MONITORING IRRIGATED LAND ACREAGE USING LANDSAT IMAGERY: AN APPLICATION EXAMPLE

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MONITORING IRRIGATED LAND ACREAGE USING LANDSAT IMAGERY: AN APPLICATION EXAMPLE

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ABSTRACT

A demonstration of the utility of Landsat imagery for quickly and cheaply estimating irrigated land area was conducted in the Klamath River basin of Oregon. Landsat color composite images, at 1:250,000 scale and acquired on two dates during the 1975 growing season, were interpreted. Irrigated lands were delineated manually, and the irrigated area was estimated, based on dot-grid sampling of the manually delineated lands. The image interpretation estimate of irrigated area was then adjusted by a comparison of interpretation results with ground data on 45 sample plots, each 1 mi^2 (2.6 km^2) in size.

Two interpreters independently estimated the irrigated area. Their adjusted estimates were 285,000 acres (115,000 ha) and 267,000 acres (108,000 ha) respectively, with corresponding 95 percent confidence intervals of ±19,500 acres (7,880 ha) and ±34,700 acres (14,000 ha). The estimated cost of the survey, exclusive of management costs and training, was $1,500.

INTRODUCTION

Due to an agreement between the States of Oregon and California regarding the allocation of the water of the Klamath River[1/], the Oregon Water Resources Department (OWRD) must periodically estimate the area of irrigated land in the Klamath River basin of Oregon (figure 1) to ascertain how closely the State is approaching the limit

[1/] Klamath River Basin Compact, between the States of Oregon and California. Effective September 11, 1957. Chapter 142, Oregon State Laws, 1957; Chapter 113, California Statutes, 1957.

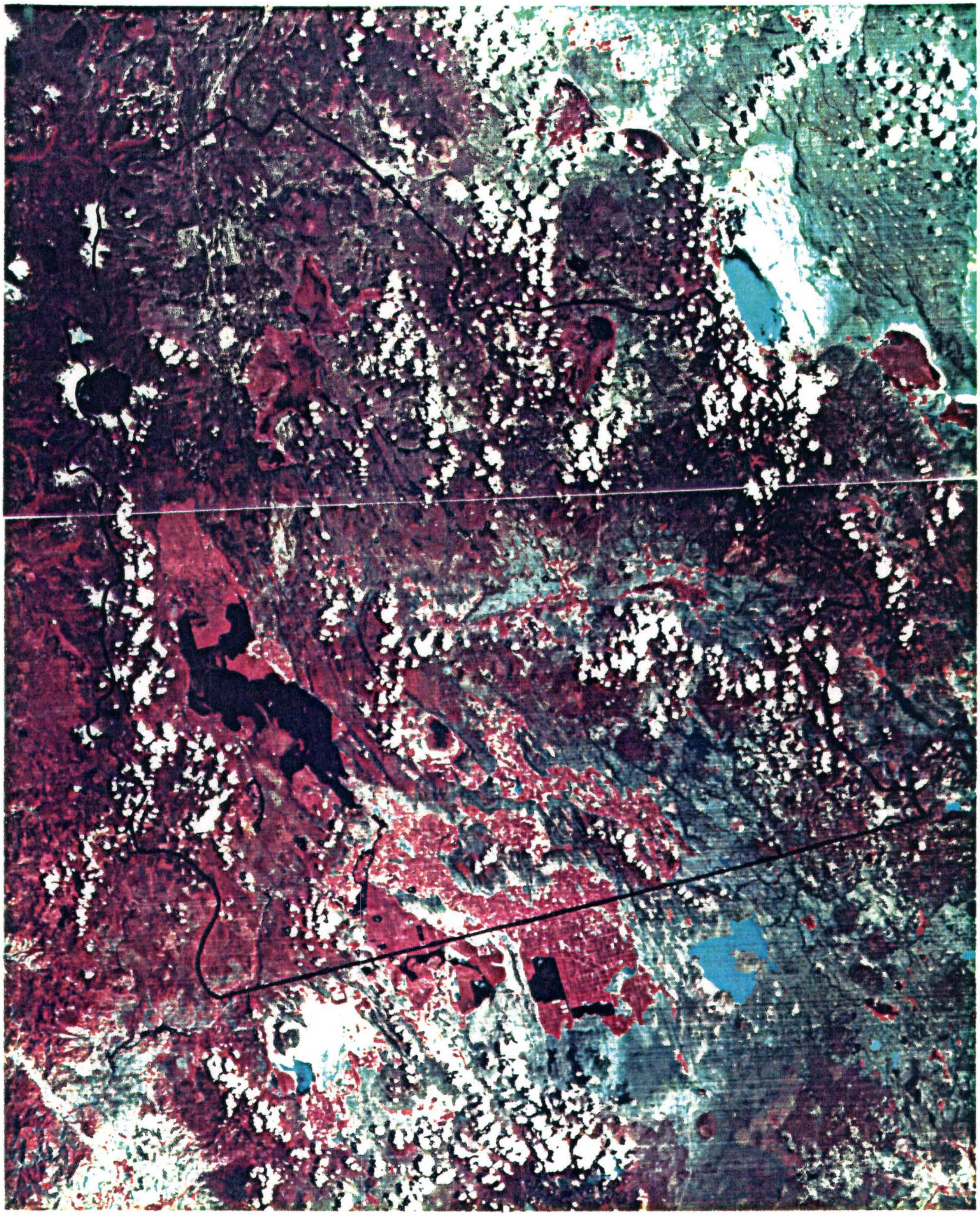

Figure 1.--The Klamath River basin in Oregon is outlined on this mosaic of two Landsat color composite images, scale approximately 1:1,000,000. Crater Lake is near the upper left edge of the watershed, and Klamath Lake at the left center. The Oregon-California state line forms the boundary at the southern edge of the basin.

stipulated in that agreement. When the irrigated area approaches the limit, a very detailed survey will be needed; at that time the State will impose appropriate controls on the increase of irrigation in the basin. Prior to the advent of repetitive Earth observations from space, no quick and inexpensive method was known for making rough annual estimates of irrigated land in areas as large as the Klamath River drainage (approximately 5,700 mi^2 or 14,800 km^2).

In response to this need, the EROS Data Center (EDC), and the OWRD, carried out a project to demonstrate the feasibility of estimating irrigated land area using Landsat images. This work was performed as a part of the Pacific Northwest Regional Commission Land Resources Inventory Demonstration Project.

The objectives of the project were to demonstrate the methodology, to determine the time and costs required to make an estimate of total irrigated acres in the Oregon portion of the Klamath River drainage, and to ascertain the accuracy that could be achieved. The techniques used were those which could be reasonably undertaken by the OWRD at the present time, and which could be repeated at 1- or 2-year intervals. Thus, the project was designed to demonstrate the application of existing techniques to a resource management problem, rather than to develop new techniques.

METHODOLOGY

Problem Definition

It was first necessary to define accurately the type of information required by the OWRD. This was accomplished through a number of meetings of EDC, NASA, and OWRD representatives. It was concluded that at the present time a rough estimate of the total acreage of irrigated land in the Klamath River drainage, repeated every 1 to 5 years, would suffice. Accurate mapping of the lands is not necessary. It was agreed that a method using manual interpretation techniques would be best, in that it would more likely be adopted on an operational basis (providing it was judged to be sufficiently cheap and accurate) by the OWRD. The objectives of the project did not include an exhaustive testing and comparison of all possible methods, but rather a demonstration of the method that was deemed most likely to prove successful.

The chosen method consisted of an interpretation of 1:250,000-scale Landsat color composite images, with the area estimation based on dot-grid sampling of manually delineated agricultural lands. The area estimate was then adjusted through a comparison of interpretation results with ground data on selected sample plots, using a ratio estimation procedure.

Imagery Selection

Landsat imagery used in the interpretation consisted of four 1:250,000-scale color composite prints acquired during the 1975 growing season. It was felt, based on OWRD knowledge of the cropping practices and crop condition change through the growing season, that both a mid-summer and late-summer image would be necessary to discriminate definitively between irrigated and dry-farmed land. A search of all 1975 images led to the selection of those acquired on July 21 and September 4. On each date, portions of two Landsat scenes were needed to cover the entire study area, thus requiring a total of four images. In July all irrigated fields are red on the color composite, but a few nonirrigated fields are also still red. By September, all of the dry-farmed fields are dry, and hence tan in color on the image, while the vast majority of the irrigated fields are still red. Thus, by comparing the two dates of imagery, the interpreter could identify irrigated fields more accurately than with any one single date of imagery (figures 2 and 3).

On July 31, 1975, the NASA U-2 aircraft acquired color infrared photographs at a scale of approximately 1:120,000 of the Klamath River basin. These photographs were used by the field crew as aids in locating plots and plotting the area of irrigated lands within the sample plots (figure 4). The aircraft photos were not used for the overall interpretation because they could not be expected to be available on a repetitive annual basis as are Landsat images. Furthermore, it was assumed that for most areas to which this estimation approach might be applied, some kind of air photo coverage would be available (U-2 photos are not specifically required).

Sample Plot Selection

Prior to the interpretation of irrigated lands, all agricultural land within the Klamath River basin was delineated on overlays of the Landsat images. This was performed by OWRD personnel familiar with the region. An effort was made to ensure that all irrigated or potentially irrigated land was included within the delineated area. The agricultural land thus delineated was then assigned to one of eight strata representing various types of agricultural land in the region. The description of the strata and assignment of land into strata were based on experience and knowledge of OWRD personnel. The strata were as follows:

Figure 2.--A Landsat color composite image, taken June 21, 1975, scale approximately 1:250,000, of a portion of the study area. Agricultural areas have been delineated and sample plots outlined. Plain numbers refer to stratum numbers, and circled numbers identify adjacent sample plots.

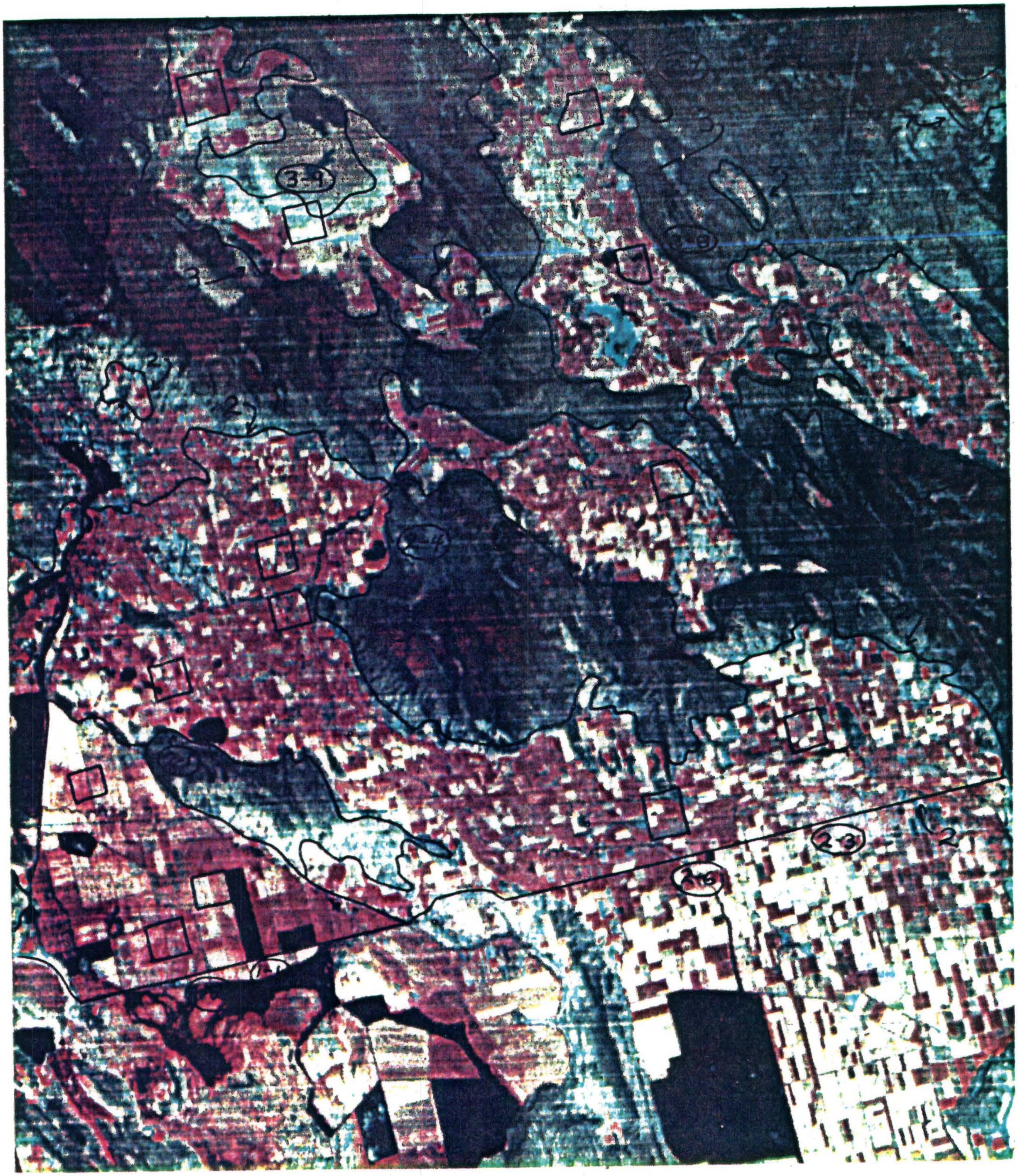

Figure 3.--A Landsat color composite, acquired on September 4, 1975, of the same area as shown in figure 2.

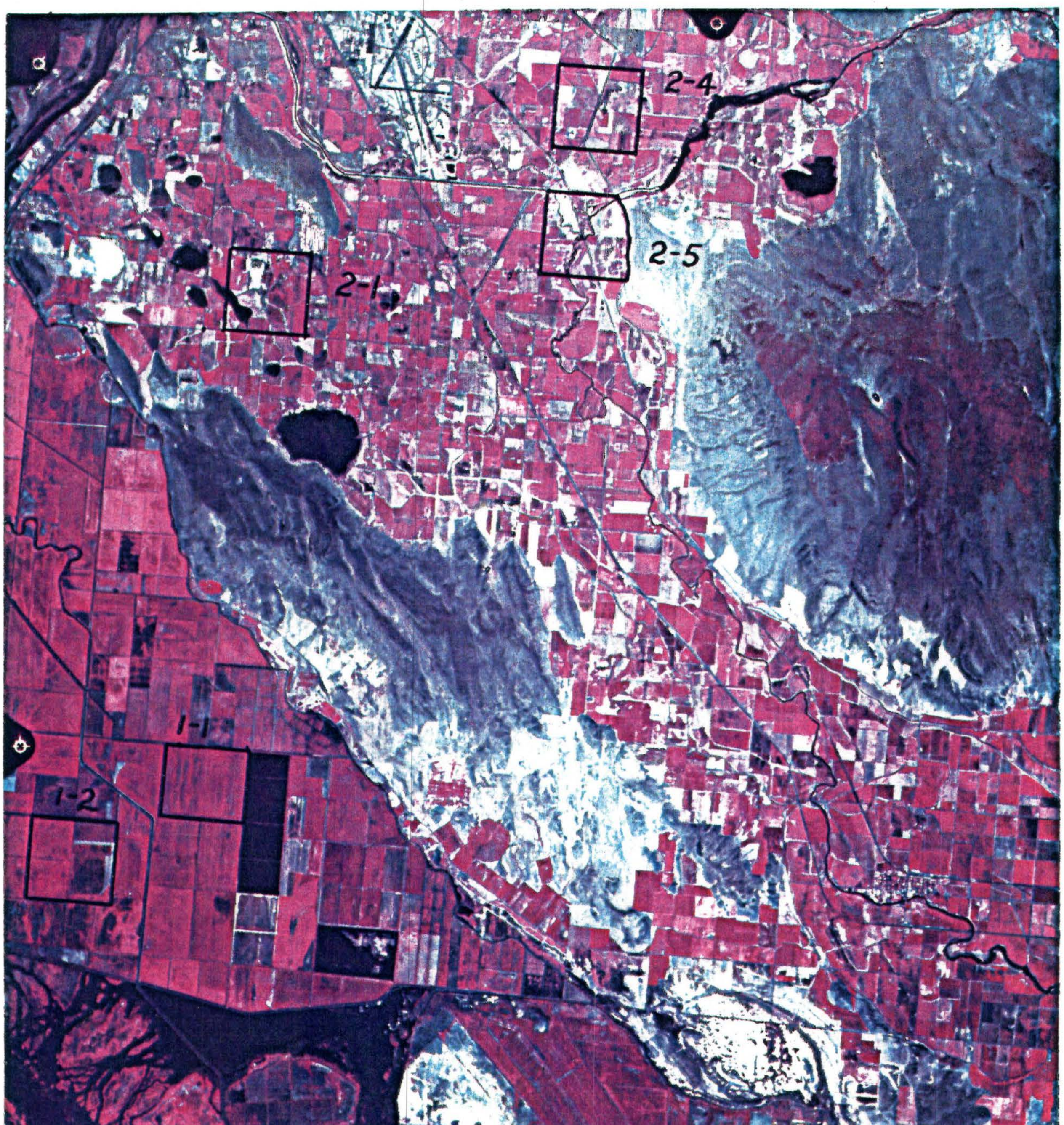

Figure 4.--A U-2 color infrared photograph, scale 1:120,000, taken on July 31, 1975. Several sample plots are outlined. The area shown here corresponds to that illustrated on the left side of figures 2 and 3.

Stratum	Description	Average field size
1	low elevation, diverse, poorly drained	40 acre (16 ha)
2	low elevation, diverse, generally well drained	40 acre (16 ha)
3	medium elevation, hay and pasture, well drained	40 acre (16 ha)
4	marshland, use on marsh edges	irregular
5	medium elevation, pasture, poorly drained	640 acre (260 ha)
6	reclaimed swamp or marsh	100 acre (40 ha)
7	high elevation, meadow, and hayland	irregular
8	confined basin, agriculture on areas from which lake has receded	irregular

Sample plots were assigned to strata on the basis of a subjective evaluation of the relative size and diversity of the strata, whereby the largest and/or more diverse strata received the most plots, acknowledging the fact that there may be a bias in the estimates due to disproportionality. The total number of plots was based primarily on an estimate of the number that could be reached by a ground crew during the time allotted for field work on the project.

Stratum	No. sample plots	Approximate total area of stratum
1	3	56 mi^2 (145 km^2)
2	6	224 mi^2 (580 km^2)
3	9	304 mi^2 (787 km^2)
4	7	216 mi^2 (559 km^2)
5	4	80 mi^2 (207 km^2)
6	4	72 mi^2 (186 km^2)
7	10	104 mi^2 (269 km^2)
8	2	16 mi^2 (42 km^2)
Total	45	

Each sample plot was randomly selected. This was accomplished by superimposing a rectangular grid over a stratum overlay and selecting grid intersection points using random number tables until the required number in each stratum was obtained. These points were numbered by stratum and transferred to both the Landst imagery overlays and the U-2 colored infrared photos. On the aerial photos, a plot approximately 1 mi^2 (2.6 km^2) in size was constructed around each point. The boundaries of each plot were then transferred to the Landsat strata overlay using an optical transfer device.

Ground Data Collection

Each sampling plot was visited in the field by OWRD personnel during the summer of 1975. A map was prepared by the field crew delineating growing season. Using these maps and the aerial photos, the ground crew estimated the percentage of the area of each plot that was irrigiated. These data are tabulated in table 1.

Image Interpretation

The interpretation of the Landsat images was performed by two interpreters, independent of each other. One of the interpreters (interpreter A) was quite familiar with the study area, and had collected most of the ground data, while the other (interpreter B), was unfamiliar with the area. The intention was not to statistically compare the performances of the two interpreters, but only to obtain some indication of the effects of familiarity on interpretation accuracy.

The estimation of irrigated land on the Landsat imagery was done stratum by stratum. A random dot grid was laid over the July Landsat color composite images and the strata sample plot overlay. Each dot represented approximately 25.6 acres (10.3 ha).[2/] The interpreter counted the dots that appeared to fall on the irrigated land, and accumulated his count by strata. Although the bulk of the interpretation was done on the July images, the interpreters referred to the September images to aid their interpretation. Only that area within the initial agricultural land delineations was interpreted, and only dots falling on presumed irrigated land were tallied.

In addition to the overall stratum tally, a separate record was kept of interpretation results for each sample plot. Both the total number of dots in each plot and dots on irrigated land within the plots were tallied, and percent irrigated land was calculated for each plot. The results of the sample plot interpretation are shown in table 1.

One stratum in which the interpreters encountered some difficulty was in stratum 4, the marshland areas. In some cases it was difficult to differentiate between lush irrigated fields and the naturally subirrigated marshland areas. Although in this instance the interpreters did correctly identify irrigated land (see table 1), they both felt that this was probably due to their prior knowledge of the area, and not due strictly to a reliance on image parameters.

[2/] Actually, the scale on the Landsat prints varied somewhat from image to image and from place to place on the same image. However, the average scale of the images was approximately ¼ inch=1 mile which corresponded to a dot equivalent to 25.6 acres.

Table 1

SAMPLE PLOT IRRIGATED AREA (IN PERCENT)

AND STRATUM AVERAGE VALUES

Sample Plot	Ground Estimate	Landsat Estimate Interpreter A	Landsat Estimate Interpreter B
1-1	100	100	95
1-2	97	100	92
1-3	96	100	95
Stratum 1 average	98	100	94
2-1	73	83	79
2-2	84	85	71
2-3	92	96	86
2-4	85	88	92
2-5	69	80	60
2-6	80	87	82
Stratum 2 average	81	87	78
3-1	72	95	79
3-2	53	71	57
3-3	0	0	0
3-4	32	33	7
3-5	98	81	85
3-6	75	69	73
3-7	90	100	94
3-8	29	40	35
3-9	49	46	44
Stratum 3 average	55	59	53
4-1	0	0	0
4-2	0	0	0
4-3	0	0	0
4-4	0	0	0
4-5	0	0	0
4-6	0	0	0
4-7	100	100	100
Stratum 4 average	14	14	14
5-1	71	79	84
5-2	99	100	84
5-3	75	94	76
5-4	63	71	63
Stratum 5 average	77	86	77

Table 1.--Continued

Sample Plot	Ground Estimate	Landsat Estimate Interpreter A	Landsat Estimate Interpreter B
6-1	99	100	100
6-2	99	91	84
6-3	69	62	50
6-4	48	100	92
Stratum 6 average	79	88	82
7-1	54	56	43
7-2	40	64	50
7-3	0	0	0
7-4	0	0	0
7-5	39	67	56
7-6	18	19	12
7-7	39	70	56
7-8	39	48	33
7-9	0	0	0
7-10	7	33	22
Stratum 7 average	24	36	27
8-1	5	7	11
8-2	21	29	38
Stratum 8 average	13	18	24

Thus, in the future it might be better to survey marshlands separately, using satellite photos together with intensive ground checks.

Statistical Compilation

Following the computation of ground estimates and interpretation estimates of irrigated area for each sample plot and interpretation estimates for each stratum, an adjusted acreage estimate for each stratum was computed, and the sampling error of that estimate was calculated (Appendix).

The original interpretation results were adjusted by means of a ratio estimation procedure. For each stratum, the ratio of the average ground estimate of percent irrigation on the sample plots to the average interpretation estimate of percent irrigated land on the plots was calculated. The original dot count for the entire stratum when multiplied by this adjustment ratio, equals the adjusted dot count for the stratum. The interpretation estimate is thus corrected, based on the ratio of ground estimate to interpretation estimate for the sample plots. The corrected dot count for each stratum was then converted to acreage by multiplying by 25.6 acres (10.3 ha) per dot. The basin total is a sum of the stratum totals. The interpretation dot counts, as well as the corrected counts and acreage figures are given in table 2.

As shown in table 2, the final adjusted acreage estimates of irrigated land in the study area were 285,000 acres (115,000 ha) and 267,000 acres (108,000 ha) by interpreters A and B respectively.

The sampling error of the estimate was calculated for each stratum independently. These were then combined to obtain the sampling error and confidence limits for the entire area. The methodology is explained in Appendix A. Results of the computations are shown in tables A-1, A-2, and A-3 (see Appendix).

DISCUSSION OF RESULTS

The estimates made by the two interpreters of the irrigated acreage in the Klamath River basin differ by 18,000 acres (7,300 ha), or approximately 6 percent. Considering the rather inexact techniques used, this agreement is quite encouraging. As shown in table 2, the only stratum in which their adjusted acreage estimates differed greatly was stratum 7. This was to be expected, however, as that stratum presented by far the greatest interpretation problems due to small and irregular fields and the presence of subirrigated areas (fields which remained green through the growing season due to available natural ground water).

In general, Interpreter A tended to overestimate irrigated acreage on the sample plots, and hence his adjustment ratios were less than 1.0, whereas the opposite was true for Interpreter B.

Table 2

INTERPRETATION RESULTS AND ADJUSTED IRRIGATED

LAND ESTIMATES, BY STRATUM

	Interpreter A				Interpreter B			
Stratum	Raw dot count	Adjustment ratio	Adjusted dot count	Adjusted acreage	Raw dot count	Adjustment ratio	Adjusted dot count	Adjusted acreage
1	941	.98	920	24,000	971	1.04	1,010	25,900
2	3,469	.93	3,200	82,000	3,008	1.04	3,130	80,100
3	3,103	.93	2,900	74,000	2,513	1.04	2,610	66,800
4	1,032	1.00	1,000	26,000	987	1.00	987	25,300
5	1,626	.90	1,500	38,000	1,424	1.00	1,420	36,400
6	1,365	.90	1,200	31,000	1,167	.96	1,100	28,000
7	581	.66	380	9,700	196	.89	170	4,400
8	18	.72	13	330	24	.54	13	330
Total	12,135		11,013	285,030	10,290		10,440	267,230

Thus, there was considerable difference between their overall counts before adjustment, but the difference was reduced by the adjustment process. Nevertheless, the correction ratios for all the major strata were between .90 and 1.04, indicating a reasonably accurate interpretation of the sample plots by both interpreters.

The overall estimates, however, are of little use in evaluating the precision of the estimation process. This can only be done through an evaluation of the agreement between interpretation and ground data estimates on the sample plots as expressed by the sampling error and confidence limits which are described and tabulated in Appendix A.

As shown in table A-1 the stratum sampling errors for Interpreter A are considerably lower, in general, than those of Interpreter B (low sampling errors are desirable). The individual stratum sampling errors are combined to give overall estimate sampling errors as shown in table A-2. Note that here again Interpreter A had a much lower sampling error (3.8 percent) than did Interpreter B (7.2 percent), although both can be considered good for interpretation methods used. That Interpreter A was familiar with the test area, and had collected ground data on the sample plots, probably explains his superior performance.

The 95 percent confidence limits are tabulated in table A-3. As confidence limits are a direct function of the standard error ($S\bar{y}_T$) as is sampling error, here again Interpreter A had a better performance than Interpreter B. The 95 percent confidence limits can be interpreted as: unless a chance occurrence with a probability of 5 percent had occurred, the interval specified contains the true value. Thus there is a high probability (95 percent) that, based on the work of Interpreter A, the actual irrigated land acreage is between 265,000 acres (107,000 ha) and 305,000 acres (123,000 ha).

Upon completion of the survey, the results were submitted to OWRD for evaluation. Their statement regarding the survey is "The PI (photo interpretation) of irrigated lands in the Klamath Basin provided a quick, economical method of estimating total irrigated lands. We recognize that the method is perhaps the least refined of the methods available at current technological levels. We also believe that the PI is adequate for the purpose for which it was intended, namely to give a gross estimation of the total irrigated area. The stratification of irrigated areas into eight classifications served to identify some PI problems, especially the marsh land strata. While a statistical level of accuracy can be computed, the actual accuracy as measured against a measured standard is not yet available. The standard will be available upon completion of the upcoming Klamath Basin adjudication survey. In summary, we believe the PI, as demonstrated is a useful, economical and quick method of accomplishing a reasonable estimate of the number of acres irrigated in the

Klamath Basin in 1975. We also believe that a repetition of this procedure would serve to monitor the irrigated development in the basin."

The costs of conducting the survey as estimated by OWRD, exclusive of management and training were:

Ground data collection	
Salary of field personnel, 65 hours	$ 365
Mileage, 1,206 miles at 14¢/mile	169
Miscellaneous expense	17
Photo interpretation	
Salaries of two interpreters, 84 hours	471
Imagery costs	
Four Landsat color prints, scale 1:250,000 at $40	160
Twenty color aerial photos, scale 1:120,000 at $12	240
	$1,422

In addition, an estimate was made by OWRD as to the costs of inventorying irrigated acreage with 95 percent accuracy using conventional methods. These were:

Low-altitude aerial photos, 300 at $4.00 (used for plotting ground data)	$ 1,200
Salaries - 2-man crew - ground data	3,747
Per diem - 2-man crew - ground data	5,416
Mileage - 2-man crew - ground data	1,170
Draftsman - making map and computing acreage	8,540
	$20,073

The results reported here are encouraging in that the sample errors are quite low given the relatively unsophisticated interpretation methods used. Certainly the results could be improved, but only by expending considerably more time and money. Thus, it is reasonable to speculate whether a small improvement in accuracy would be worth the additional expenditure. The results should, however, be evaluated with some reservation. There is no way to ascertain exactly how correct the interpretation estimates are, short of ground data collection for the entire area. We can, however, make a probability statement in the form of the calculated confidence limits.

A selected methodology has been demonstrated which yields an acreage estimate and a statement about the expected reliability of that estimate. It is a simple and inexpensive methodology requiring no sophisticated equipment except that needed to produce the Landsat imagery. The size and number of sample plots and their number were selected somewhat arbitrarily, and changes might yield significantly different results. Nevertheless, given the costs and accuracies discussed here, there does exist a basis for evaluating the demonstrated method on its own merits.

APPENDIX

Computation of Sampling Error and Confidence Limits: Detailed Description

I. Individual stratum computations

n_j = number of sample plots in j^{th} stratum

N_j = total possible number of sample plots in j^{th} stratum

x_{ij} = interpretation estimate (in percent) of i^{th} plot in j^{th} stratum

y_{ij} = ground estimate (in percent) of i^{th} plot in j^{th} stratum

$\hat{R}_j$ = adjustment ratio for j^{th} stratum

$S\bar{y}_j$ = estimated standard deviation of the mean for j^{th} stratum

$\hat{A}_j$ = estimated mean percent irrigated land (per 640 acre sampling plot) in j^{th} stratum

SE_j = sampling error of the mean for j^{th} stratum

$$SE_j = \frac{S\bar{y}_j}{\hat{A}_j} \times 100 \quad \text{where}$$

$$\hat{A}_j = \frac{\text{irrigated land interpretation estimate (unadjusted) in } j^{th} \text{ stratum}}{\text{total land area in } j^{th} \text{ stratum}} \times 100, \text{ and}$$

$$Sy_j = \sqrt{\frac{S^2y_j + \hat{R}_j\, S^2x_j - 2\hat{R}_j\, Sx_jy_j}{n_j}\left(1 - \frac{n_j}{N_j}\right)} \quad \text{where:}$$

$$S^2y_j = \frac{\sum_{i=1}^{n_j} y_{ij}^2 - \frac{\left(\sum_{i=1}^{n_j} y_{ij}\right)^2}{n_j}}{n_j - 1}, \qquad S^2x_j = \frac{\sum_{i=1}^{n_j} x_{ij}^2 - \left(\sum_{i=1}^{n_j} x_{ij}\right)^2}{n_j - 1}$$

, and

$$Sx_jy_j = \frac{\sum_{i=1}^{n_j} x_{ij}y_{ij} - \frac{\left(\sum_{i=1}^{n_j} x_{ij}\right)\left(\sum_{i=1}^{n_j} y_{ij}\right)}{n_j}}{n_j-1}$$

The values used in the calculations and results for this investigation are shown in table A-1.

Table A-1

SAMPLING ERRORS OF THE MEAN, BY STRATUM,

AND DATA REQUIRED FOR COMPUTATION

Interpreter A

Stratum	n_j	N_j	$\hat{R}_j$	$S\bar{y}_j$ (%)	$\hat{\bar{A}}_j$ (%)	SE_j (%)
1	3	56	.98	1.16	65.8	1.76
2	6	224	.93	3.04	57.6	5.28
3	9	304	.93	4.00	37.9	10.6
4	7	216	1.00	0	19.1	0
5	4	80	.90	3.80	73.2	5.2
6	4	72	.90	7.98	68.2	11.7
7	10	104	.66	2.70	14.7	18.4
8	2	10	.72	.075	3.25	2.3
Total	45	1066				
Total excluding Stratum 4	38	850				

Interpreter B

Stratum	n_j	N_j	$\hat{R}_j$	$S\bar{y}_j$ (%)	$\hat{\bar{A}}_j$ (%)	SE_j (%)
1	3	56	1.04	1.11	72.1	1.5
2	6	224	1.04	3.57	55.9	6.4
3	9	304	1.04	7.62	34.3	22.2
4	7	216	1.00	0	18.3	0
5	4	80	1.00	5.60	71.2	7.9
6	4	72	.96	13.77	62.2	22.0
7	10	104	.89	3.99	6.7	59.6
8	2	16	.54	3.47	3.3	105.2
Total	45	1066				
Total excluding Stratum 4	38	850				

II. Total area computations

Due to the fact that all sample plots in stratum 4 were devoid of irrigated land except one, which was 100 percent irrigated, and that in each case the plots in stratum 4 were perfectly interpreted by both interpreters, the data for that stratum do not lend themselves to a meaningful computation of sampling error (it is, in effect, zero). Thus all computations for the entire watershed shown below exclude stratum 4 data.

N_T = total possible number of sample plots in test area (see table A-1)

$S\bar{y}_T$ = estimated total area standard deviation of the mean (from weighted stratum variances)

$\hat{A}_T$ = estimated mean percent irrigated land (per 640 acre sample unit) in test area

SE_T = sampling error of the mean for entire test area

$$SE_T = \frac{S\bar{y}_T}{\hat{A}_T} \times 100 \quad \text{where:}$$

$$\bar{A}_T = \frac{\text{irrigated land interpretation estimate (unadjusted) for entire test area}}{\text{total land area in entire test area}} \times 100, \text{ and}$$

$$S\bar{y}_T = \sqrt{\frac{1}{N_T^2} \sum_j \left[\frac{N_j^2 \, S^2\hat{y}_j}{n_j} \left(1 - \frac{n_j}{N_j}\right)\right]} \text{, where}$$

$$S^2\hat{y}_j = S^2y_j + \hat{R}_j^2 \, S^2x_j - 2\hat{R}_j \, Sx_jy_j$$

Variance and sampling error values obtained in this investigation are shown in table A-2.

Table A-2

STANDARD DEVIATION OF THE MEAN AND SAMPLING ERROR OF THE MEAN FOR ENTIRE SURVEY AREA

	Interpreter A	Interpreter B
$S\bar{y}_T$ (in %)	1.82	3.17
$\hat{\bar{A}}_T$ (in %)	47.3	44.3
SE_T (in %)	3.8	7.2

Confidence limits were obtained by converting the percent irrigated land values to acreage assuming 640 acres per sample plot and a total of 856 possible sample plots in the entire area (excluding stratum 4). Hence:

$$\hat{\bar{A}}_T \text{ (in acres)} = \hat{\bar{A}}_T \text{ (in \%)} \times 856 \text{ plots} \times 640 \text{ acres/plot}$$

and

$$S\bar{y}_T \text{ (in acres)} = S\bar{y}_T \text{ (in \%)} \times 856 \text{ plots} \times 640 \text{ acres/plot}$$

The results of the confidence limit computations for this investigation are shown in table A-3.

$$95\% \text{ confidence limits} = \hat{\bar{A}}_T \pm 1.96\ S\bar{y}_T$$

Table A-3

CONFIDENCE INTERVALS (95% LEVEL)

FOR TOTAL AREA ESTIMATE

	Interpreter A	Interpreter B
$\hat{\bar{A}}_T$ (in acres, excluding stratum 4)	259,000	242,000
$\hat{\bar{A}}_T$ (in acres including stratum 4)	285,000	267,000
$S\bar{y}_T$ (in acres)	9,971	17,367
1.96 $S\bar{y}_T$ (in acres)	19,500	34,700
Upper limit (in acres, including stratum 4)	305,000	302,000
Lower limit (in acres, including stratum 4)	265,000	232,000