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A CONTRACT TO INVENTORY IRRIGATED LANDS ON SELECTED AREAS IN SOUTHERN IDAHO

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The objective of the investigation was to determine if LANDSAT imagery can be effectively used to inventory irrigated cropland. The irrigated cropland of three test sites in Idaho were inventoried using multistage variable probability sampling procedures. Multiscale remote sensing data, LANDSAT imagery (1:1,000,000), U-2 photography (1:125,000), and large scale 70mm photography (1:8,000) were used to conduct the multistage sampling and obtain additional agricultural land use information. Multiscale photography does provide an effective means of obtaining specific agricultural land use information such as irrigation methods and crop types.

Multistage variable probability sampling scheme is well suited to be used with multiscale data and does yield acceptable inventory results. Since multistage sampling is sensitive to LANDSAT interpretation errors, optimally timed imagery from the last week in July or the first week of August should be used to inventory irrigated croplands in Idaho.

From this multistage sampling scheme, we were able to estimate the total acres of irrigated cropland in the three test sites to acceptable levels of accuracy within a reasonably short time and small budget. The irrigated cropland estimates for the test sites are as follows:

		Sample Error @ 1 Std. Dev.	
Site	Acres	Acres	Percent
Western	156,790	8,862	6
Eastern	554,724	36,932	7.4
Silver Creek	19,374	4,998	25.8

LANDSAT imagery was also used to determine the location and magnitude of irrigated cropland expansion by constructing multidate color composite images. The composite images are made with LANDSAT scenes from two different growing seasons. Newly irrigated cropland is indicated by fields possessing a distinctive coloration. This method is a rapid and inexpensive means of monitoring agricultural land use change throughout a large area.

Crop identification by optical interpretation of LANDSAT imagery is not possible using single date imagery. Identification may be possible in some areas of Idaho by using multidate imagery and noting changes in individual fields throughout the growing season. However, many agricultural areas in Idaho have fields too small to be delineated on LANDSAT imagery, and crop identification within these areas by optical interpretation is not possible.

Computer classification of crop types from LANDSAT Computer Compatible Tapes (CCT's) was conducted by NASA/Ames and the USGS Geography Program. Only preliminary data are available and conclusions are not possible. Indications are that single date data are insufficient to identify all crop types, but irrigated cropland can be identified.

INTRODUCTION

The Idaho Department of Water Resources has planning and regulatory responsibilities concerning the water resources of the state. The planning responsibility requires the Department of Water Resources to establish water resource plans for the river basins of Idaho. (A draft Water Plan for the Snake River Basin was released for review in March 1976.) Any resource plan, in order to be effective, requires accurate information as a basis for the decision-making process. In the case of water resource planning, a wide variety of information dealing with the physical environment, cultural perception, and the economic demands of water resources is necessary. In addition to the varying nature of the information, the geographic area over which the information must be collected can be extensive.

Irrigated agriculture 1/ is a major industry in Idaho and is the major water user, consuming an estimated 5 to 6 million acre feet of water annually. The current extent and future development of irrigated agriculture in Idaho will play a major role in water resource planning. In order to formulate effective water resource plans, accurate information about irrigated agriculture is necessary. Such information is difficult to obtain because of the wide distribution of irrigated agriculture in the state and its constant dynamic growth. Irrigated agriculture has expanded at an average rate of 60,000 acres annually from 1950 to 1970, and future growth rates are projected at 36,000 to 46,000 acres annually through 2020. Because of the expansion of irrigated agriculture, it is necessary to continually revise irrigated land use information.

The objective of this investigation was to determine if remote sensing techniques can be effectively used to obtain water related land use information. This research project was conducted as a joint effort involving the University of Idaho, College of Forestry Remote Sensing Lab. and the Department of Water Resources as participants in the Pacific Northwest Regional Commission (PNRC) Land Resource Inventory Demonstration Project. The project is a joint effort by NASA, USGS, PNRC, and various state and local agencies to develop remote sensing techniques and capabilities for the collection, analysis and application of land resource information to meet specific planning and management needs. Through this joint effort, various remote sensing data products were made available. NASA and USGS actively participated in the project by supplying training for Idaho personnel and undertaking computer classification of LANDSAT Computer Compatible Tapes (CCT's) for identification of irrigated croplands and crop types.

1/ Irrigated cropland is defined as land which has water applied to it for agricultural purposes by artificial means or by seepage from irrigated fields, canals, or reservoirs, land which is flooded during or times of high water if the flow of water is due to canals, check dams, or other man-made items. This is the definition used by the U.S. Bureau of Census and conforms with definitions used by the Soil Conservation Service, the Pacific Northwest River Basin Commission, and the Idaho Department of Water Resources.

O B J E C T I V E S

The overall objective of this investigation was to determine if remote sensing, specifically those techniques utilizing satellite imagery and high altitude photography, can be effectively used to obtain water related land use information required by the Idaho Department of Water Resources. The specific objectives were to evaluate remote sensing techniques for obtaining the following types of data pertaining to irrigated agriculture, in order of priority:

1. Identify irrigated croplands
2. Measure acreages of irrigated croplands
3. Identify and measure annual changes in acreages of irrigated croplands
4. Identify source of irrigation water
5. Identify method of irrigation
6. Identify crop types and measure acreages of crop types
7. Identify urban and other non-agricultural lands

All of the objectives were investigated by the Forestry Remote Sensing Lab. or by NASA/USGS as a part of the computer classification procedures. Specifically, the Forestry Remote Sensing Lab. addressed its investigations to the first five objectives. The objectives of the computer classification performed by NASA/USGS was to identify irrigated croplands, identify crop types, and identify other land uses according to the Anderson land use classification system (1972). The Forestry Remote Sensing Lab. is currently unable to conduct computer classification of LANDSAT data. The activities of the lab and procedures reported are concerned only with the photographic LANDSAT data products and optical interpretation techniques.

IDWR indicated that quantitative data, rather than cartographic data, based on geographical areas would best meet their needs. IDWR has developed computer models of the Snake River groundwater and surface water systems. A major role of remotely sensed data would be to obtain land use information in a form which is compatible for input into the computer models.

I N V E N T O R Y O F S E L E C T E D I R R I G A T E D C R O P L A N D S

Test Sites

In order to meet the defined objectives of the research, it was decided that the best method would be to conduct a pilot inventory of irrigated croplands within three selected test sites in southern Idaho. For data collection and inventory analysis purposes, each of the test sites was treated as an independent unit. The location of the three test sites is shown in Figure 1.

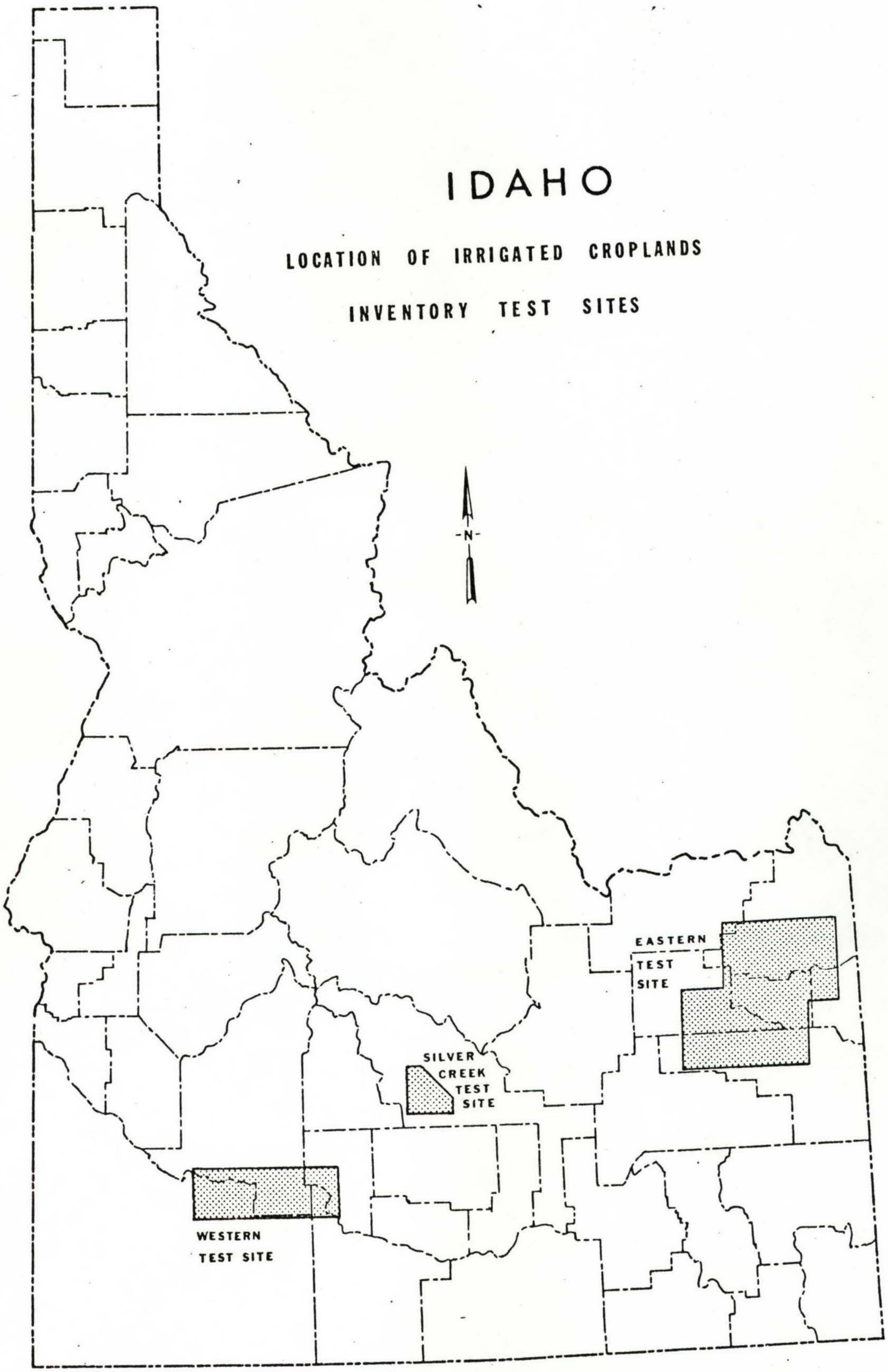


Figure 1. Location of pilot inventory test sites.

Western Test Site

The Western Test Site is a rectangular area 18 by 60 miles (1080 sq. mi.) bisected lengthwise by the Snake River, with the western boundary three miles west of C. J. Strike Reservoir and the eastern boundary six miles east of Bliss. The area is that of a plain dissected by the Snake River within a canyon averaging 400 feet in depth. The area consists of a series of plateaus, separated by the canyons of the Snake River and its tributaries, with elevations from 2800 to 3200 feet above sea level. Within the canyons, irrigated agriculture has existed for some time. On the plateaus newly irrigated lands have been recently developed by the use of high lift pumping from the Snake River. The climate of the test area is dry with precipitation averaging less than 10 inches annually. The summers are hot and winters mild.

Eastern Test Site

The Eastern Test Site is an area of 2268 square miles with Idaho Falls at its southern border and Ashton near the northern border. The physiography of the area varies. A small mountainous area occupies the southeastern portion of the site. Immediately to the west is a region of loess covered benches and terraces which are extensively utilized for dryland farming. West of the benches are the alluvial fans of the Snake, Teton, and Henry's Fork rivers. Within these alluvial fans, some of the earliest irrigated agriculture in Idaho using gravity flow delivery systems began in the late 19th century. Currently flood irrigation is still the predominant form of irrigation in the area. The western third of the test site consists of igneous flows overlain by aeolian soils of variable depths. Where soils are of sufficient depth and water is available, either by pumping from surface water or groundwater, sprinkler irrigated croplands have recently been developed. Elevations of the test site range from 5000 to 6000 feet in the west and on the benches to 7500 feet in the mountains on the southeast. As elevation increases, so does precipitation, with the average annual precipitation of the area being 12 inches.

Silver Creek Test Site

The Silver Creek Test Site is a triangular-shaped area of 159 square miles with Bellevue on the north, Magic Reservoir on the southeast, and Picabo on the southwest. The area is an alluvial valley drained by the Big Wood and Little Wood rivers. Surrounding the valley are mountains exceeding 7,000 feet in elevation. Winters and summers in the valley are mild while the precipitation averages 13 inches annually. Irrigated agriculture and ranching utilizing irrigated pasture are practiced throughout the valley. The valley has experienced increased irrigation by groundwater pumping, and commercial development has expanded because of the area's proximity to Sun Valley. There has been concern expressed that the changing agricultural practices and the development within the valley may alter the groundwater system. Currently the groundwater system continually supplies a series of springs along the southern portion of the valley which combine to form Silver Creek, a tributary to the Little Wood river and a nationally famous trout fishing stream.

Inventory Design

In order to develop quantitative information, a statistical sampling procedure was used to conduct the inventory. A quantitative value with confidence limits would be generated for the total irrigated acreage of each test site which in turn could be applied for determining water demand and use due to irrigation. When using a statistical system, a population unit such as one square mile must be defined. Therefore acreages of irrigated croplands could be recorded by geographically identifiable units which could be used as input for existing computer models. Because of previous successes reported by Langely (1975), Thorley, el al. (1973), and Heller, Aldrich and Langely (1969), a multistage variable probability sampling scheme was employed. A detailed description of the multistage variable probability sampling procedures used is given in the Appendix.

The multistage sampling scheme is well suited to be applied through the use of different remote sensing imagery. Three levels of remotely sensed data were used to conduct the inventory. Small scale (1:1,000,000) LANDSAT imagery can be used as the first level to estimate the total irrigated cropland acreage by enumerating each of the primary units. Primary Sample Units (PSU's) are selected based on the amounts of irrigated cropland determined by LANDSAT interpretation. Once the PSU's are selected, a more detailed and accurate estimate of irrigated cropland acreages can be made for each PSU using a larger scale of aerial photography (second level) such as high altitude U-2 small scale photography (1:125,000). Then Secondary Sample Units (SSU's) may be selected based on the interpretation of the U-2 photography. Finally, specific irrigated acreage measurements and crop identifications can be made by employing large scale 70mm aerial photography of the SSU's (third level) combined with information resulting from ground visits, referred to as "ground truth". This procedure allows increasingly more detailed information to be collected as the actual area of observation decreases. The information capability of each type of imagery or aerial photography is utilized sequentially to obtain the increasingly specific information which can then be applied to the total population by use of the multistage sampling statistics. Data, such as irrigated cropland acreages can be recorded by primary units which are physical entities. The data can then be utilized to supply resource information for decision-making purposes on a wide variety of scales and are compatible for input to computerized geographical information systems or area models such as those developed by IDWR.

Sample Selection

The first step was to develop a means of defining the primary units. Based on previous experience and the size of the test sites, a primary unit size of four square miles was used. Because of irregularities of the township and range survey and the necessity that the units be of equal size, an arbitrary two mile by two mile grid was constructed for each test site. The grids were drafted using aeronautical charts at a scale of 1:500,000. In addition to the grid, major water bodies, large reservoirs and the Snake River, were also included. The drafted grids were photographically reduced to a scale of 1:1,000,000 which corresponds to the scale of the standard 7.5 inch LANDSAT color composite transparencies.

The water bodies located on the grid overlays were used to register the grids correctly on the LANDSAT imagery.

Interpretation of LANDSAT imagery was done using a Zoom Transfer Scope. The percent of irrigated cropland for each primary unit was recorded for each test site. LANDSAT images employed for the initial interpretation are listed below:

Test Site	Image Identification	Date
Western Test Site	E1702-17512	June 25, 1974
Eastern Test Site	E1358-17465	July 16, 1973
	E1358-17465	July 16, 1973
Silver Creek Test Site	E1035-17525	Aug. 27, 1972

Because of the time constraints, it was necessary to use imagery that was on hand at the Forestry Remote Sensing Lab. to conduct the initial estimations. This imagery was not ideally suited for determining acreages of irrigated croplands because it was several years old and not from the optimum dates. However, it was the only imagery readily available at that time.

Based on the LANDSAT interpretation of primary units, a total of 25 PSU's were selected throughout all the test sites. The Eastern Test Site had 14 PSU's, the Western Test Site had 9, and the Silver Creek Test Site 2 PSU's. The total number of PSU's selected was an arbitrary decision based on the time and money available to conduct field investigations. The distribution of PSU's achieved approximately the same sampling percentage for each of the test sites.

It was necessary to locate each PSU on USGS 7½' maps and U-2 photography in order to conduct the second stage sample selection. Because of the scale changes and minor imperfections of the grids on the LANDSAT scenes, each PSU location had to be individually transferred from the LANDSAT to the U-2 photography and then to the USGS maps. The transfer was accomplished by measuring proportional distances from identifiable points to the PSU location on the LANDSAT imagery and U-2 photography. The map location of the PSU was determined from the U-2 photography location and checked against the location of the PSU's on the LANDSAT imagery. Although this procedure was tedious, it is the opinion of the investigators that the location of the PSU's on the ground is within the accuracy capabilities of LANDSAT imagery.

Again, for the purpose of selecting sample units, information on hand at the Forestry Remote Sensing Lab., U-2 photography flown in support of previous ERTS investigations was used for selecting the SSU's. It was not possible or desirable to obtain current U-2 photography prior to conducting the field investigations. The U-2 photography used was color infrared (CIR) photography at a scale of 1:125,000 obtained during May and October of 1973. In the case of Silver Creek, suitable U-2 photography and base maps were not available, so the SSU's were selected randomly.

Each PSU was subdivided into ten secondary units (2 mile by 0.2 mile) having a north-south orientation. Based on photo interpretation of the U-2 photography, the percentage of irrigated cropland was estimated for each secondary unit. Two SSU's were selected from each PSU utilizing variable probability sampling procedures. The 50 SSU's formed the basis upon which current (1975) irrigated cropland data were collected and applied to determine the amount of irrigated croplands in each test site. Both the ground inspections of the SSU's and the photo interpretation of 70mm photography were considered as the third level of information for the multistage sampling design.

Data Collection

Five data sources based on the 1975 agricultural season were obtained. The data sources were: LANDSAT imagery; LANDSAT CCT's; high altitude, CIR, U-2 photography; large scale, CIR, 70mm photography; and ground truth. As noted by a number of researchers, the timing of obtaining agricultural remote sensing data is important. If imagery or photography is obtained too early in the growing season, those fields planted to row crops cannot be identified because of insufficient vegetative cover. All such fields appear as bare soil. On the other hand, remote sensing data must be obtained prior to the harvesting of crops. In Idaho, the small grains are harvested beginning in early August in the warmer areas. Throughout the three test sites, the timing of phenological development varies by approximately 30 days, with the Western Test Site the earliest followed by the Eastern and Silver Creek Test Sites (Everson and Caprio, 1974). Because of the different rates of phenological development between the test sites, it was not necessary to collect all remote sensing data at the same time. Table 1 is a listing of the data sources used and the dates when the data were collected. For all test sites, the majority of crops were still in place when the data were obtained. The only exception was in the case of the Western Test Site where harvesting of early maturing malting barley had just begun as the photography was obtained.

Ground Truth

As indicated in Table 1, ground truth was collected during the last week of July and the first week of August. Visitations were made to each of the SSU's. The field locations, crop types, and crop conditions were recorded for fields within the SSU's. Also, normal color and color infrared terrestrial photography was obtained of each crop type and crop condition observed. Figure 2 contains examples of the terrestrial photography.

70mm Large Scale Photography

Following the ground visitations, 70mm CIR aerial photography was flown over each of the SSU's. The photography was at a scale of 1:8,000. The 1:8,000 scale was selected because the complete width of the SSU would be included in each frame, allowing each SSU to be photographed at the largest scale possible while using only one flight line per SSU. The 70mm photography was obtained with a Hulcher model 102 camera with a 150mm lens (Fig. 3). The initial 70mm photography of all the SSU's was flown on August 6 and 7, 1975. Unfortunately, a camera malfunction necessitated a reflight of some SSU's in the Eastern and Silver Creet Test Sites. The reflight was made on September 2, 1975. In both test areas, all crops were still in the fields when the reflight was made.

A

B

Figure 2. Examples of normal color and color infrared terrestrial photography of harvested grain stubble (A) and immature grains (B). Fields of similar conditions are located on the U-2 photography in figure 3 designated "A" for grain stubble and "B" for unharvested grain.

Data Form	Purpose of Analysis	Dates — Test Sites: Western	Eastern	S.C.
LANDSAT imagery color composite transparency 1:1,000,000	Determination of acreages of irrigated cropland for each test site.	13 Aug 75	02 Aug 75	25 July 75
LANDSAT computer compatible tapes	Determination of acreages of irrigated croplands. Crop type identification for each test site.	13 Aug 75	30 May 75 02 Aug 75	24 July 75
U-2 high altitude photography 1:125,000	Determination of acreages of irrigated croplands and crop types for PSU's. Mapping of field boundaries for PSU's.	06 Aug 75	10 July 75 26 Aug 75	06 Aug 75
70mm large scale sampling photography 1:8,000	Determination of acreages of irrigated croplands and crop types for SSU's.	06 Aug 75	07 Aug 75 02 Sept 75	07 Aug 75 02 Sept 75
Ground truth	Development of photo interpretation criteria to be used with aerial photography.	01-05 Aug 75	29-31 July 75	03 Aug 75

Table 1. Data obtained and utilized during the 1975 agricultural season.

Figure 3. Hulcher 70mm camera, intervalometer, and viewfinder mounted in Cessna 206 aircraft used to obtain large scale aerial photography.

U-2 Photography

The U-2 aerial photography was obtained during three photographic missions flown by NASA in support of the PNRC Land Resource Inventory Demonstration Project. The Western and Silver Creek sites were photographed on August 6, 1975. Since the U-2 photography and the 70mm photography for the two test sites was obtained within 24 hours, the process of photo interpretation was greatly enhanced. The Eastern Test Site was completely photographed on July 10, 1975. However, the photography obtained during the July flight was not suitable for effective interpretation of agricultural land use. It was obtained too early in the growing season, and most row crops could not be distinguished because of insufficient vegetative cover. Photography from another flight flown August 26, 1975, supporting PNRC related research, was obtained. The later photography did include nine of the PSU's in the Eastern Test Site and the row crops were distinguishable.

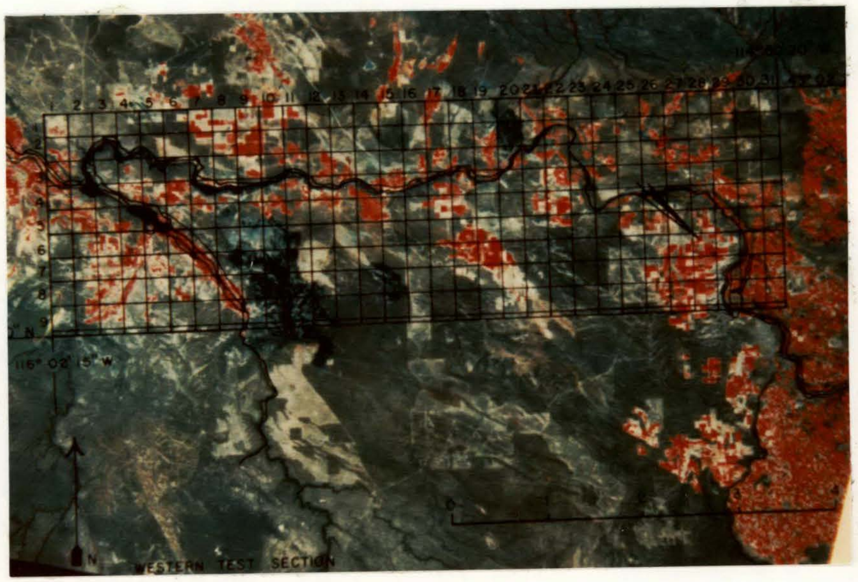
LANDSAT Data

The LANDSAT imagery and CCT's were obtained through NASA/Ames. The data obtained were for those dates closest to the first week of August that cloud free imagery was available. In the case of the Eastern Test Site, it was decided to perform computer classification of multidate data. It was determined that LANDSAT data obtained in late May or early June would best aid in the discrimination of dryland farming from irrigated croplands when combined with the August data.

Thus, the remote sensing data collected during the 1975 agricultural season provided a series of multiscale remote sensing products that corresponds to the multistage variable probability sampling scheme. A graphic illustration of the imagery is shown in figure 4. In this illustration note the arrow on the LANDSAT imagery locating PSU 28-07. The same PSU is shown on the U-2 photography with the 70mm flight lines for the two SSU's indicated. Also, on the U-2 photography the arrow indicated the location of the stock pond which is present on the 70mm photograph.

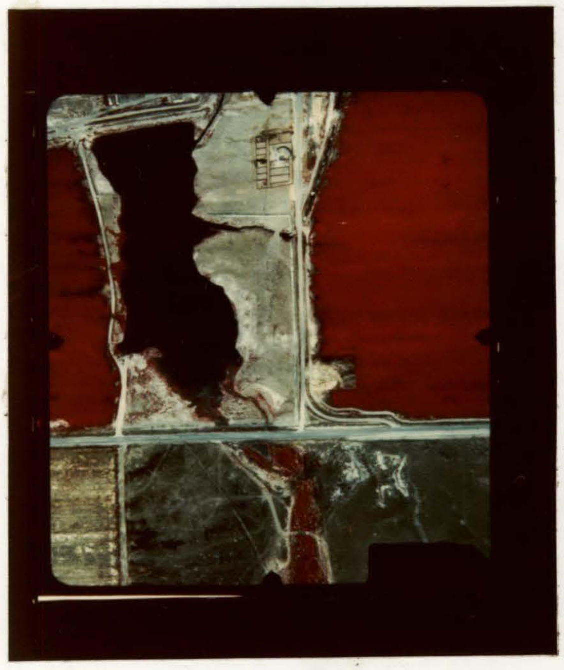
Data Interpretation and Recording

During the investigation, interpretation of irrigated cropland in the test sites was conducted using two sets of LANDSAT imagery, 1973-74 and 1975. The first set of imagery, 1973-74, was used to establish the



A

B



C

Figure 4. Multiscale imagery used to conduct the inventories. The 1:1,000,000 LANDSAT imagery (A) of the Western Test Site shows the subdivision of the entire area into 2 by 2 mile population units. The 1:125,000 CIR U-2 photography (B) was interpreted to select secondary sample units. Finally, specific crop information is determined from 1:8,000 70mm CIR photography (C) and ground truth. Dashed lines on photo B shows location of the 70mm flight lines.

sampling scheme as described. The second set of imagery was obtained during August 1975 and is listed in Table 1. Interpretation of the first set of imagery was done using a Zoom Transfer Scope while the second was interpreted using a zoom microscope. The zoom microscope proved to be far superior to the Zoom Transfer Scope for conducting interpretation.

During the investigations it became apparent that the initial interpretation of the LANDSAT imagery had inaccuracies, especially in the Eastern Test Site. Three factors contributed to the inaccuracy of the initial interpretation. The primary factor was that timing of the imagery was not well suited for the identification of irrigated lands. It was assumed that irrigated croplands would be readily apparent on the June and July imagery of the Western and Eastern test sites. But as was found with the July U-2 photography, the crops in many irrigated fields are not sufficiently developed. As a result, some areas were identified as dryland or fallow fields rather than as irrigated land. The second factor contributing to discrepancies in the initial interpretation is that more land was put under irrigation between the time of the 1973-74 imagery and the actual conditions in the 1975 season. The third factor is that the researchers had little or no prior knowledge of the agricultural practices and distributions in the test areas. If some prior knowledge had existed, it is probable that some of the misclassification of irrigated cropland as dry cropland would have been avoided.

In order to fully evaluate the potential of LANDSAT imagery for inventorying irrigated cropland, 1975 imagery of the Western and Eastern test sites was interpreted. The imagery was obtained at a time (early August) when all irrigated cropland supported a full cover of crops, thus allowing for more accurate classification. Also, as a result of fieldwork, a greater understanding of the agricultural practices within the test sites assisted in improving the accuracy of irrigated cropland identification.

Interpretation of photographic data was done to meet two objectives. The first objective was to obtain acreage measurements of irrigated croplands necessary to derive total acreage values for each of the test sites. The second objective was to obtain acreages of crop types to be used as training information and for evaluation of the computer classification of LANDSAT CCT's. In order to achieve both objectives, it was necessary to determine the acreages of irrigated croplands and crop types for both the SSU's and the PSU's. The measurement of irrigated croplands and crop type by PSU is not necessary to determine the total acres of irrigated croplands in each test site. Only the SSU's need to be measured.

Irrigation and crop type were recorded for measurement by agricultural fields. The first step in the interpretation process was to determine the field boundaries in each of the PSU's. For this purpose, an agricultural field is defined as an agricultural management unit consisting of a single crop that is not physically divided by fences, canals, hedgerows, roads, or any other physical barrier. The field boundaries were transferred from the 1975 U-2 photography to USGS 7½' maps for each PSU using the Zoom Transfer Scope.

Crop type, irrigation method, and field size were determined for all fields occurring in each PSU. Since data were being obtained for the entire PSU, the majority of photo interpretation was done from the U-2 photography. The Manual of Remote Sensing (ASP, 1976) notes that identification of crop types using high altitude photography is difficult because the identification of various farming practices, used to assist with crop identification, often is not possible. The interpretation is much more dependent on the notation of variations in color, texture, field size, and shape to determine crop types.

It was found that the employment of the multistage concept using remote sensing data was very effective in developing photo interpretation procedures. Utilizing the ground truth data, specific fields were identified by crop type and irrigation method on the large scale 70mm photography. Once all fields were identified on the 70mm photography, they were located on the U-2 photography and used as training fields to identify the crop types and irrigation methods for the remaining fields in each PSU. A major advantage of this method is that ground truth and 70mm photography was available for each PSU. It would be difficult to extend photo interpretation criteria for an entire test site, such as the Eastern Test Site, based on only a few ground plots or selected 70mm coverage. The average dates for like phenological development of indicator plants, such as lilacs, differs by as much as 14 days within the Eastern Test Site (Everson and Caprio, 1974). Therefore, crops do have significantly different appearances from one area of the test site to another. Also, by using the multistage approach for photo interpretation, the number of ground observations is reduced. It is not difficult to accurately identify crop types on large scale 70mm photography given only a few ground observations. By using the 70mm photography, a wide range of crop types and conditions occurring in a given area are identified on the U-2 photography. This gives the photo interpreter a set of training fields likely to include all of the conditions encountered in a given area to be interpreted. Because of the distance to the test sites and the temporary nature of crop information, it was difficult to check much of the photo interpretation. A field check of 31 fields in the Western Test Site, interpreted using the U-2 photography, showed only one field misinterpreted. The area used for the field check is the same area as shown in the U-2 photograph in Figure 4.

Both the 70mm and U-2 photography had sufficient overlap to facilitate stereo viewing, which was employed to conduct the photo interpretation. Stereo viewing was found to significantly aid in the interpretation of both types of photography. With the 70mm photography, stereo viewing aided in the perception of crop texture, which was used to distinguish potatoes from beans. Crop height, also determined by stereo viewing, was used to identify corn. The U-2 photography had slight vignetting in the corners of the photos which resulted in a difference in color balance from the center of each frame to the edges. By viewing the area to be interpreted in stereo, the difference in color balance as perceived by the interpreter, was cancelled out since the vignetting effect is opposite between the two frames making up the stereo model. Since color differences are a major criteria for crop identification with high altitude photography, the use of stereo viewing greatly assisted in the photo interpretation process.

A number of researchers in the agricultural sector have noted that crop identification can be greatly improved by using multidate photography and noting changes in the appearance of fields from one date to another. For a portion of the Eastern Test Site, multidate U-2 photography was available. The comparison of photographs from the two dates, July 10 and August 26, was used to assist in identification of alfalfa and potato fields. On

August 26 photography, grains were maturing and readily identifiable, but potatoes and mature, uncut alfalfa often appeared identical. By referring to the July 10 photography, the identification could be made. Alfalfa on July 10 was visible while fields of potatoes appeared as bare soil.

Because it is subject to the widest variety of management practices and growing patterns, alfalfa is the most difficult crop to identify. In many areas, alfalfa is harvested as many as three times each season and at irregular periods. Throughout the growing season alfalfa possesses a wide range of characteristics from freshly cut (low in IR reflectance) to fully mature (very high in IR reflectance). Besides difficulty in crop identification, land use with alfalfa can change from an agricultural field with a crop at one period, to a pasture being grazed by livestock at another. This change was noted several times using the multidate photography of the Eastern Test Site.

The acreage of individual fields in each PSU was measured according to the field boundaries located on USGS maps. The fields were measured to the nearest 0.1 acre using an electronic digital graphics calculator.

For each field, the crop type, irrigation method, field size, and field area within the SSU's were recorded with field identification on computer cards. Within each PSU and SSU, the measured acreages were adjusted by weighted mean differences so that all values totaled to the absolute area of the PSU (2560 ac.) or the SSU (256 ac.). Computer processing was used to summarize the data and determine the irrigated cropland acreages for each test site.

Data Analysis

Once all acreage values were determined for the PSU's and SSU's, total acreages of irrigated cropland and the sample errors were calculated for each test site. Multistage variable probability sampling can yield excellent population estimates with low sample errors, but this sampling method is sensitive. Langley (1976) notes that high variances result from low correlations between predicted values, in this case irrigated cropland acreages, and observed values in each sample unit. Also, data outliers, even a single observation, can significantly increase the sample error of the total population value. Our experience during this investigation demonstrates the sensitive nature of the multistage variable probability sampling scheme.

As explained, interpretations from 1973-74 LANDSAT imagery have inaccuracies which affect the total acreage estimates and sample errors. The second set of LANDSAT imagery (1975) being more up to date and timely, does demonstrate the best capability of the LANDSAT data and multistage variable probability sampling. The PSU's and SSU's were selected based on the interpretation of the 1973-74 LANDSAT imagery and are the source of the ground truth information. They were used to derive values based on the 1975 LANDSAT interpretations also. Undoubtedly the use of the same set of PSU's for the generation of data based on the 1975 LANDSAT introduced some bias into the total estimates. It is felt that the bias is not significant. For purposes of general evaluation, the values resulting from the interpretation of the 1975 LANDSAT should be considered as indicating the best possible results that can be expected from an operational inventory using the same criteria as existed in the pilot inventory.

Western Test Site

The tabulations for the PSU's of the Western Test Site are shown in Table 2. The initial total irrigated cropland estimate for the test site is 149,493 acres with a sample error of 13 percent. The coefficient of determination (r^2) of the interpreted acreage compared to the observed acreage in each PSU is 0.38. The major reason for the misclassification, as earlier explained, was the lack of vegetative cover in fields supporting row crops. Another major factor for the discrepancies between the LANDSAT and the observed was the change in amount of irrigated cropland. Increases in irrigated acreages occurred in PSU's 1705, 2807, 2708, and 2909. In one case, PSU 1405, a decrease of irrigated cropland occurred. Another source of interpretation error occurred in the case of PSU 0809 which includes a portion of the Bruneau River flood plain. Using satellite data, it can be difficult to differentiate between river bottomland which may be subirrigated and irrigated croplands.

Based on the 1975 LANDSAT imagery, the total acreage of irrigated cropland was calculated to be 156,790 acres with a sample error of 6 percent. The r^2 between the interpreted and measured acreage is 0.93. When using optimum date imagery (August), sources of misclassification are in areas of subirrigated cropland, such as flood plains, and those areas where irrigated cropland is irregularly distributed. For example, in PSU 2904 the soil depth varies greatly, but water is available through groundwater pumping. The result is that those areas with sufficient soils are irrigated, but interspersed are non-crop areas usually consisting of basaltic caprock. The actual extent of the basalt, when interpreted on the LANDSAT imagery, has been underestimated.

Eastern Test Site

The total irrigated cropland acreage for the Eastern Test Site based on the initial LANDSAT interpretation is 714,260 acres with a sample error of 22 percent. A summary of data for the Eastern Test Site by PSU and SSU is listed in Table 3. As stated earlier, the multistage variable probability sampling scheme is very sensitive to outliers in the data. In the case of the Eastern Test Site, outliers do exist - specifically with PSU's 0621, 0717, and 0718. All three of the PSU's are in the western portion of the test site which consists of recently developed sprinkler irrigation projects having no visible crop cover at the time of the 1973 LANDSAT imagery. The effect of the three outliers was significant. The interpreted data compared to the observed acreages has an r^2 of 0.28. If the three outliers were dropped from the data, an r^2 of 0.76 is achieved which would yield a much better total acreage value.

As with the Western Test Site, the total acreage of irrigated cropland was estimated with August 1975 LANDSAT imagery. The total irrigated cropland acreage was determined to be 554,724 acres with a sample error of 7.4 percent. The r^2 for the 1975 interpretation compared to the ground data is 0.92. Again changes between the 1973 LANDSAT and ground observations were noted in the Eastern Test Site, while other errors can be attributed to the difficulty in distinguishing irrigated cropland from subirrigated land and over estimation of irrigated acreage where it is irregularly distributed.

	PSU 1405	SSU 7	SSU 10	PSU 1705	SSU 5	SSU 8	PSU 0801	SSU 4	SSU 9
		Acres			Acres			Acres	
1973-74 LANDSAT/U-2	1972	230	192	768	156	228	768	64	179
1975 LANDSAT	1536	-	-	1536	-	-	1024	-	-
1975 Photo/Ground	1248	215	239	1629	221	237	1059	67	182
	PSU 1002	SSU 1	SSU 3	PSU 2094	SSU 3	SSU 6	PSU 2807	SSU 3	SSU 9
		Acres			Acres			Acres	
1973-74 LANDSAT/U-2	1024	213	200	640	131	64	1408	128	251
1975 LANDSAT	1152	-	-	896	-	-	2176	-	-
1975 Photo/Ground	1129	218	169	538	104	59	2142	206	256
	PSU 2708	SSU 7	SSU 9	PSU 2909	SSU 7	SSU 6	PSU 0809	SSU 5	SSU 9
		Acres			Acres			Acres	
1973-74 LANDSAT	1536	256	223	640	149	138	640	51	38
1975 LANDSAT	2048	-	-	1280	-	-	384	-	-
1975 Photo/Ground	1952	254	215	1185	203	211	456	33	91

1974 Multistage
sample total = 149,493 Ac

Sample error = 13%

Coefficient of determination
1974 LANDSAT - 1975 Photo/Ground = 0.38

1975 Multistage
sample total = 156,790 Ac

Sample error = 6%

Coefficient of determination
1975 LANDSAT - 1975 Photo Ground = 0.93

Table 2. Summary of the data for the Western Test Site. Irrigated land acreage estimates from the nine PSU's.

	PSU 0621	SSU 3	SSU 5	PSU 0622	SSU 7	SSU 9	PSU 0717	SSU 5	SSU 10	PSU 0718	SSU 4	SSU 9	PSU 0211	SSU 5	SSU 9
		Acres			Acres			Acres			Acres			Acres	
1973 LANDSAT/U-2	384	250.8	250.8	256	87	108	1024	251	246	1152	243	251	1792	154	236
1975 LANDSAT	2304	-	-	384	-	-	2432	-	-	2432	-	-	2176	-	-
1975 Photo/Ground	2533	256	254	694	90	130	2386	247	231	2515	251	254	2216	197	235

	PSU 2205	SSU 1	SSU 8	PSU 2213	SSU 2	SSU 7	PSU 1220	SSU 5	SSU 10	PSU 2404	SSU 5	SSU 10	PSU 1118	SSU 5	SSU 7
		Acres			Acres			Acres			Acres			Acres	
1973 LANDSAT/U-2	896	102	13	128	-	-	2304	243	246	1536	218	251	2048	251	251
1975 LANDSAT	768	-	-	384	-	-	2432	-	-	2304	-	-	2432	-	-
1975 Photo/Ground	433	106	36	357	78	66	2169	224	229	2343	246	246	2397	252	240

	PSU 1515	SSU 3	SSU 7	PSU 1708	SSU 3	SSU 7	PSU 1015	SSU 1	SSU 8	PSU 1216	SSU 2	SSU 10	
		Acres			Acres			Acres			Acres		
1973 LANDSAT/U-2	1920	192	241	1048	166	192	1920	241	236	2048	243	230	
1975 LANDSAT	2304	-	-	2048	-	-	2432	-	-	2432	-	-	
1975 Photo/Ground	2096.2	198	217	1520	165	130	2274	231	250	2121	296	215	

1973 Multistage
sample total = 714,260 Ac

Sample error = 22%

Coefficient of determination
1973 LANDSAT - 1975 Photo/Ground = 0.28

1975 Multistage
sample total = 554,724 Ac

Sample error = 7.4%

Coefficient of determination
1975 LANDSAT - 1975 Photo/Ground = 0.92

Table 3. Summary of data for the Eastern Test Site. Irrigated land estimates from 14 PSU's.

Silver Creek Test Site

Estimated and observed acreages for the Silver Creek Test Site PSU's and SSU's are listed in Table 4. The irrigated cropland acreage for the complete test site is 19,374 acres with a sample error of 25.8 percent. The large sample error is because of the small number of samples (2) in the test site and the unique hydrologic environment of the valley. Across the southern portion of the valley a number of springs, which are the origin of Silver Creek, occur. Within this area the fields appear on imagery as irrigated croplands with high IR reflectance and a relatively dense crop cover. Although these fields do receive water throughout the growing season, it is because of the natural flow of the groundwater system. Since the fields are naturally watered they can not be classified as irrigated fields. PSU 0505 does occur in this region of the test site. Because of the unique nature of the Silver Creek Test Site, the investigators do feel the area should be considered an anomaly compared to the majority of irrigated land use in Idaho. Being an anomaly, the Silver Creek Test Site is not well suited for the application of large area sampling procedures based on remotely sensed data.

RECOMMENDATIONS FOR FUTURE INVENTORIES

LANDSAT imagery does provide an effective data base for conducting an inventory of irrigated cropland that will result in quantitative data by geographical units that are compatible for computer modeling input. The primary advantage of the LANDSAT data is its ability to provide an effective means of initially estimating the amounts and distributions of irrigated cropland so that a sampling scheme providing quantitative values can be implemented.

In the design of the state-wide survey of irrigated cropland, a number of factors should be considered. The inventory grid used to define the population units should be based on an established survey or grid system so as to insure consistent location of sample units. The arbitrary grid used during the pilot inventories proved difficult to work with. Minor errors in the grid complicated the positioning of ground plots and made it difficult to consistantly repeat the grid on multidate or new imagery. The grid was also difficult to reproduce in order to facilitate the location of sample units with computer classification output. Ideally any grid system used should be based on ground locations. The Department of Water Resources has established a 5km by 5km grid using the UTM coordinate system as a basis for hydrologic computer models; to be consistent the 5km grid should be used to conduct irrigated cropland inventories.

The timing of the LANDSAT data so that all irrigated croplands have sufficient vegetative cover to facilitate classification, is essential. As a general rule, imagery should be from the last week of July to the first week of August. Based on phenological data, imagery of irrigated regions west of Lake Wollcott, taken between July 15 and August 1 would be suitable.

	PSU 0404	SSU 1	SSU 5	PSU 0505	SSU 1	SSU 7
		Acres			Acres	
1972 LANDSAT	1792	-	-	1536	-	-
1975 Photo/Ground	1815	152	231	918	814	108

1972 Multistage sample estimate = 19,374 Ac

Sample error = 25.8%

Table 4. Summary of data for the Silver Creek Test Site. Estimated irrigated acreages for two PSU's.

Imagery for regions east of Lake Wollcott and intermountain valleys should be from August 1 to August 21. Classification of LANDSAT data should be conducted with the active participation of Department of Water Resources personnel. The greater the knowledge of the individuals conducting remote sensing data interpretation of any resource, the more accurate the interpretation results will be. The Department of Water Resources is continually involved with the agricultural industry in Idaho, and through the experience of its personnel is capable of improving data interpretation accuracy. Since inventory accuracy is dependent on the initial LANDSAT data interpretation, improvement of inventory accuracy will be greatest by improving LANDSAT interpretation accuracy.

A major limitation of the methodology used to conduct the pilot inventory is the dependence of the sampling scheme on high altitude, small scale photography such as the U-2 photography. Such photography is expensive to obtain on a repetitive basis for all irrigated areas, but is necessary for selecting the secondary sample units. The useful lifespan of such photography, especially for irrigated cropland, is also limited.

In Idaho, irrigation is expanding rapidly. During this study, increases of irrigated cropland were noted on the two sets (1973 and 1975) of U-2 photography, and these changes of irrigated cropland did influence the inventory results. For operational inventories it will be necessary to select secondary sample units by some other means. One method is that used by Heller, Aldrich, and Langley (1969) which employed a Polaroid-backed camera to obtain small scale photography of a complete PSU. SSU's can then be selected in-flight with real time photography. The large scale photography of the SSU's can be flown immediately, thus reducing cost and time for obtaining the necessary aerial photography.

MONITORING GROWTH OF IRRIGATED CROPLAND

An objective of this research was to investigate means of determining the growth of irrigated cropland. An operational inventory using LANDSAT imagery will not reflect increases of irrigated cropland until a year after they occur. Therefore means were investigated for determining annual changes in irrigated cropland. A valuable characteristic of LANDSAT is that repetitive data is obtained, allowing for the effective monitoring of land use change. By comparing classification of multidate data, the amount and nature of land use change can be determined.

One method of determining change is to establish a base level of information and, by periodically comparing new data to the base information, the location and magnitude of change can be noted. Currently in the case of irrigated cropland in Idaho, the only base level of information is considered too out of date (1967) and too general to be used effectively. Identification of newly irrigated cropland in Idaho can be best achieved by direct comparison of the multidate imagery.

An effective means of comparing two date imagery is by making a single multidate image. Using the Remote Sensing Lab.'s additive color image combiner (Fig. 5), 70mm black and white single band images from two different years were optically combined to form a single multidate image. For the purpose of demonstration and evaluation, 1972 and 1975 imagery of the Western Test Site, where large increases of irrigated cropland has occurred, were combined. The imagery used was from August 13, 1975 and September 15, 1972. The September imagery is not the optimum date to be used, but was the best imagery available. A number of multispectral scanner band and filtration combinations were tried. The best rendition was a result of the combination of bands 5 and 7 of the 1975 imagery projected with green and blue filtration respectively, combined with band 7 of the 1972 imagery projected with red filtration. The image combiner has been interfaced with an intervalometer and adapted so that an 8 by 10 inch film carrier can replace the viewing screen. Using the intervalometer to control exposure time, new photographic products of the composite image can be produced. The resulting multidate image is shown in Figure 6. Those lands that were newly irrigated between 1972 and 1975 are identified as those areas appearing violet or light turquoise blue.

Using such composite imagery, the location and estimates of newly irrigated lands can be determined. An advantage of this approach is that the newly irrigated cropland occurring in regions previously containing irrigation are more positively identified. On the composite image note the presence of the newly irrigated areas immediately to the east of the test site. These areas appear as small circles typical of central pivot irrigation systems. These newly developed areas occur within a region already containing substantial amounts of irrigated cropland. If the 1975 imagery had been compared to an existing small scale map of irrigated cropland, these new irrigated areas probably would not have been detected.

The process of producing the multidate imagery is fast when compared to the process of constructing land use maps based on imagery interpretation from one date and comparing the maps to imagery of another date; and the process is relatively inexpensive. The value of such multidate imagery for locating newly irrigated lands became apparent when Department of Water Resources personnel pointed out that they were unaware of the new developments that were described earlier. In specific areas of the state where groundwater pumping has caused excessive depletion of groundwater, a moratorium on expansion of irrigated cropland has been declared. By producing multidate imagery, compliance with the moratorium can be verified.

DETERMINATION OF IRRIGATION METHODS

Two major irrigation methods are used in Idaho: flood irrigation and sprinkler irrigation. Flood irrigation is defined as the application of water throughout a specific field by using gravity flow techniques such as siphon tubes or open flow. Sprinkler irrigation is the application of water throughout a specific field by using a pressurized system and sprinkler nozzels designed to spray water onto the land surface.

Figure 5. Additive color image combiner used to produce multidate imagery.

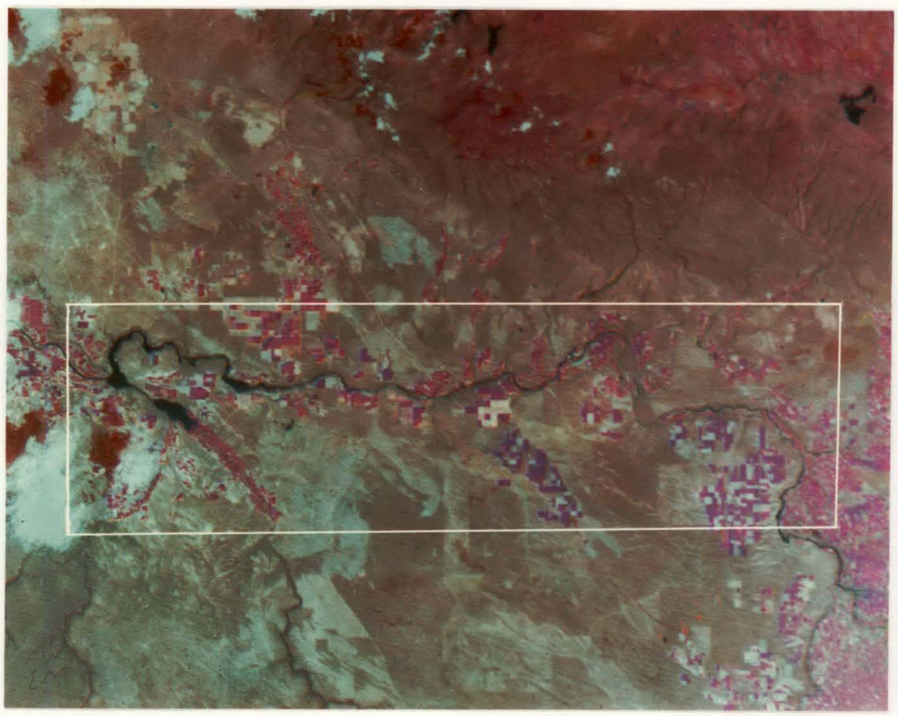


Figure 6. Multidate, 1972 & 1975, imagery of the Western Test Site. Newly irrigated croplands are violet and turquoise blue. Lands under irrigation in both 1972 & 1975 appear red to magneta.

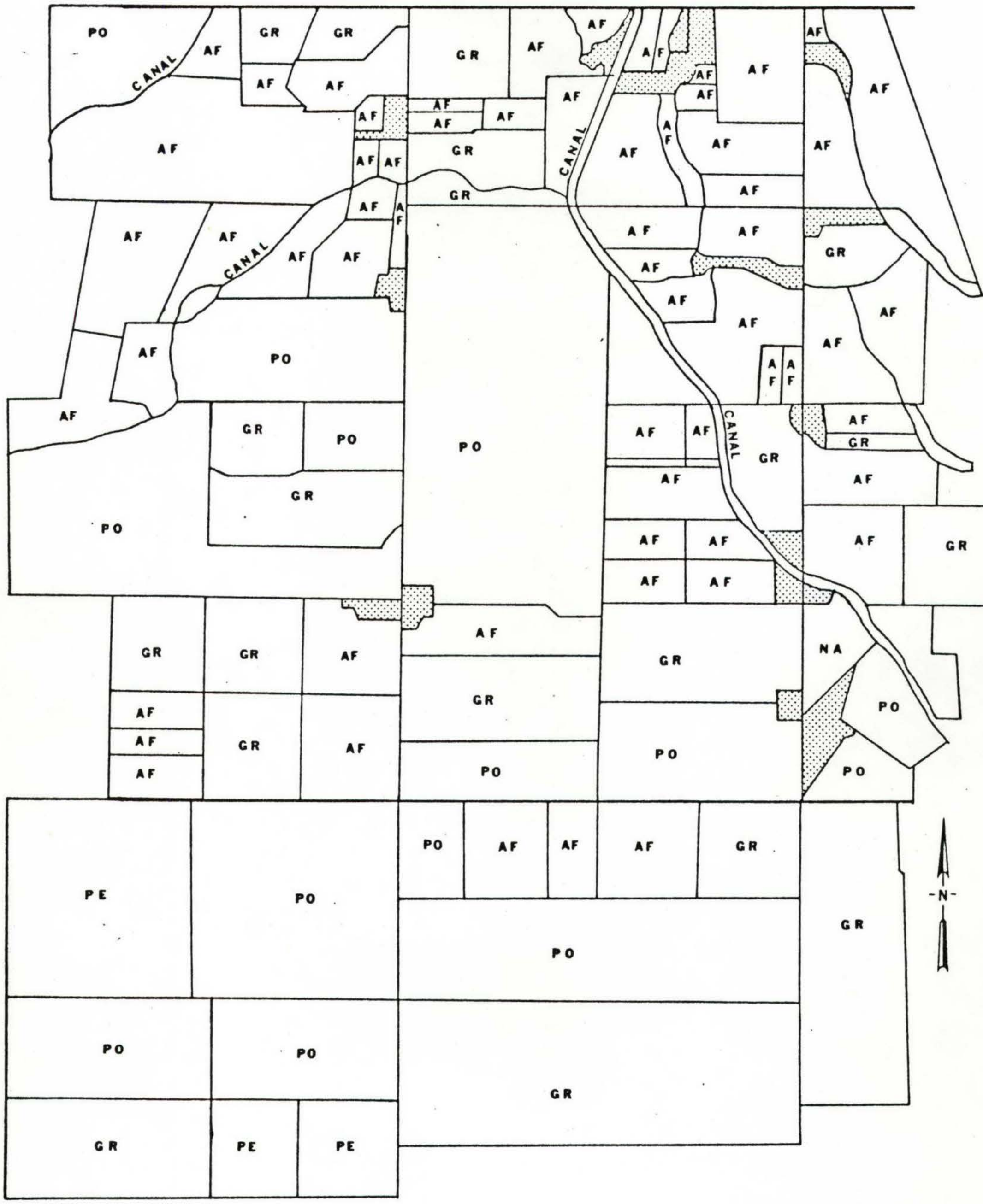
Determination of the method of irrigation directly from LANDSAT imagery is generally not possible. At times a banding effect in fields caused by sprinkler systems can be observed. The banding is because of the lower reflectance, especially in the IR bands, of wet soil. Since soil moisture resulting from the application of water is the cause of the banding, this characteristic is best observed on early season (June imagery). In order for the banding to be observed, irrigation must be active at the time of, or shortly prior to observation. The identification of sprinkler irrigated cropland based on banding is haphazard at best.

Another example of direct observation of an irrigation method occurs in the Egin Bench area of the Eastern Test Site. In this area, irrigation is accomplished by artifically maintaining a high water table. The soils of the area are exceptionally porous and unable to maintain sufficient field capacity to support crops. By diverting large amounts of water, often in excess of 10 acre feet annually, the water table is maintained at a high enough level to supply moisture for plant consumption. Much of the water used by this method is diverted early in the growing season. On May LANDSAT imagery, these areas of Egin Bench can be identified because of extremely high soil moisture.

Upon examination of preliminary data, it was felt that major irrigation methods could be identified based on field size. The method of applying water often controls the optimum field size. In the case of flood irrigation, water is distributed throughout the field by overland flow. Those areas closest to the delivery point of the water receive greater amounts of water than those areas farther away. If a field is excessively large, water will not be adequately distributed throughout the field. Other factors, such as soil characteristics and water velocity, do influence the size of an area that can be effectively irrigated by flood irrigation, but the method of irrigation is most influential. In the case of sprinkler irrigation, water is delivered under pressure throughout the field by piping, allowing water to be evenly distributed throughout a large area.

Since similar irrigation practices do occur in the same general area, it was felt that particular irrigation methods could be identified on the LANDSAT imagery. Field size is a major component of the pattern of agricultural land use. Various regions can be distinguished based on differences in appearance because of differing field sizes. By noting the variations of pattern, different irrigation methods can be noted for different areas.

Data were collected in the Western and Eastern Test Sites as to field size and irrigation methods in each PSU. Highly significant differences between the average field sizes for the two irrigation methods were found in both test sites. Table 6 lists the average field sizes for the two test sites and the 99 percent confidence intervals for field sizes. Based on these observations, one can conclude that the large difference in field sizes associated with irrigation methods can be used to delineate areas of flood and sprinkler irrigation. Figure 7 demonstrates the difference of field sizes associated with different irrigation methods. Since the average field size does differ greatly with the irrigation method and field size is a major component of agricultural land use patterns, it is hypothesized that areas of flood and sprinkler irrigation can be delineated using LANDSAT imagery. Data collected during this investigation are not



PO - potatoes
PE - field peas
GR - grain

AF - alfalfa/forage
NA - non-agricultural
Shaded - farmsteads

Figure 7. The difference in field size associated with irrigation methods is evident. The northern and northeastern portions of the area, where canals exist, are flood irrigated, while the southern and southeastern portions of the area are sprinkler irrigated. The area is from PSU's 0717 and 0718 of the Eastern Test Site.

suitable for testing the hypothesis which will be investigated during the 1976 agricultural season.

	Irrigation Method					
	Flood			Sprinkler		
	Mean	Error 1/	Range	Mean	Error 1/	Range
	Acres			Acres		
Western Test Site	11.4	±2.9	8.4-14.3	94.5	±19.6	74.8-144.1
Eastern Test Site	16.2	±0.9	15.3-17.1	77.2	±18.4	58.7- 95.6

1/ At 99 percent confidence level.

Table 5. Mean field sizes and confidence limits by irrigation methods.

It should be noted that these conclusions are based on the average field size. The variance of the data for individual fields is too great to consistantly use field size as a criteria for identifying irrigation method of an individual field. There are cases where small fields are being irrigated by handline sprinkler irrigation and a few cases where previously flood irrigated fields have been converted to sprinkler irrigation. The criteria of field size may be best applied for delineation of different areas of irrigated cropland that have different water use characteristics.

IDENTIFICATION OF SOURCE OF IRRIGATION WATER

No means were found to identify the source of irrigation water. The physical appearance of agricultural lands does not vary with differing sources of water. It is felt that LANDSAT imagery could play only a limited role in defining areas supplied by surface water or groundwater sources.

IDENTIFICATION OF CROP TYPE

The Forestry Remote Sensing Lab. did not attempt identification of crop types using LANDSAT imagery. A majority of crop identification using the LANDSAT photographic products has been accomplished using sequential imagery and noting the change of appearance of individual fields during the growing season. In order for this method to be used, individual fields must be identifiable. In the case of the agricultural areas of Idaho, many of those fields being flood irrigated are to small to be individually located on LANDSAT imagery, prohibiting the identification of crop type based on changes of field appearance during the growing season.

In support of the PNRC Land Resource Inventory Demonstration Project, NASA/Ames and the USGS Geography Program are conducting classification of LANDSAT CCT's. The objectives of the classification are to: 1) identify irrigated cropland; 2) identify crop types; and 3) identify other land uses according to Anderson's (1972) Level II classification scheme. Computer processing of the Silver Creek Test Site has been completed. Agricultural lands were identified accurately but were not properly classified as irrigated or non-irrigated because of the unique situation of extensive subirrigation within the test site. Most cropland in the test site supports pasture and forage crops which exhibit a wide range of spectral reflectance values. Because of wide variation of spectral reflectance values among the same crops and the limited ground truth information for the area, classification of crop types was prohibited. Croplands were thus divided into activity classes of idle and growing. Four classes of growing crop conditions were identified based on the degree of infrared reflectance, but these classes could not be associated with a particular crop type.

Computer classification results for the Western and Eastern Test Sites were not received in time to include a detailed analysis of the results in this report. Initial observations of the Western Test Site indicate that single date data cannot discriminate individual crop types because spectral variations within a single crop are as great or greater than variations between crops. This is due to greater differences in farming practices and wider variations in field conditions. In order to achieve a classification, crop types in the Western Test Site were classed as row crops, cereal crops, and forage crops. The Eastern Test Site classification, using multidate data, is much more detailed. The specific row crops have been identified. Accuracy statements will be made as soon as the data are analyzed.

Examples of computer classification output products of the Western Test Site based on September 1974 data (Fig. 8) and preliminary classifications of the test site using August 1975 data (Fig. 9) are included. Each color of the classified scenes represents a specific spectral reflectance class that may be directly associated with ground conditions. Figure 8 is produced by a DICOMED high resolution color film recorder. Figure 9 is a photograph of the high resolution CRT display of classified LANDSAT data produced by the IDIMS (Interactive Digital Image Manipulation System). Both classifications were produced by the USGS Geography Program at the NASA/Ames Research Center.

Figure 8. DICOMED output of computer classification of the Western Test Site using September 1974 data. Various green and purple areas represent irrigated cropland.

Figure 9. IDIMS display of preliminary computer classification of the Western Test Site using August 1975 data. Yellow represents grains, light greens row crops, and blue forage crops.

CONCLUSIONS

LANDSAT imagery can effectively be used to provide quantitative inventories of irrigated croplands in Idaho. The primary value of the imagery is its synoptic view which allows the total population of irrigated cropland to be estimated and divided into population units. Multistage variable probability sampling is well suited to be used in conjunction with multistage remote sensing data to conduct an inventory. Although multistage sampling is sensitive to inaccuracies in interpretation of imagery, the use of optimally timed imagery taken the last week of July or the first week of August will result in initial estimations sufficiently accurate to yield sample errors of less than 10 percent. To insure locational accuracy, data flexibility, and computer model compatibility, the established 5km by 5km UTM grid system should be used for future inventories. Multiscale imagery or photography can be effectively used to expand ground truth information so that more detailed information over large areas may be obtained.

LANDSAT imagery does allow the increases of irrigated cropland to be measured on an annual basis. By making color composite multidate images, newly irrigated cropland can be identified. An advantage of the multidate imagery is that the information is contained within a single data format facilitating rapid assessment of irrigation expansion. Procedures to determine irrigation expansion throughout the state can be easily implemented.

The deliniation of different agricultural regions within Idaho may be accomplished using LANDSAT imagery. The distribution of major agricultural practices such as different irrigation methods can be deduced from LANDSAT and small scale CIR imagery. Other agricultural land use criteria may be determined based on imagery stratification which will allow more detailed water related land use information to be obtained for computer hydrologic models.

Classification of crop types in Idaho by optical interpretation of imagery is not possible for many areas of the state because of the small fields associated with flood irrigation. Classification of crop types within areas of large fields may be possible by using sequential imagery from throughout the growing season. Sample estimates of individual crop types can be made from large scale CIR photos when supplemented with ground examination.

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APPENDIX

Multistage Variable Probability Sampling

The following is a description of the multistage variable probability sample procedure used to conduct the pilot inventories of irrigated cropland. This description and the equations are based on that given by Langley (1975). In order to employ any form of variable probability sampling, three criteria must be met: 1) every member of the population must have a known probability, not necessarily equal, of being selected; 2) the sample must be drawn by some method of random selection; and 3) the probabilities of selection are taken into account when making the estimates from the sample.

It is by satisfying the first criteria of variable probability sampling that LANDSAT imagery is essential. The synoptic, large area view of LANDSAT allows the total population (the irrigated croplands) to be defined. The test areas were arbitrarily divided into four square mile units. Each unit is an identifiable member of a finite population. By visually interpreting the LANDSAT scene, the percentage of irrigated croplands was estimated for each four square mile unit in each test site. The sampling is based upon the amount of irrigated croplands, thus insuring that we observe and measure the phenomenon of primary interest. If a random sample were used, essentially the total ground cover of a test site would be sampled even though we were only interested in irrigated cropland. It is with the use of LANDSAT imagery that a large area can easily be viewed and the resources to be inventoried, interpreted and delineated.

The four square mile sample units, referred to as primary sample units (PSU's) are selected based on the probability of each containing irrigated croplands. When the interpretation of a test site is completed, the estimated percentages and cumulative totals of irrigated croplands are listed. Then, using a random number table, random numbers from 0 to ΣE_i, where E_i is the estimated percent of irrigated cropland in the i^{th} population unit are selected. Those sample units which account for the randomly selected values become primary sample units. By following this sample selection procedure the second criteria of variable probability sampling is met.

The final criteria is that of establishing an estimate in accordance with the variable probabilities of selection. If a random sample is used the population estimator is:

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

A = the total irrigated acreage in the population
a_i = the measured irrigated acreage in the i^{th} sample unit
n = the number of sample units
N = the total number of units in the population

Which is equal to:

$$A = \frac{1}{n} \sum_{i=1}^{n} a_i \Big/ \frac{1}{N}$$

$\frac{1}{N}$ is the probability of randomly selecting any given unit on a single draw.

In the case of variable probability sampling, the probability of selecting any given unit P_i is the estimated irrigated acreage of a given unit divided by the sum of all the estimated irrigated acres in the test site. The ratio of observed acreage and the probability of selection, a_i/P_i is an estimator of the total population for a single sample estimate. Therefore, a single stage variable probability estimator is:

$$A = \frac{1}{n} \sum_{i=1}^{n} a_i/P_i \quad (3)$$

(All symbols previously defined)

The accuracy or variance of the estimate is dependent on the correlation between the acreage of irrigated croplands predicted in each PSU and the actual acreages measured on the ground. If the values were to correlate precisely (r=1), the variance would be zero. Such a condition is not realistic. If the variance were zero then the true amount of irrigated croplands would be known and sampling would be unnecessary. Langley also states that the variance of a variable probability sample may be estimated by the following equation:

$$\text{Var}(A) = \frac{1}{n(n-1)} \left[\sum_{i=1}^{n} \frac{a_i}{P_i} - nA^2 \right] \quad (4)$$

(All symbols previously defined)

This estimator of variance, based on a single stage estimate, may also be used to determine the unbiased estimate of sample variance for a two or more stage sample estimate (Langley, 1975, p. 25).

In many instances, especially when working with large areas, the PSU's are too large to effectively be measured on the ground. If this is the case, each PSU can be subdivided into secondary sample units (SSU's). Again applying the variable probability sampling process, SSU's can be selected from each PSU for measurement. This process of subsampling may be continued through as many stages as necessary to obtain a measureable sample size. For inventorying irrigated cropland, a two stage sampling routine was used. The estimator for a two stage sample is:

$$A = \frac{1}{m} \sum_{i=1}^{n} \frac{1}{P_i n_i} \sum_{i=1}^{m} \frac{a_{ij}}{P_{ij}} \quad (5)$$

A = estimated total irrigated acreage.
A_{ij} = observed irrigated acreage in the j^{th} sub-sample of the i^{th} primary sample.
P_{ij} = the conditional probability of selecting the j^{th} sub-sample. from the i^{th} primary sample.
P_i = the probability of selecting the i^{th} primary sample.
n_i = the number of sub-samples in the i^{th} primary sample.
m = the number of primary sample units.