work - photos, cut and weigh pieces, quad sheets - fall into this category. They are media for storing information and not ends in themselves. The ultimate products, if there are any, materialize along with countless administrative decisions in the form of dams, irrigation channels, fish screens, etc. Land use survey information thus must be seen as just one node in an entire network of planning and decision-making processes.

Irrigated Lands Project results should be viewed similarly. On a superficial level, ILP's "product" might be considered the irrigated acreage statistics produced for ten counties. But examination of the project's objectives reveals that ILP is concerned more with developing an "operationally feasible process" than with producing statistical products. To evaluate ILP strictly on the basis of its product runs the risk of overlooking its process considerations. How well is the ILP process likely to mesh with DWR's land use survey

[4] Department of Water Resources, Land Use in California, Bulletin No. 176, December 1971, p. 3.

activities? What special technology transfer difficulties or opportunities are apparent? Are there ways of restructuring land use information acquisition procedures within either ILP or DWR to better serve the Department's needs? Questions such as these are unlikely to arise if attention is focused exclusively on product contributions.

6.3 Users. Organizations other than DWR enlarge the decision network in which the land use information products are used. An informal listing recently prepared by DWR indicates a wide variety of uses and users of their land use maps.[5] In addition to DWR, the list includes the following organizations:

U.S. Bureau of Reclamation
State Department of Employment Development
State Department of Fish and Game
State Department of Health
University of California
Economic Research Service
Fresno County Assessor
Merced County Association of Governments
Stanislaus Area Association of Governments
Tulare County Planning Association
Los Angeles Department of Water and Power
Pacific Gas & Electric

The Bureau of Reclamation and DWR both use the land use quadrangles in their water demand forecasting activities, mainly for estimating present water requirements, for projecting future crop acreage, and for locating remaining irrigable lands. Other agencies use the maps to locate the acreages of various crops, prime agricultural areas, or wildlife habitat, to facilitate local planning functions, land appraisal, or environmental assessment, and to estimate farm labor requirements or to establish ground truth.

These diverse applications suggest a land use survey system patterned after ILP might be able to supply information useful to other organizations as well as DWR. Evaluation of the current ILP, however, should proceed by assuming DWR would be the sole user of information resulting from an operational system incorporating ILP procedures. To do otherwise would require far more intensive research into the nature and extent of the applications outside DWR.

6.4 Costs. To know only the purpose, outputs, and intended beneficiaries of particular programs is insufficient for evaluating them. Alternative approaches not only imply certain impacts or effects, but also include associated sacrifices or costs. Cost estimates supply much of the fabric from which program evaluations are woven. As a result, the assumptions and accuracies surrounding a program's estimated costs deserve special scrutiny. Far too many evaluative tapestries, it turns out, are composed of shoddy materials or conceal numerous imperfections. The fact is there is no standard set of rules to be mastered in the evaluation trade. Instead, there is a set of general principles to be combined on an ad hoc basis with an analyst's sensitivity, ingenuity, and good judgement.

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5 Department of Water Resources, Staff Memorandum, 1976.

Approach. An evaluation of the cost picture surrounding ILP leads directly back to the original "so what?" question. The objective here is to determine, at least from the standpoint of cost, whether an ILP approach appears worthwhile. This necessarily implies comparisons with alternative approaches. In the context of this project, it means a comparison with DWR's land use survey approach, the only operational alternative available in California.

At first inspection, the two survey systems appear poorly suited to a comparative evaluative framework. Their differences with regard to objectives, products, and users have already been described. One system is developmental and aimed toward frequent inventories of irrigated lands, while the other has been employed for years to produce less frequent but far more detailed land use inventories. Moreover, meaningful cost comparisons are hard to come by because of differing compensation scales and a lack of directly comparable data.

Stanislaus County provides the principal source of comparable DWR cost information. Not only is Stanislaus County one of the 10 ILP test areas, but it was also the site for DWR's land use survey inventory effort for 1975, the base year for ILP. Stanislaus County is, in essence, the only point of geographical and temporal overlap between the two survey systems. Fortunately, the county's land use diversity enhances its use as a point of comparison. All that is needed is the assumption that DWR's costs per acre surveyed in Stanislaus County are representative of the unit costs DWR would have incurred had they themselves surveyed all 10 ILP counties in 1975.

Attention to the conceptual nature of these costs is necessary before plunging blindly ahead with an analysis. When one normally thinks of costs there is a tendency to focus on direct expenditures or what are defined usually as accounting costs. To properly evaluate programs from a social perspective, however, one needs broader concepts such as opportunity costs to better represent the social sacrifices associated with choices among alternatives. DWR's contributions of photo interpretation and tabulation time, for example, did not appear on ILP's budget but were nevertheless part of the project's costs. Similarly, one needs to exclude certain accounting costs to establish a fair basis of comparison. ILP's budget contains numerous development costs of a research nature that have no equivalent in DWR's land use surveys. These costs cover project monitoring, special testing and experimentation, software development, periodic progress reports, and analytical postmortems like this section.

Some preliminary attention should also go toward constructing a suitable framework for deriving cost information. The method of cost estimation used here is an "ingredients approach" consisting of two phases. The first phase involves writing a task-by-task description of the program, deciding what resource inputs or ingredients are accounted for. Typical ingredients include personnel, facilities and equipment, materials, and

Table 9. Cost data on DWR land use survey - Stanislaus County, 1975.

		All LU Categories		Irrigated LU Only	Assume: 20% all LU	25% all LU
PLANNING & ADMINISTRATION						
coordination	5d @ $70/d	$ 350				
DWR overhead @ 105% of salary		370				
			~$ 700			
PHOTO ACQUISITION						
pilot & aircraft	16h @ $75/h	$1,200				
photographer	20h @ $18/h	360				
observer	3d @ $70/d	210				
DWR overhead @ 105% of salary		220				
travel expenses		100				
film		70				
processing		280				
			~$ 2,400			
PHOTO INTERPRETATION						
field work	70d @ $65/d	$4,550				
DWR overhead @ 105% of salary		4,780				
travel expenses		1,960				
in-house work	45d @ $70/d	3,150				
DWR benefits @ 105% of salary		3,310				
			~ $17,700			
			~ $20,800		~$4,200	~$5,200
TABULATION						
cut & weigh (all LU)	65d @ $50/d	$3,250		$ --		
cut & weigh (irrig LU)	5d @ $50/d	--		250		
DWR overhead @ 65% of salary		2,120		160		
materials		20		20		
			~$ 5,400		~$ 400	~$ 400
			~ $26,200		~$4,600	~$5,600
Unit Costs (includes orchards & vineyards)						
~ 600,000 acres observed			4.4¢/ac		0.8¢/ac	0.9¢/ac
~ 400,000 irrigated acres			--		1.2¢/ac	1.4¢/ac

Table 10. Cost data on ILP survey - 10 counties, 1975.

PLANNING & ADMINISTRATION				
coordination	75d @ $45/d + 15d @ $70/d	$4,430		
sample design	25d @ $60/d	1,500		
RSRP overhead @ 50% of salary		2,440		
*DWR overhead @ 65% of salary		680		
computer time		100		
				~ $ 9,200
PHOTO ACQUISITION				
Aerial				
coordination	12.5d @ $60/d	$ 750		
pilot & aircraft	75h @ $50/h	3,750		
observer	12d @ $50/d	600		
RSRP overhead @ 50% of salary		940		
travel expenses		90		
film		210		
processing		1,060		
			$7,400	
Landsat				
coordination	10d @ $45/d	450		
RSRP overhead @ 50% of salary		220		
imagery		3,830		
processing		200		
			$4,700	
				$12,100
PHOTO INTERPRETATION				
Ground Data				
collection	54h @ $45/d	300		
compilation	20d @ $45/d	900		
RSRP overhead @ 50% of salary		600		
travel expenses		450		
			$2,250	
Aerial				
preparation	17d @ $45/d	770		
training	8h @ $45/d + 20h* @ $70/d	220		
interpretation	72h @ $45/d + 50h* @ $70/d	850		
RSRP overhead @ 50% of salary		610		
*DWR overhead @ 105% of salary		650		
			$3,100	
Landsat				
preparation	34d @ $50/d	1,700		
training	16h @ $60/d + 7d* @ $70/d	610		
intepretation	60h @ $50/d + 52h* @ $70/d	830		
RSRP overhead @ 50% of salary		1,100		
*DWR overhead @ 105% of salary		1,000		
travel expenses		60		
			$5,300	
				~ $10,700
TABULATION				
aerial	49h @ $45/d + 99h* @ $60/d	1,020		
Landsat	32h @ $50/d + 48h* @ $50/d	500		
RSRP overhead @ 50% of salary		240		
*DWR overhead @ 65% of salary		680		
				~ $ 2,400
				~ $34,400

Unit Costs (excludes orchards & vineyards)

~ 3,707,000 acres observed	0.9¢/ac
~ 2,968,000 irrigated acres	1.2¢/ac

miscellaneous inputs. The second phase involves determining who bears the costs and which costs should be taken into account. Client time, for instance, is a cost often neglected in such calculations.

Results. The two accompanying tables set forth cost estimates associated with the major ingredients of DWR's 1975 Stanislaus County survey and RSRP's 10-county Irrigated Lands Project. Activities within both surveys are organized into similar groupings: administration, photo acquisition, photo interpretation, and tabulation. In Table 9, costs estimated for the full Stanislaus County survey are reduced to reflect what the survey might have cost had it inventoried just irrigated and non-irrigated land use categories. Based on discussions with DWR personnel, it was assumed that the less ambitious survey could be performed at roughly 20% to 25% of full survey costs. The resulting unit costs appear at the bottom of Table 9. Since DWR's 1975 survey located some 400,000 irrigated acres in Stanislaus County, this works out to a cost of around 1.2¢ to 1.4¢ for each irrigated acre observed.

Table 10 portrays a corresponding set of costs for ILP. The cost categories generally follow the activities outlined in the ILP progress reports except that developmental costs are omitted. What remains are cost estimates associated with the "operational" components of ILP, i.e., those tasks directly concerned with producing irrigated acreage statistics. The sum of these estimated costs is roughly $34,000; of this, the time and expenses contributed by DWR accounts for some 20%. With nearly 3,000,000 irrigated acres included in the 10-county survey, ILP unit costs amount to about 1.2¢ for each irrigated acre observed.

Comparability. Superficially, the two sets of unit costs may appear directly comparable. Closer examination, however, reveals certain differences that complicate comparisons. One difficulty, reminiscent of classic "apples and oranges" problems, is actually an "orchards and vineyards" problem. Simply stated, the DWR survey included orchards and vineyards, while the ILP survey excludes them. Regions known to contain relatively static parcels of irrigated acreage were eliminated from the ILP sample design at the suggestion of DWR personnel. These acreages comprise mainly orchards, vineyards, wildlife refuges, and military reservations. All DWR and ILP irrigated acres, in other words, are not equal.

The consequence of this dissimilarity on unit cost comparisons depends on the extra effort required to survey the excludable acreage. If the goal is just to separate irrigated from non-irrigated acreage, fruit trees are among the easiest irrigated land uses to identify from aerial photography. Large segments of unirrigated pasture and fallow land also are easily identifiable, especially with the aid of multidate imagery. A graphical comparison of the acreages involved in the two surveys appears in Figure 11. DWR's survey included around 600,000 acres in Stanislaus County, of which 2/3 was irrigated (including

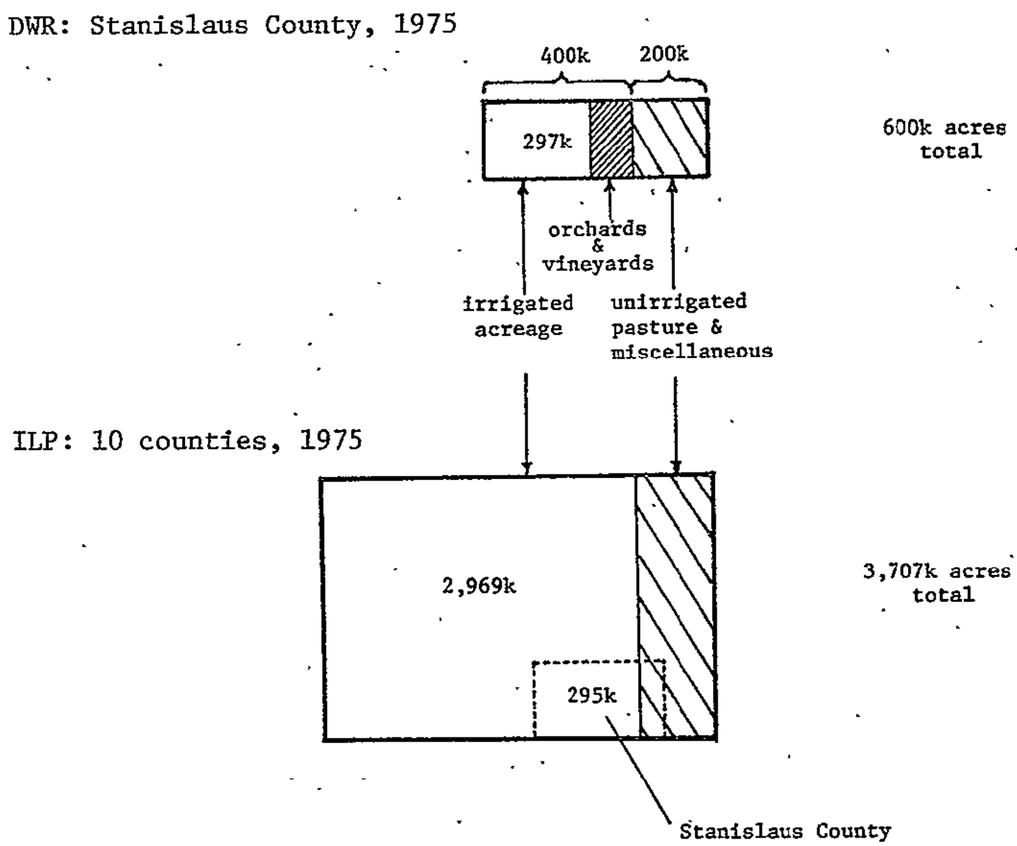

Figure 11. Comparison of areas surveyed.

some 100,000 acres in orchard[6]) and 1/3 unirrigated. The 10-county ILP survey covered an area roughly 6 times larger, divided 80:20, orchardless irrigated acres to nonirrigated acres. Stanislaus County acreage accounted for about 8% of the ILP survey total. From such facts and figures, one might expect that if the two surveys had looked at the same kind of irrigated acreage, ILP's relative unit cost picture, if anything, would be enhanced.

Other inconsistencies emerge when the two lists of cost data (Tables 9 and 10) are scrutinized. For instance, not all the estimates are of equal precision. Photo acquisition costs, because they leave relatively tangible records, are the easiest to pin down. Photo interpretation and tabulation activities, consisting mainly of well-defined and repetitive tasks, provide the next most reliable level of cost data. Planning and administrative costs are the most difficult to untangle from the other categories and, hence, the least precise. The task of isolating administrative costs in ILP is complicated further by the abundance of development costs related to research administration. A heavy reliance on subjective judgement is thus essential for sorting out these intermingled expenses. Yet care must be exercised to avoid judgements that unfairly bias the comparative framework. Examination of the work here should show that most judgements, if they exhibit bias at all, lean in favor of DWR's survey system. The amorphous area of planning and administrative activities, for example, accounts for 27% of the ILP survey's total costs; in the comparative DWR system, these tasks are estimated to consume only around 3% of total costs.

Additional differences become apparent upon inspection of the individual cost data "ingredients". DWR salaries and overhead rates generally exceed those applicable within the University's Remote Sensing Research Program (RSRP). The higher rates, however, usually suggest greater experience, capabilities, benefits, or indirect costs. For example, the higher of DWR's two overhead rates reflect added costs associated with maintaining field operations. In another case, it is obvious the two systems have differing photo acquisition costs. DWR's aerial surveys originated in Merced, close to the survey site, using a pilot plus two men, whereas RSRP's two-man team flew from Oakland while surveying the ILP counties. The two systems also show divergent photo interpretation and tabulation costs, mainly because of the methodologies employed. The DWR system, designed to differentiate between many crops, involves considerable direct observation of resources. Similarly, the DWR system favors a cut-and-weigh tabulation method (over Graf pen, for example) because it provides a permanent file of land uses.

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6 The Stanislaus County Annual Crop Report for 1975 shows 102,848 acres of bearing fruit and nut crops, of which about 25,000 acres are vineyards.

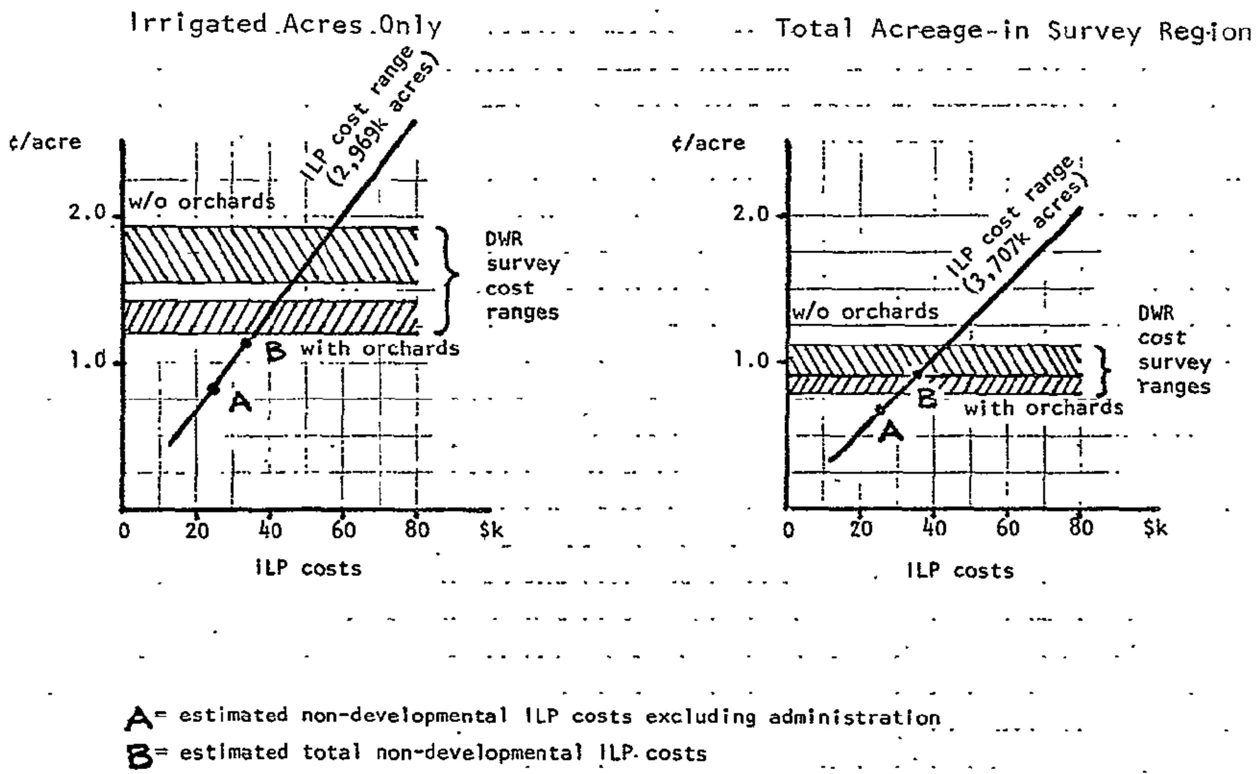

Figure 12. Comparative unit costs:
ILP survey vs. DWR survey of Stanislaus County, 1975.

Summary. Clearly, an assessment of the results and comparability issues associated with costs demands an analytical balancing act: on one hand, it is important that the "trees" of comparative questions do not obscure the evaluative forest; on the other hand, it is essential that any conclusions are interpreted with knowledge of the shortcomings built into the evaluative framework. Figure 12 draws on the unit cost information in Tables 9 and 10 to illustrate comparisons between the two survey systems. Costs are compared using two views of the "units" involved: irrigated acres only (left graph) and total acreage in the sample region (right graph). The unit costs of both survey systems (in cents per acre) appear on the vertical axes, while the horizontal axes register the full costs of ILP (in thousands of dollars). Each graph shows two cost ranges for the DWR survey, the lower range including orchards and vineyards and the upper excluding them. Since the second cost range implicitly assumes the additional cost of surveying the excluded acreage is zero, it represents an outside limit to estimates of DWR costs. The diagonal lines indicate the range of unit costs that would result for an ILP survey (excluding orchards) at various budget levels. Point A, near the $25,000 level, shows the unit costs expected from an ILP budget including cost estimates for photo acquisition, photo interpretation, and tabulation activities. Point B, near the $34,000 level, shows the same thing given the total estimate of non-developmental ILP costs. Planning and administrative cost estimates, in other words, account for the difference from A to B.

Figure 12 provides a natural opportunity to return to the "so what?" question. By momentarily putting aside structural dissimilarities and comparability difficulties, it is possible to reach a general conclusion: namely, as far as unit costs are concerned, ILP compares favorably with a hypothetical DWR-style survey of irrigated lands. In other words, Figure 12 shows estimated ILP costs falling into roughly the same "ballpark" as DWR costs. This conclusion holds for comparisons involving both types of "units", using either the entire acreage surveyed or just irrigated acres alone.

6.5 Accuracies. Unit costs furnish one set of criteria for evaluating irrigated lands survey methodologies. Information on survey accuracies provides another. Both criteria sets depend strongly on comparative judgements, and the results of these judgements in turn depend on what is being compared. There are two basic ways of judging the accuracies achieved in ILP acreage estimates: (1) through an "internal" analysis of their statistical consistency, or (2) through an "external" comparison with the results of independent surveys of the same region.

Since a description of the first approach appears in an earlier section (pp. 25-31), little on this subject needs repetition here. It should suffice to say that although ILP failed to attain the accuracy levels established at the project's outset, the accuracies demonstrated under imperfect test conditions were

Table 11. Comparison of ILP irrigated acreage results with other surveys.

County	[A] 1975 ILP	[B] 1974 Census of Agriculture[1]	[C] 1975 Annual Crop Report	[D] 1975 DWR LU Survey	Relative Standard Error[5]	([A]-[B]) / [B]	([A]-[C]) / [C]	([A]-[D]) / [D]
Fresno	1,046,921 a	1,102,534 a	1,012,949 a		4.8%	- 5.0%	+ 3.4%	
Madera	144,720	224,121	212,525		12.8	-35.4	-31.9	
Merced	399,290	387,222	389,655		6.9	+ 3.1	+ 2.5	
Monterey	122,990	206,041	231,288		5.6	-40.3[7]	-46.8[7]	
Plumas	36,495	21,362[2]	49,100		7.2[6]	-- [8]	-25.7	
Sacramento	182,453	148,738	230,867		13.7	+22.7	-21.0	
San Joaquin	486,287	448,268	505,500[3]		8.4	+ 8.5	- 3.8	
Sierra	13,734	5,692[2]	22,600		7.2[6]	--- [8]	-39.2	
Stanislaus	295,431	300,449	272,398	297,000[4] a	5.9	- 1.7	+ 8.5	-0.5%
Sutter	239,437	196,220	307,174		7.1	+22.0	-22.1	
Total	2,967,758 a	3,040,647 a	3,234,056 a			- 2.4%	- 8.2%	

1 1974 Census of Agriculture, Preliminary Report.

2 From 1969 Census of Agriculture; unavailable for 1974 Census until mid-1977.

3 Increased by 500 acres to reflect addition of nursery crops.

4 Stanislaus is the only county here surveyed by DWR in 1975; total equals 400,000 acres less orchards and vineyards.

5 From Table 8; no signs because figures are ratios.

6 Plumas and Sierra Counties combined.

7 Low figures reflect the exclusion of Monterey County lands outside the Salinas Valley.

8 Omitted for lack of 1974 base year.

nonetheless encouraging. The original accuracy requirements, discussed in earlier progress reports, were set at ±3% for a 99% level of confidence. This means an observer should find irrigated acreage estimates to be within ±3% of the actual acreages in 99 out of 100 cases. ILP accuracies and confidence intervals were displayed in Table 8. There, results at the 99% level of confidence were ±7.04%. Further improvement in these accuracy levels would have been likely had ILP sampled lands throughout the state. As it was, the ILP test area included roughly 1/3 of California's 9,000,000 irrigated acres and thus about 1/3 of the strata needed to inventory the entire state. Other things equal, more strata would mean a lower standard error of estimate, and hence, greater overall accuracies. Similarly, experience with ILP indicates that restratification of certain counties would significantly reduce interpretation errors.

A county-by-county comparison of ILP acreages with those of three independent surveys appears within the eight columns of Table 11. Taken in their entirety, acreage estimates for the ILP counties (column 1) are about 2% less than comparable estimates from the 1974 Census of Agriculture (columns 2 and 6) and around 8% less than combined estimates from the 1975 county crop reports (columns 3 and 7). The ILP acreage estimates for Stanislaus County are almost the same as in DWR's 1975 survey minus the county crop report estimate of orchards and vineyards (columns 4 and 8). Results for individual counties show considerably more variation between surveys. The list of ILP relative standard errors (column 5) is useful for reviewing the "internal" accuracy of county estimates beside their "external" counterparts. A comparison that emphasizes irrigated acreage estimates within individual counties, however, overlooks ILP's fundamental objective, i.e., that of surveying irrigated agriculture across very large regions. The bottom lines in Table 11 suggest that ILP did that job fairly well. By adding to this the results concerning ILP's "internal" statistical consistency, it is again possible to generalize: <u>ILP results, when considered for the entire study area, closely approximate those of comparable surveys and they do so at relatively high levels of accuracy.</u> This statement is meant as another "ballpark" assertion, implying that aggregate ILP results demonstrate a range of credibility similar to that of more intensive surveys.

6.6 Timeliness. The concept of timeliness introduces an important third dimension into the evaluation of any information-producing system. It is this perishable quality that can mean the difference between accurate, cost-efficient information and irrelevant words and digits. Obviously, what is timely and what is not must be determined by the purposes and priorities of the information users. Often decisions about timeliness are dominated by other decisions concerning the desired level of information detail. For example, the comprehensiveness (and associated expense) of DWR's land use inventory program has tended to restrict the coverage of their annual surveys. On the average, around 10% to 20% of DWR's survey area is updated each year. Statewide estimates of irrigated lands, when required, are constructed from a mosaic of annual surveys, each adjusted and extrapolated to reflect recent land use changes.

Parallel information from two other statewide surveys also present timeliness and reliability difficulties. The Census of Agriculture, repeated at five-year intervals (1969, 1974,...), is unavailable until two to three years after the census year. Moreover, DWR personnel have found that the Census Bureau's estimates of irrigated land in California farms, when they finally appear, often fall below DWR's own estimates. Crop reports from each of the County Agricultural Commissioners also provide a source of information on irrigated acreage. While these reports are filed within a year following the growing season, DWR finds that their reliability depends strongly on the county involved. Furthermore, neither the Census nor the crop reports furnish irrigated lands information in a spatial context consistent with DWR's own surveys.

The possibility of establishing a relatively inexpensive, consistent, and timely data base for monitoring statewide changes in irrigated land uses was the motivating idea behind ILP. At the outset, the ILP approach was to be capable of completing a statewide survey of irrigated lands within one year, with results available six months later. Experience from ILP indicates that its design objectives concerning timeliness are still realistic. This conclusion bears little relationship to the project's actual duration. As in many prototypes, the bulk of time spent on ILP was consumed by research and development details. Nevertheless, ILP has increased the likelihood that an "operationalized" ILP could indeed deliver a statewide inventory of irri-lands within 18 months. Compared with existing surveys, this sort of performance would place the ILP approach in a timeliness "ballpark" all its own.

6.7 Conclusions. The foregoing paragraphs, tables, and figures have already outlined the fundamental conclusions apparent from an evaluation of ILP. A comparison with DWR's land use survey program reveals numerous differences in objectives, products, and users. Despite these and other dissimilarities, it is possible to advance several tentative generalizations about the two approaches. In terms of costs and accuracies, the prototype system produces results in roughly the same range as the operational system. In terms of timeliness, an ILP approach promises an improvement over existing surveys, but an actual demonstration of this ability has yet to be performed. In terms of all these areas, it is possible to identify improvements that could further enhance the relative performance of the ILP approach: e.g., lower administrative expenses could greatly reduce costs; greater stratification could significantly improve accuracies; and additional practice would insure more timely results.

It is important, however, to recognize that the "so what?" question really encompasses more than the basic evaluative measures of cost, accuracy, and timeliness. Herein lies the subtle distinction between evaluation of a technology's results and the more comprehensive notion of technology assessment. Mere measures of relative performance can often overlook critical characteristics of the social environment into which a new technology is being introduced. While a thoroughgoing assessment of an ILP-style approach reaches beyond the scope of the study here, a glance at two assessment-related questions is in order: What types of changes could implementation of an ILP system produce? In what areas would an ILP system be of greatest value to DWR?

The first question relates to the probable side effects associated with a transfer of ILP technology. These considerations frequently escape more formalized evaluative procedures because they possess poor visibility, or defy meaningful quantification, or both. Failure to adequately assess and anticipate such "intangibles" can deny success to any technology transfer effort. From DWR's standpoint, implementation of an irrigated lands program patterned after ILP might be expected to raise legitimate concerns about the following sorts of changes:

- Changes in activities. A reexamination of the cost data in Tables 9 and 10 indicates some of the activity differences between the two survey approaches. ILP involves less direct observation of the agricultural resource and more in-house photo interpretation work. For those who prefer "windshield surveys" to stereoscopes, such activity changes might result in lower job satisfaction. Of the DWR employees who participated in the ILP photo interpretation work, most had favorable comments about the activity, although several admitted it was "somewhat tedious" and should be performed in smaller doses.

- Changes in budget. The possibility that any savings generated by new methods would result in reduced budgetary discretion is a concern very real to agencies exploring new technologies. Whether ILP is likely to have any effect (positive or negative) on DWR's budgeted resources is unanswerable at this time. Much depends on the reaction of state officials to the post-ILP survey work.

- Changes in equipment. For the most part, an ILP approach is immune from the sorts of "people vs. machine" controversies that accompany many high technology applications. Outside of extra stereoscopes and acetate overlays, ILP uses very little equipment or material not already used by DWR in their own surveys. ILP in its present form requires only a small amount of computer time for its sample design and statistical package, although the approach could be adapted to automatic analysis procedures. The greatest equipment difference between the two survey systems is one of format: DWR relies almost exclusively on 35mm low altitude photography while ILP uses color prints. Concern that an ILP-style system would force DWR to "use or lose" their 35mm equipment seems unfounded.

- Changes in information. ILP's product -- irrigated acreage estimates over large areas -- differs in scope and detail from its DWR counterpart. Should an ILP successor be integrated into DWR's land use survey program, it is conceivable that the new information mix would differ from the existing configuration. How this might affect DWR operations and the interests of outside users is problematic. Presumably DWR would not implement an ILP approach if the result did not yield some information improvement.

- Changes in jurisdiction. A related issue concerns the possibility that new information combinations might alter existing jurisdictions over information sources. Land use information of various types is common to many government agencies, and changes initiated by one agency sometimes affect the others. Efforts to consolidate the information-gathering activities of state agencies undergo periodic revival[7], and it is possible that an ILP-style system, because of its synoptic data base, could either influence or be influenced by such developments.

- Changes in skills. One of the successes of ILP has been a demonstration of ease with which interpretative skills may be transferred to DWR employees. The project involved some 70 hours of training and interpretation designed to acquaint DWR land use survey specialists with the ILP methodology. Presumably, the familiarity of these employees with aerial photographs and the resources in their respective areas greatly simplified the skills transfer task. Longer training sessions probably would be required for persons with less of a "head start".

The second assessment-related question is really the bottom line in all technology transfer programs: Where will technology X be of greatest value to user Y? It is one thing deciding whether ILP represents a "better mousetrap". It is quite another thing deciding whether there are enough mice to justify the trap. There is also the possibility that the contraption should be entirely redesigned for some other kind of pest.

Recent DWR activities give clues to their interest in "pest control" matters. The current drought in California, underway since 1975, has served to increase the value of information on irrigated agriculture. Last year, DWR undertook one of the largest land use surveys they have conducted in years -- the entire Sacramento Valley. This year, it is likely DWR will perform a similar survey covering the San Joaquin Valley. Much of this

[7] For example, see Legislative Analyst, State of California, "Water Resources Planning and Agricultural Water Needs," January, 1973.

accelerated survey activity is a reaction to changing (and drought-related) information needs. DWR is particularly interested in determining how a record dry year affects their hydrological models. Also, they hope to observe how cropping patterns change given the prospect of reduced water deliveries. Common to both interests is the desire to survey large areas during the same growing season.

Perhaps DWR's desire for frequent and extensive land use information will subside when more "normal" water years return. But if it achieved little else, ILP has provided state agency employees first-hand experience with an alternative procedure for accomplishing some of their land use surveying responsibilities. The fact that the procedure uses spaceage remote sensing technology is not so important as its ability to help real users solve their information collection problems.

Several ILP follow-on projects -- one in progress, others in planning stages -- demonstrate that ILP will be more than a one-shot research project. Outside its cost, accuracy, and timeliness performance characteristics, ILP's versatility and fundamental simplicity appear to be its strongest attributes. Crop identification abilities can be incorporated into the ILP approach with relative ease. Similarly, automatic analysis procedures can be introduced into the procedure if the scope and diversity of the sample area is suitable. Both of these variations will receive greater attention in the post-ILP projects. Yet while experimentation with refinements ultimately should help the ILP approach better match DWR's needs, it is certain little progress could be made without the continued support and understanding of DWR personnel. And here, as usual, the keys are understandability and responsiveness to user needs. Without these qualities firmly built into their core, few "mousetraps", no matter how elaborate, can expect to succeed at state and local user levels.

7.0 Summary of the Research Project

Irrigated Lands Project had three main goals that guided the design and implementation of the research: (1) to develop an operationally feasible process whereby satellite imagery of the type obtained from Landsat can be used to provide irrigated land acreage statistics on a regional basis; (2) to develop a technique that would enable DWR to perform this inventory for the entire state of California in a one year period and have the data available for publication within six months following the end of the calendar year of the inventory; and (3) to achieve a level of accuracy for the test area and the state to within $\pm$ 3% at the 99% level of confidence. These goals were addressed by the design and implementation of a multiphase sampling scheme that was founded on the utilization of a Landsat-based remote sensing system. The synoptic coverage of Landsat and the eighteen day orbit cycle allowed the project to study agricultural test sites in a variety of environmental regions and monitor the development of crops throughout the major growing season. The capability to utilize multidate imagery is crucial to the reliable estimation of irrigated acreage in California where multiple cropping is widespread and current estimation systems must rely on single date survey techniques. In addition, the magnitude of agricultural acreage in California (DWR estimates it to be 12 million acres) makes estimation by conventional methods impossible. The project demonstrated that reliable estimates of irrigated acreage could be made using a Landsat-based remote sensing system and the multiphase sampling design. Since DWR is accustomed both to flying their own large scale aerial photography and collecting ground data, the implementation of these two phases in their operational survey system should be relatively easy. Furthermore, DWR personnel actively participated in the interpretation and tabulation phases and are cognizant of the techniques required for this part of the estimation.

In terms of costs and accuracies, this initial ILP system produced results in approximately the same range as the operational DWR system. Although an actual demonstration of the timeliness of the ILP system has yet to be preformed it appears that the Landsat based system promises an improvement over existing surveys. Based on the results of the study, it is possible to offer some recommendations that could improve the performance of the ILP approach.

One major recommendation is that of applying a detailed stratification for more optimum allocation of sample units. This stratification would be based on cropping practices/environmental conditions as they affect both irrigation procedures and interpretation techniques. Minor revisions such as reorienting the direction of the Phase II sample units to north-south are also suggested. This reorientation does not affect the sampling design and importantly does integrate into DWR's standard county survey techniques.

The success of the project has depended greatly on the continuing growth of interest and participation by the California Department of Water Resources. This strengthening cooperative interaction has led to follow-on project work in which we (DWR and the University of California) will implement the recommendations derived from this research on a larger regional demonstration and expand the research to include computer assisted analysis techniques and crop identification procedures.

Appendix A. Matched phases used in MPHASE to compute the estimate of irrigated acreage. The numbers shown are the proportion of each sample unit interpreted as irrigated at each phase.

County	Sample Unit	Phase I (Landsat)	Phase II (Large scale aerial photography)	Phase III (Ground Data)
Fresno	FR03	.91	.91	.94
	FR05	.84	.83	.83
	FR14	.90	.92	.93
	FR01	.97	.98	
	FR02	1.00	1.00	
	FR04	.88	1.00	
	FR06	.72	.71	
	FR07	.68	.70	
	FR08	1.00	1.00	
	FR09	.65	.70	
	FR10	.90	1.00	
	FR11	.81	.79	
	FR12	.81	.96	
	FR13	.95	.94	
	FR15	.94	1.00	
	FR16	1.00	.99	
	FR17	.85	.88	
	FR18	.92	.88	
	FR19	.66	.99	
	FR20	.73	.78	
	FR21	.67	.54	
	FR22	.85	.66	
	FR23	.93	.76	
	FR24	.96	.95	
	FR25	.95	.94	
Madera	MA03	.48	.69	.56
	MA01	.90	.92	
	MA02	.51	.51	
	MA04	.79	.67	
	MA05	.78	.90	
	MA06	.35	.43	
	MA07	.76	.76	
Merced	ME06	.91	.87	.88
	ME07	.68	.89	.86
	ME01	.77	.75	
	ME02	.82	.73	
	ME03	.44	.41	
	ME04	.86	.79	
	ME05	.87	.86	
	ME08	.68	.79	
	ME09	.63	.76	

Appendix A. Continued

County	Sample Unit	Phase I (Landsat)	Phase II (Large scale aerial photography)	Phase III (Ground Data)
Monterey	MO02	.81	.88	.86
	MO03	.82	.77	.82
	MO01	.81	.79	
	MO04	.67	.73	
	MO05	.62	.64	
	MO06	.10	.08	
	MO07	.82	.83	
Plumas	PL01*	.27	.30	.27
	PL02	.06	.05	.05
Sacramento	SA01	.51	.51	.54
	SA02	.34	.50	
	SA03	.02	.06	
	SA04	.45	.42	
	SA05	.75	.77	
	SA06	.37	.36	
	SA07	.58	.50	
San Joaquin	SJ08	.51	.53	.56
	SJ01	.97	.83	
	SJ02	.64	.67	
	SJ03	.43	.43	
	SJ04	.30	.30	
	SJ05	.82	.78	
	SJ06	.94	.95	
	SJ07	.13	.14	
	SJ09	.73	.65	
	SJ10	.83	.77	
	SJ11	.95	.94	
	SJ12	.87	.83	
	SJ13	.81	.88	
	SJ14	.46	.47	
Stanislaus	ST03	.96	.97	.98
	ST06	.58	.66	.57
	ST01	.96	.92	
	ST02	.83	.88	
	ST04	.92	.89	
	ST05	.94	.88	
	ST07	.34	.34	
	ST08	.56	.59	
	ST09	.40	.41	

*Plumas matching phases were also used for Sierra County

Appendix A. Continued

County	Sample Unit	Phase I (Landsat)	Phase II (Large scale aerial photography)	Phase III (Ground Data)
Sutter	SU07	1.00	.79	.98
	SU08	.73	.68	.72
	SU01	.50	.59	
	SU02	.73	.52	
	SU03	.57	.51	
	SU04	.42	.40	
	SU05	.75	.80	
	SU06	.98	.92	