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Estimating Irrigated Land Acreage from Landsat Imagery

This study relied entirely on visual photo interpretation of false color composites or color infrared transparencies coupled with a probability sampling design.

INTRODUCTION

DURING THE PEAK of crop growth in irrigated fields, near infrared reflectance of plant growth (0.7 to 1.1 μm) is very high. During this growing period, on Landsat false color composite (FCC) images produced by the EROS Data Center, irrigated croplands show up as geometrically regular shapes in strong reddish hues. Since most irrigated lands occur in arid to semi-arid areas of the world, the contrast between irrigated cropland and surrounding dry land is great; the two land uses are easily separated on Landsat color composite transparencies.

ABSTRACT: *Multistage variable probability sampling using multiscale remote sensing data was used to inventory irrigated cropland within one large test site, 1060 sq. mi (2715 km²), in southwestern Idaho. Landsat color transparencies (scale 1:1,000,000) were interpreted for the presence of irrigated agriculture by estimating the percentage of irrigated lands within two by two square mile (3.2 by 3.2 km) blocks within the test site.*

Four interpreters made independent estimates of the amount of irrigated land on all 270 blocks from which nine were selected with probability proportional to prediction. Sampling errors ranged from 6 to 10 percent and coefficients of determination (r^2) were between 0.81 and 0.99 (three of the four were above 0.93). All four estimates were well within one standard deviation of the known acreage of irrigated land for the test site as measured from 1:120,000 scale color infrared aerial photo transparencies.

For developing countries with limited computer processing facilities and personnel, this approach requires minimal training and equipment to make acceptable estimates of irrigated lands at low cost. The sampling equations are given and methodology explained in the paper.

Landsat imagery was also used to determine the location and magnitude of irrigated cropland expansion by constructing two date (1972 and 1975) color composite images. Newly irrigated cropland was indicated where fields possessed a coloration distinct from ones previously irrigated.

A large part of southern Idaho is considered high desert with native vegetation con-

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sisting of sagebrush species (*Artemisia* spp.) and various rangeland grasses. However, there are presently adequate sources of water for irrigation purposes from the Snake River and the Snake River aquifer. Flood irrigation has been practiced for at least 80 years in some parts of the state. More recently, sprinkler irrigation methods (especially center pivot installations) have been used in developing new fields for agriculture. Because the rate of growth of newly installed irrigation systems is difficult and expensive to assess by ground records and visits, the Idaho Department of Water Resources[1] was interested in trying new techniques to inventory irrigated lands. These data in turn would be used to determine water demand from existing known water sources and permit more realistic planning for future use of available supplies.

While it is recognized that computer assisted classification methods could be used to estimate irrigated lands, this study relies entirely on photo interpretation of FCC or CIR transparencies coupled with a variable probability sampling design. Visual interpretation methods require both less training and less expensive equipment than methods using computer assisted techniques. Also, simpler methods may be more practical for developing countries limited by low budgets, manpower constraints, and inaccessibility of computer technology.

There is some precedence for using photo interpretation techniques on satellite images and photos to inventory irrigated and forested lands. For example, Draeger (1976) described an image interpretation method used for estimating irrigated lands in Oregon. For this test, interpreters placed a dot grid with 400 dots per square inch (6.45 cm^2) over a Landsat FCC print enlarged to a scale of 1:250,000. Sample errors at the 95 percent confidence interval for two interpreters were 7 and 13 percent respectively. Langley *et al.* (1969) described a technique using a multistage probability sampling design to estimate timber volume within a grid composed of four mile square blocks (6.4 km) overlaying an Apollo 9 CIR transparency. In one area, including parts of Mississippi, Louisiana, and Arkansas, the error of estimate was about 13 percent with a ground sample size of one per million in terms of area.

Armed with the knowledge that irrigated lands exhibit a characteristic spectral signature on the color composites, and a sampling design that was applicable to the estimation problem, we selected a pilot test area, 18 by 60 miles (28.8 by 96 km), in southern Idaho to determine how closely we could estimate irrigated lands by visual interpretation methods.

Procedures and Methodology

Description of Study Area

In southwestern Idaho a series of plateaus, separated by the canyons of the Snake River and its tributaries, range in elevation from 2800 to 3200 feet (850 to 970 m) above sea level. Irrigated agriculture has existed within the canyons for some time. On the plateaus, newly irrigated lands have been developed by the use of high lift pumping from the Snake River. The pilot inventory test site (Figure 1) is an 18 by 60 mile (28.8 by 96 km) plain bisected by the Snake River within a canyon averaging 400 feet (130 m) in depth. The climate of the test site is dry during the growing season, with precipitation averaging less than 10 inches (25 cm) annually. Summers are hot and winters are mild.

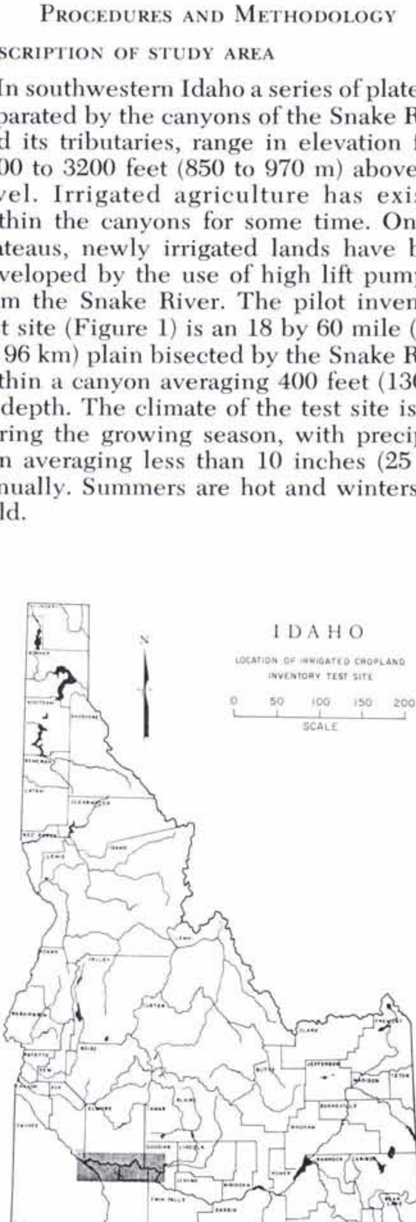

Fig. 1. Shaded area indicates the location of the study site 18 by 60 miles (29.8 by 96 km) along the Snake River in southwestern Idaho.

[1] The study described herein was done cooperatively with and partially funded by the Idaho Department of Water Resources, Boise, Idaho.

INVENTORY DESIGN

Because of constraints imposed by funds, manpower, and time, a sampling design, rather than a complete enumeration, is usually relied on when a land managing agency needs inventory information. This situation faced the Idaho Department of Water Resources.

Many kinds of sampling designs are available for consideration: simple random sampling, stratified random sampling, ratio estimation, cluster sampling, double sampling with regression, systematic sampling, and probability sampling. Multistage variable probability sampling was chosen as most appropriate to the kinds of remote sensing data available—Landsat false color composites and small scale aerial photography (1:120,000 color infrared (CIR) transparencies). Based upon successful remote sensing surveys conducted earlier (Wert and Roettgering, 1968; Langley *et al.*, 1969; Heller and Wear, 1969; Langley, 1975), the use of coarse resolution data afforded by Landsat to select areas for more extensive examination seemed to apply for irrigated lands.

A sampling grid which corresponds to a map base in common use by the land manager should be selected. The size of each sampling block should not be too large or too small. Too large a grid makes it difficult to estimate irrigated areas accurately; too small a grid has too many lines which, in turn, obscure detail. We chose a block size of two by two miles (3.6 by 3.6 km). A five by five km block would also be a convenient size. Each block is our primary sampling unit (PSU).

Preparation of sampling grid. Prepare a grid in ink at some convenient map scale, e.g., 1 in. = 5 mi, 1 cm = 5 km, or 1:250,000. Number rows and columns for subsequent photo interpretation and block relocation. For registration purposes include major water bodies on drafted grid. Copy drafted

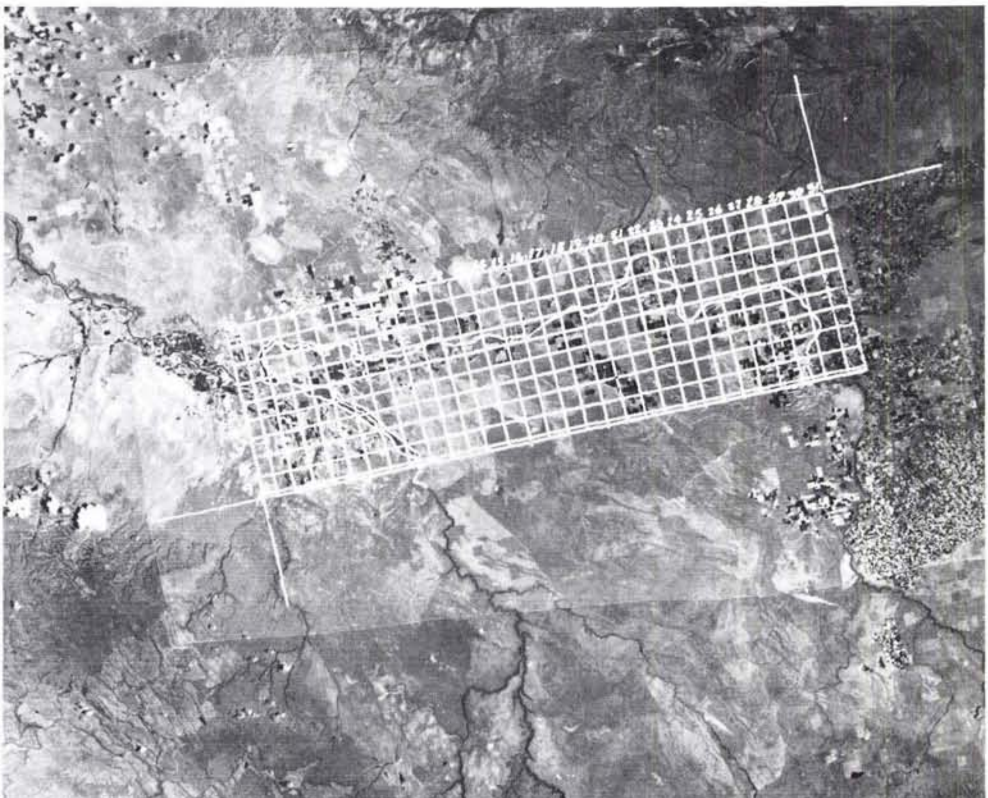

FIG. 2. A portion of the Landsat image (ID - E-1702-17512) used in the southwestern Idaho study (scale = 1:1 000 000). The grid has 9 rows and 30 columns; each square was interpreted for percentage of irrigated lands. The grid covers the shaded area of the map shown in Figure 1. This black-and-white print was made from the Landsat false color composite.

grid onto orthochromatic film (Kodalith or equivalent) with a copy camera. Enlarge negative to exactly 1:1,000,000 scale onto stable base film; this procedure will produce a positive transparency at the same scale as the Landsat false color composite. Orient grid in a north-south or east-west direction to correspond to normal map orientation and tape the positive transparency to the Landsat false color composite over the area selected for sampling, using water bodies for registration (Figure 2).

PHOTO INTERPRETATION

The photo interpreter should take care to select a Landsat image which was taken at a time when the bulk of the irrigated crops are near maturity. In southern Idaho, this period occurs near August 1 each year. If possible, underflight photography is most useful if taken during the same period as that in which the Landsat data were collected. In Idaho, the Landsat data were imaged on August 5, 1975, while the high altitude CIR photos were photographed on August 6, 1975, a fortunate coincidence.

On Landsat false color composites, formed by transmitting blue, green, and red light through Landsat wavebands 4, 5, and 7 respectively, irrigated fields appear brilliant red because of the high infrared reflectance of the vegetation. These irrigated fields can be separated easily from non-irrigated lands because of the regular geometric shapes and red hue.

Equipment. A binocular microscope, set at a 10× to 15× magnification, is the best instrument to use in assessing each block for the amount of irrigated land. A 10× hand lens may be substituted if a microscope is not available.

Interpretation of Landsat transparencies. Examine each block (PSU) in the grid systematically by rows and columns and estimate the amount of irrigated land present to the nearest five percent. When the irrigated land

MULTISTAGE SAMPLING - TALLY SHEET

LANDSAT ID E5116-17331 DATE 3/10/77 TIME:

TEST AREA Aug 5, 1975 PI RCH.

Ended 1100
Started 1037
Elapsed 23

Column	Row	Percent: Irrigated Croplands	Cum	Dry Croplands	Rangelands	Other	Total
1	1	65	65		35		100
	2	55	120		45		100
	3	55	175		35	10	100
	4	35	210		65		100
	5	20	230		80		100
	6	0	230		100		100
	7	1	231		99		100
	8	0	231		100		100
	9	0	231		100		100
2	1	2	233		98		100
	2	20	253		65	15	100
	3	10	263		55	35	100
	4	35	298		55	10	100
	5	40	338		60		100
	6	15	353		85		100
	7	10	363		90		100
	8	30	393		70		100
	9	10	403		90		100

FIG. 3. Sample tally form used to record and accumulate the percentage of irrigated land on the southern Idaho study. Note how the percentages are accumulated in the fourth column.

estimate falls below 5 or above 95 percent, estimate to the nearest 1 percent. Record your estimate on a form similar to that shown in Figure 3. If estimates of other land use are desired, such as rangeland, forestland, etc., their percentage occupancy should be recorded, keeping in mind that the PSU total should be 100 percent. As each block is interpreted, add the estimated percent of irrigated land to that of the preceding block (Figure 3, column four). In other words, accumulate the percent of irrigated land as the interpretation proceeds.

Selection of sample blocks (PSU's). Select some predetermined number of PSU's from the total number of PSU's examined. On the Idaho test site, nine samples from a total of 270 were selected, which represented 3.2 percent of the area. Often one is restricted by lack of time and money from conducting an adequate ground check. Usually, a five percent sample is adequate.

A random number table is used to select the sampled PSU's. The random numbers range from zero to the total accumulated percentage of irrigated lands (final cumulated percentage, Figure 3). On the Idaho test with 270 PSU's, this total was 5320. Nine random numbers were selected within this range. The PSU's whose cumulative percent value contains the random number value becomes the sampled PSU. All PSU's with one or more percent irrigated land have an opportunity of being selected; for example, see the wide range in predicted percentages of irrigated lands for interpreters three and four (Table 1).

Supplemental aerial photography. One must determine the actual area of irrigated lands (a_i) within the selected PSU's in order to compare it with the estimated amount from Landsat interpretation. Any scale of aerial photography (1:125,000 or larger) may be used to provide this comparison. Photos should be taken over the randomly selected PSU's during the same time period if at all possible. CIR transparencies are preferred because they provide better discrimination of irrigated lands than other films and their color representations are close to those of Landsat false color composites. In the event that aerial photography cannot be obtained, the PSU boundaries can be transferred to existing maps and the irrigated lands delineated completely on the ground to obtain actual acreage (a_i) within each PSU.

If aerial photography is available, the block boundaries of the sample PSU's are transferred from Landsat to the photographs by the use of a transfer device such as a Bausch and Lomb Zoom Transfer Scope. Then, within the PSU all identifiable irrigated lands can be drawn on an overlay of the air photo. Both the area of the irrigated lands and the total area of the PSU are carefully planimetered, and the irrigated land percentage of the total PSU area is calculated. This percentage is then multiplied by the total area of the PSU (acres or hectares) to determine the actual irrigated land acreage (a_i). The computations are shown in tabular form in Table 2. For more details on the derivation of the probability sampling formula and the application to irrigation, see Langley (1975) and Johnson (1977), respectively.

Results. The results of four independent estimates are shown on the bottom portion of Table 1. The actual acreage of irrigated land in the Idaho test site subsequently was measured accurately by planimeter on the 1:120,000 CIR transparencies and found to contain 149,500 acres (59,800 ha). All four estimates of total irrigated lands were close to the actual irrigated acreage and well within one standard deviation of the estimate. Interpreter two had the largest variance and sample error (10.3 percent). His fifth observation (underlined on upper portion of Table 1) was responsible for this increase in variance. He predicted 55 percent irrigated area from Landsat, and the air photos measured 91.7 percent. Upon examination of this PSU on the Landsat image, we found that many wheat fields had lost their IR reflectance because they had been harvested earlier in the season. However, these were fields with permanently installed irrigation systems which had been irrigated earlier in the season. This kind of error can occur, causing the variance and sampling error to be inflated. Such errors can be minimized if some ground checking of various irrigated croplands can be done to recognize the reflectance anomalies that can occur on Landsat imagery. Recognition of these anomalies will reduce photo interpretation errors on the satellite images.

All computations can be made on a small desk or hand calculator. The method is surprisingly accurate and can be repeated with equally good results. The photo interpretation, measurement of areas, and computations take 12 to 15 hours to complete. If countries with developing irrigated agriculture would be satisfied with sampling errors of 6 to 10 percent, this technique should be considered.

CHANGE DETECTION

Landsat images can be used to detect

TABLE 1

TABLE 1. COMPARISON OF FOUR INDEPENDENT ESTIMATES OF IRRIGATED LAND BY FOUR INTERPRETERS ON SOUTHWESTERN IDAHO TEST SITE FROM LANDSAT COLOR COMPOSITE (E 5116-17331) IN AUGUST 1975.

Interpreter 1				Interpreter 2				Interpreter 3				Interpreter 4			
Predicted		Measured		Predicted		Measured		Predicted		Measured		Predicted		Measured	
%	Acres	%	Acres	%	Acres	%	Acres	%	Acres	%	Acres	%	Acres	%	Acres
60	1536	48.8	1248	40	1024	47.4	1212	20	512	26.3	672	20	512	22.4	575
60	1536	63.4	1629	50	1280	33.1	846	10	256	8.6	220	40	1024	44.5	1138
40	1024	41.3	1059	55	1408	67.1	1716	60	1536	57.3	1468	30	768	39.4	1009
45	1152	44.1	1129	60	1536	54.9	1404	55	1408	50.2	1286	95	2432	88.0	2252
35	896	21.0	538	55	1408	91.7	2347	05	128	7.6	191	95	2432	89.2	2283
85	2176	82.8	2142	10	256	7.4	189	15	384	13.2	337	30	768	31.5	805
80	2048	76.4	1952	85	2176	80.0	2048	90	2304	89.1	2281	15	384	14.0	358
50	1280	46.2	1185	90	2304	81.1	2075	30	768	29.5	755	20	512	20.4	521
15	384	17.8	456	50	1280	39.6	1012	40	1012	39.6	1012	05	128	9.1	232

Parameters Estimated	Interpreter 1	Interpreter 2	Interpreter 3	Interpreter 4
A (total acres)[1]	156,790	157,509	149,856	154,739
Var (A)	88,499,175	263,575,961	111,996,940	168,208,470
Stand. Dev. (acres)	9,407	16,235	10,235	12,970
Sample error	6%	10.3%	7.1%	8.4%
95% Conf. Int. (acres)	21,694	37,438	24,404	29,909

[1] 149,500 acres measured from U-2 photos taken in 1975.

TABLE 2. PROBABILITY SAMPLING COMPUTATIONS TO ESTIMATE AMOUNT OF IRRIGATED LANDS IN SOUTHWESTERN IDAHO TEST SITE. INCLUDES COMPUTATION OF VARIANCE, STANDARD DEVIATION AND SAMPLING ERROR FOR INTERPRETER NUMBER FOUR (4).

No.	PSU Row	PSU Col	Square Inches Total of Irrig. Field	Square Inches Total of PSU	% of Total PSU's	Actual Acres 2560 × % Irrig.	Predicted Irrig. %	p_i	a_i/p_i	a_i^2/p_i^2
1	10	5	0.2126	0.9468	0.2245	574.7	20	0.0037590	152,870	2.3374253×10^{10}
2	5	4	0.4792	1.0781	0.4450	1137.9	40	0.0075188	151,341	2.2903989×10^{10}
3	22	3	0.3850	0.9769	0.3940	1008.6	30	0.0056391	178,858	$3,1990301 \times 10^{10}$
4	28	7	0.8685	0.9875	0.8796	2251.8	95	0.0178570	126,102	1.5901666×10^{10}
5	19	7	0.9565	1.0724	0.8919	2283.3	95	0.0178570	127,866	1.6349668×10^{10}
6	30	6	0.3500	1.1125	0.3146	805.4	30	0.0056390	142,827	2.0674824×10^{10}
7	7	2	0.1443	1.0310	0.1400	358.4	15	0.0028190	127,115	1.6158100×10^{10}
8	4	3	0.1970	0.9680	0.2040	521.0	20	0.0037590	138,601	1.9210151×10^{10}
9	28	4	0.0902	0.9945	0.0907	232.2	05	0.0009398	247,073	6.1045485×10^{10}

$$p_i = \frac{\text{\% of predicted irrig. acres on } i^{th} \text{ PSU}}{\text{Sum of \% of all PSU's on test site}}$$

$$A = \frac{1}{n} \sum_{i=1}^{9} \frac{a_i}{p_i}$$

$$\text{Var}(A) = \frac{1}{n(n-1)} \left[\sum_{i=1}^{9} \frac{a_i^2}{p_i^2} - nA^2 \right]$$

$$\text{S.D.}(A) = \sqrt{\text{Var}(A)}$$

$$\text{Sample error} = \frac{\text{S.D.}(A)}{A}$$

$$\sum_{i=1}^{9} \frac{a_i}{p_i} = 1,392,653$$

$$\sum_{i=1}^{9} \frac{a_i^2}{p_i^2} = 2.2760843 \times 10^{11}$$

where:

a_i = measured irrigated lands in i^{th} PSU
A = total area of irrigated lands in test site
n = number of sampled PSU's
$\frac{a_i}{p_i}$ = estimate of total irrigated lands made from one PSU

changes in irrigated lands from one year to the next by using transparencies of two Landsat wavebands from the present year with one waveband from a previous year. Certain conditions should be observed. For example, images from the same growing period in each year should be selected, and, for best geometric registration, images from the same satellite should be used, i.e., Landsat 1 with 1, Landsat 3 with 3, etc.

If the interpreter has an optical combiner available, e.g., I^2S or similar additive viewer, he can combine the 1:3,300,000 scale Landsat images by using the following combinations of years of imagery, wavebands, and filters. Use a green filter with the red (5) waveband and a blue filter with the near IR (7) waveband on current imagery. Register the old imagery on the new and project a red filter through the near IR (7) waveband. With this combination, newly irrigated fields which were not under irrigation at the time of the older imagery will appear purplish to light blue. Fields under irrigation at both time periods will appear red. The projected image can then be copied onto color film and subsequently printed for enumeration and measurement of the newly irrigated fields.

A similar result may be obtained without an optical combiner by using 1:1,000,000 Landsat black-and-white transparencies. The same wavebands are used, i.e., 5 and 7 of the old imagery and 7 of the new. In place of filters, a colored foil product (3M, GAF) manufactured for the color printing industry can be used. An appropriately colored foil is exposed to a Landsat transparency under ultraviolet light and developed in ammonia fumes. Because the colored foils respond in direct proportion to the darkness of the Landsat transparencies, colored foils complementary to the filter colors described above must be used. For example, on the new imagery, a magenta foil is used with band 5 and a yellow foil with band 7. Similarly, on the old imagery a cyan foil is used on band 7. Careful registration of the three developed foils produce a very similar product.

Beginning in mid 1979, the EROS Data Center in Sioux Falls, South Dakota will begin producing rectified and geometrically corrected Landsat products. Their use will simplify overlaying imagery from one year to the next.

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Errata

Some of the text material and equations in the first column of page 1120 of the article, "Mapping of Particulate Iron in an Ocean Dump," by Craig W. Ohlhorst and Gilbert S. Bahn (*Photogrammetric Engineering and Remote Sensing,* August 1979) was inadvertently interchanged. The first line in column one should be followed by the equations (presently located near the bottom of the column)

$$X_1 = 1.7947\, R^*_3 + 2.4857\, R^*_4 + 2.1276\, R^*_5 - 116.104$$
$$X_2 = 2.5391\, R^*_6 + 3.1290\, R^*_7 + 5.2304\, R^*_8 - 6.536$$

These equations are followed by the text immediately above them, i.e.,

"where R^*_3 through R^*_8 are adjusted radiances. . . . The parameters were derived in the following steps:"

This is followed by the five numbered steps immediately after the first line in column one.