

Using Remote Sensing and GIS Technology to Help Adjudicate Idaho Water Rights

Anthony Morse, Thomas J. Zarriello, and William J. Kramber

Idaho Department of Water Resources, Boise, ID 83720

ABSTRACT: The Idaho Department of Water Resources (IDWR) is using remote sensing and GIS in the nation's largest water rights adjudication. Landsat MSS images are geometrically controlled, transformed to principal components, clustered, and classified to identify six information classes: irrigated agriculture, dryland agriculture, non-agricultural land, riparian vegetation, water, and clouds and/or cloud shadows. The Public Land Survey System (PLSS) is being converted to a digital format subdivided to the quarter-quarter section (QQ) level. The classified Landsat image is overlaid with the PLSS digital file, and the acreage of each land-cover class is computed for each QQ. The output products are Mylar film positives registered to 1:24,000-scale quads showing the land-cover classification, and tabular files listing the land cover acreage per QQ. These products are designed to assist water users in filing accurate water-right claims, and to help IDWR personnel in processing those claims. Classification accuracy is measured using regression analysis of Landsat-based irrigated acreage against acreage measured from USDA Agricultural Stabilization and Conservation Service aerial slides, for a random sample of irrigated sections. Results from the first five counties processed show an average r^2 of 0.90.

INTRODUCTION

THE IDAHO DEPARTMENT OF WATER RESOURCES (IDWR) is in the process of adjudicating all the water rights in the Snake River Basin of Idaho. This is the largest water-right adjudication attempted in the United States and includes an estimated 140,000 water rights within about 72,000 square miles, as illustrated by Figure 1. The purpose of this paper is to explain the background of this project and discuss the methodology developed at IDWR to help facilitate this huge undertaking using remote sensing, image processing, and geographic information system technology.

The Snake River Plain, which supports most of Idaho's irrigated agriculture, covers approximately 18,000 square miles of arid land. Over the last 130 years, irrigation projects have enabled farmers to bring progressively more acreage into production so that, by 1989, water is being pumped or diverted onto about 4 million acres. While Idaho farmers depend on Snake River water to supply them with three quarters of their irrigation supply, the Idaho Power Company depends on the same Snake River water for about 57 percent of its electrical generating capacity. These competing needs inevitably led to conflict, and, in 1982, the Idaho Supreme Court decided "Idaho Power Co. vs. The State of Idaho, *et al.*" The issues were complex, as is typical of western water-right controversies.

Costello and Kole (1985) describe the case in detail, but it can be summarized as follows. The Court upheld the Idaho Power Company's contention that its early 1900s water right for 8,400 CFS at the Swan Falls Dam, which is at the western (downstream) end of the Snake River Plain, was not necessarily subordinate to the water rights of upstream irrigators. With the stroke of a pen, water on the Snake River Plain went from partially appropriated to over-appropriated.

In responding to the decision, the Idaho Power Co. did not seek to confiscate any water being put to beneficial use. Instead, it filed suit against about 7500 holders of upstream permits and water-right applications for which beneficial use had not yet been proven. After two unsuccessful attempts by the State Legislature to resolve the conflict, and facing millions of dollars of costs for years of litigation, the Governor, the Attorney General,

and the Idaho Power Co. negotiated a settlement that the Legislature ratified in 1985. The affected parties agreed to several points, one of which being that all water rights in the Snake River drainage must be adjudicated. The Idaho Legislature required that IDWR provide the presiding Court with all the tech-

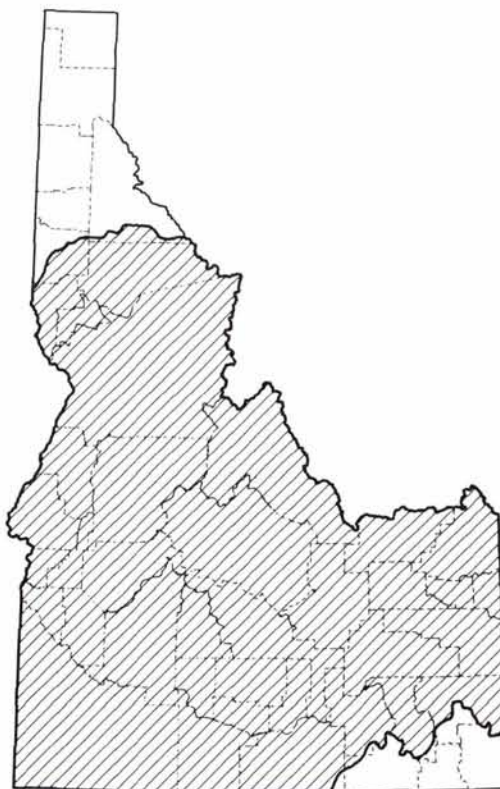


FIG. 1. The crosshatched area shows the part of Idaho subject to adjudication.

nical information necessary for the Court to make a decision about each water right.

In order to comply with the Court's mandate, IDWR is using remote sensing and GIS technology to estimate the irrigated acreage associated with each water right (Morse *et al.*, 1988). That estimate can be compared to the existing water rights file and to the claims submitted as part of the adjudication to help assess the accuracy of the claims.

PROCEDURES

The staff of the Idaho Image Analysis Facility (IIAF), a remote sensing/GIS section within IDWR, devised a three-step methodology for using image processing and GIS to help complete the adjudication in the planned ten years. For the first step, Landsat multispectral scanner (MSS) digital data are classified to produce land-cover maps with six classes, including irrigated land. Second, section corners of the Public Land Survey System (PLSS) are digitized from 1:100,000-scale, stable-base, mylar maps, and the sections are subdivided into quarter-quarter sections, government lots, Bureau of Reclamation tracts, patented mining claims, and homestead entry claims, which are referred to here collectively as "QQs." QQs are used because the location of Idaho water rights is keyed to quarter-quarter sections. Third, the Landsat data are digitally overlaid with the corresponding subdivided PLSS data, and the irrigated acreage is computed for each QQ.

IMAGE PROCESSING

The image processing aspect of the project is based on digital analysis of Landsat MSS data using in-house software, clustering and classifying software from Spectral Software Associates, Inc., and other image processing software from ERDAS, Inc. The analysis included four steps: (1) geometric control, (2) principal component analysis, (3) unsupervised classification, and (4) postclassification sorting.

Fifteen Landsat MSS scenes are required to cover the Snake River Basin. IDWR purchased the scenes from EOSAT based on minimum cloud cover and dates that corresponded to peak agricultural crop maturity. The dates of 14 of the scenes ranged from 3 July 1986 to 23 August 1986. One scene dated 16 July 1984 was acquired because no acceptable 1986 or 1985 scene was available. EOSAT radiometrically and geometrically corrected all scenes, resampling pixels to 57 by 57 metres.

IIAF personnel geometrically referenced each full Landsat scene to the UTM coordinate system with an affine transformation. The process involved using the ERDAS programs GCP, COORD2, and RECTIFY. An analyst selected approximately 25 well distributed ground control points within each scene and on 1:24,000-scale USGS quads, set the error tolerance for both the x and y directions to ± 1.0 pixels, and, based on the results of Logan and Strahler (1979), chose bilinear interpolation to resample the images.

Each scene was transformed to its principal components as the second step in image processing. Principal component analysis (PCA) is a statistical procedure that transforms a set of data into a new system of axes based, in this case, on the variance-covariance matrix (Chatfield and Collins, 1980). PCA was used to reduce the dimensionality of the data, which in turn reduced both the volume of data to be processed and the CPU time needed to process them. The ERDAS program PRINCE transformed the geometrically corrected images based on transformation coefficients computed from a 7 by 7 subsample of image data. The principal components were not scaled in order to maintain their relative magnitudes of variance. PCA effectively reduced the four MSS bands to two components containing at least 98 percent of the variance for each scene processed. The remaining image processing steps used principal components one (PC1) and two (PC2).

Spectral Software Associates software clustered and classified county sub-scenes using histograms and look-up tables for extremely fast processing of ERDAS-format images. The clustering software is based on an iterative, converging algorithm (Forgy, 1965), and generates up to 255 clusters from all image vectors. The classifier uses a table look-up method similar to those described by Shlien (1975) and Wharton (1983). Selecting the number of spectral classes to generate in unsupervised classifications is often difficult and subjective depending on the algorithm used. IIAF analysts decided that, for a project of this scale, it was inappropriate to experiment with different numbers of spectral classes for each classification, and adopted the practical and consistent solution of generating the maximum number (255) possible for each classification.

The 255 spectral classes were identified and aggregated to five land-cover types: irrigated agriculture, dryland agriculture, non-agricultural land, riparian vegetation, water, and one class of clouds and/or cloud shadows. This was done, first, by generating a scatterplot of PC1 and PC2 from the statistics file that stores the mean vector and variance-covariance matrix for each cluster. The cluster number from the statistics file was also written to the scatter plot. Next, PC1 and PC2, which approximate the brightness and greenness of Kauth and Thomas (1976), were read into the green and red image display planes, respectively. Then the ERDAS program CLASOVR wrote the classified image into the blue band. This allowed one or more spectral classes to be highlighted and labeled to one of the six information classes with the corresponding false-color image as background. This procedure allows efficient class identification and labeling.

Postclassification sorting is a common technique used in remote sensing to improve classification accuracy (Cibula and Nyquist, 1987; Hutchinson, 1982). For this project, an image interpreter delineated irrigated agriculture, dryland agriculture, and riparian vegetation using image interpretation techniques to interactively screen digitize these class boundaries with the ERDAS program DIGSCRN, while displaying a 512 by 512 subscene of the Landsat data. Areas outside of these boundaries were non-agricultural land. When the Landsat data were inconclusive, the interpreter analyzed U-2 color-infrared photographs to assist in drawing these boundaries. After all boundaries were completed, the vector file was converted to raster using the ERDAS program GRDPOL. An in-house program, TOL, overlaid the 255-class image with the file created from image interpretation using a GIS matrix operation to produce the final classification.

Using postclassification sorting reduces total classification error by preventing certain cases of commission error. For example, in many parts of Idaho, harvested fields of irrigated small-grains are spectrally similar to native rangeland. This results in spectral classes that represent both the irrigated-agriculture and non-agriculture information classes. Postclassification sorting allows each spectral class to be labeled to more than one information class and eliminates commission errors of irrigated agriculture from occurring in non-agricultural areas, thus increasing classification accuracy.

GIS PROCESSING

The first aspect of the GIS effort is digitizing the PLSS from stable-base Mylar maps at 1:100,000 scale. Under the best of circumstances, digitizing is an involved and time-consuming task, and this project is no exception. IIAF personnel decided to use 1:100,000-scale maps primarily because of the significant reduction in time needed for set-up and edge-matching over 1:24,000-scale maps, and because the accuracy of the 1:100,000-scale maps was deemed adequate for this application. In the course of the adjudication, IIAF personnel will digitize about 2000 townships, and sub-divide them into a total of about 1,100,000 polygons.

A typical township has 36 regular sections, each of one square

mile or 640 acres. Sections are divided into quarter-sections of 160 acres each. Quarter sections, in turn, are divided into quarter-quarter sections of 40 acres, so that a typical township has $36 \times 4 \times 4 = 576$ quarter-quarter sections of 40 acres. If a township has QQs that are less than or more than 40 acres they are no longer QQs, but rather government lots, and are shown as such in the PLSS data-layer. Townships are normally lotted along their north and west boundaries, but, in fact, lotting can be found along any boundary of any section.

After the 49 section corners of each township are digitized, in-house software can automatically subdivide sections into QQs. The software calculates the UTM corner coordinates of each QQ and a corresponding attribute that includes the legal description and center-point coordinates. If a section is lotted regularly, the task is complete; if the lotting is irregular, more work is needed. Sub-dividing irregular sections is complex and time-consuming, but, fortunately, only about 20 percent of Idaho townships have irregular lotting.

Editing the irregularly lotted sections is done manually. The in-house program TOWNS sub-divides regular sections, leaving the irregular sections undivided and in a form ready for editing. An analyst enlarges and prints to paper the microfiche plat-map of the irregular section, superimposes the township plot on the plat map, traces and digitizes the boundaries of the irregular lots, and adds the appropriate attributes. The analyst then appends the new data to the files produced for the regular sections of the township. At this point, the lotting of irregular sections is completely represented in the digital township-file. The job is very labor-intensive, but it produces data that very closely match the legal plat. Figure 2 illustrates part of a subdivided township that has both regularly and irregularly subdivided sections.

The second aspect of the GIS effort is to overlay the subdivided PLSS grid onto a Landsat classification. This overlay requires, first, a vector-to-raster conversion of the PLSS file. One problem with this process is that using the 57 by 57 metre pixel size of the Landsat MSS results in inaccurate acreage totals for QQs.

Using a 14.25 metre pixel for the raster PLSS reduced the severity of this problem. Table 1, which summarizes the results of regression analysis using various pixel sizes, shows that a 14.25-metre pixel more nearly estimates the correct QQ size than does a larger pixel size. At the same time, a pixel smaller than 14.25 metres is impractical due to hardware and software limitations on the volume of data. The in-house program TOWNOVER overlays the PLSS raster file on the Landsat classification to produce a tabular file that lists the acreage of the six classes per QQ.

OUTPUT PRODUCTS

The two output products for the adjudication are Mylar overlays, registered to 1:24,000-scale orthophoto quads, and tabular files. Neither product is used as a court document. Rather, they provide the State with the means to assist claimants by offering a tabulation of irrigated acreage by QQ with the graphical display of familiar land features showing the irrigated acreage as of the 1986 base date. This helps both claimants and IDWR personnel in assuring that the legal description and number of irrigated acres for a water right are accurately represented on a water right claim. Figures 3a and 3b show six sections of an orthophoto quad with its associated classification overlay.

Table 2 is an example of part of a tabular file. The tabular file shows the irrigated acreage per QQ, which is compared to the state water right file and to adjudication water-right claims. This has two purposes. First, it will show if irrigated lands exist

TABLE 1. THE COEFFICIENT OF DETERMINATION (R^2), FROM REGRESSION ANALYSIS, OF DIGITIZED POLYGON ACREAGE VERSUS RASTER ACREAGE OF QUARTER-QUARTERS, FOR THREE PIXEL SIZES.

Pixel Size in Metres	r^2
57 by 57	0.62
28.5 by 28.5	0.89
14.25 by 14.25	0.96

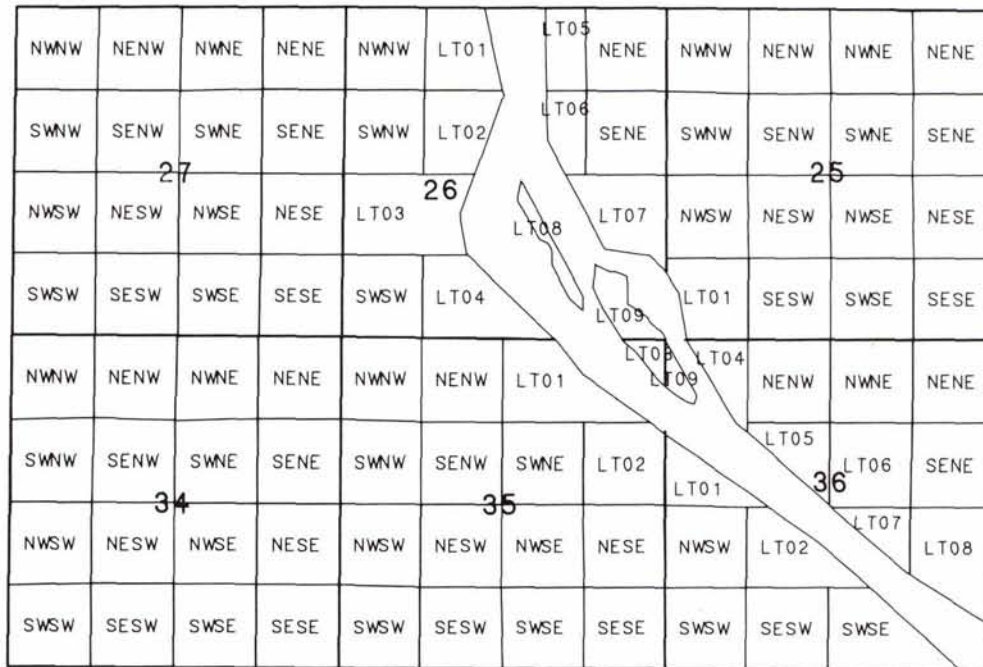
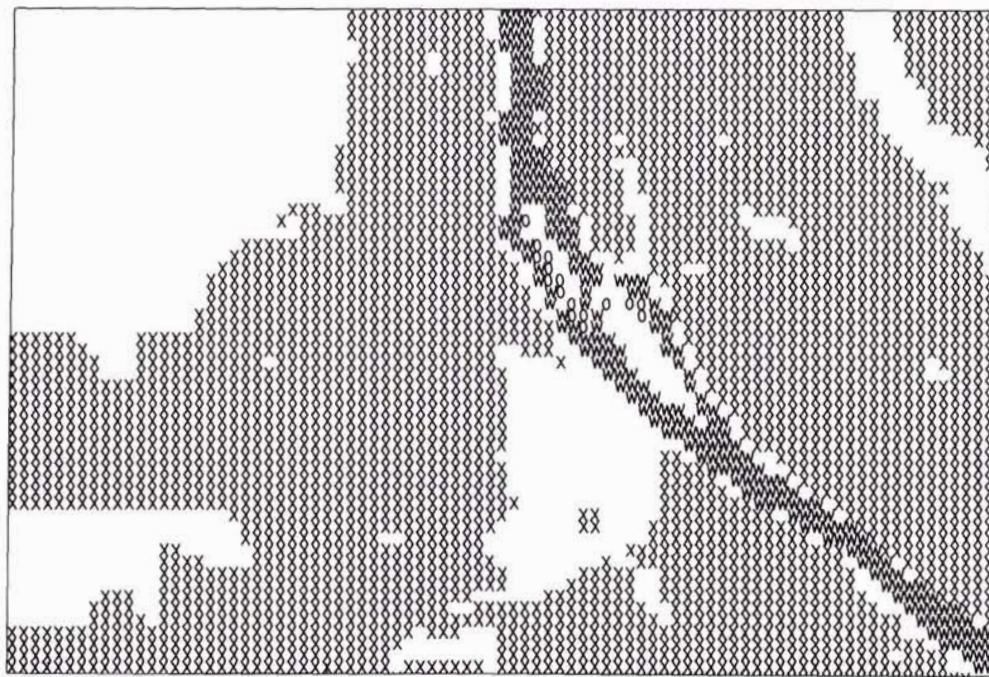


FIG. 2. A portion of Township T2NR4W of the Public Land Survey System that covers part of the Opalene Gulch quadrangle. Sections 27 and 34 are regularly sub-divided, while sections 25, 26, 35, and 36 are irregularly subdivided.



(a)



(b)

FIG. 3.(a) A portion of the Opalene Gulch, Idaho orthophoto quadrangle. (b) The Landsat classification overlay corresponding to part of the Opalene Gulch, Idaho quadrangle.

Symbol	Class
X	Non-Irrigated
O	Irrigated Agriculture
W	Riparian
	Water

where no water right claims have been filed. Property ownership is researched to allow the State to give water users every opportunity to file a water right claim. Second, it provides an estimate of irrigated acreage that is independent of both the

irrigator's claim and the recorded water right. If the claimed acreage and/or the recorded acreage differs from the Landsat estimate by a threshold, yet to be determined, the irrigator and IDWR can reconcile the difference using the Mylar overlays and

TABLE 2. A PORTION OF THE OUTPUT TABULAR FILE SHOWING THE ACREAGE BY LAND-COVER CLASS FOR EACH QUARTER-QUARTER SECTION AND GOVERNMENT LOT OF T2NR4WS36.

TNSHP	SEC	QQ	IRR	NON	DRY	RIP	WAT	C/S
02N04W	36	LT08	47	1	0	0	4	0
02N04W	36	LT05	21	2	0	0	0	0
02N04W	36	LT09	0	4	0	0	0	0
02N04W	36	LT02	36	0	0	0	0	0
02N04W	36	LT04	14	1	0	0	0	0
02N04W	36	LT07	12	1	0	0	2	0
02N04W	36	LT01	18	1	0	0	0	0
02N04W	36	LT06	40	0	0	0	0	0
02N04W	36	NENE	38	2	0	0	0	0
02N04W	36	NENW	39	0	0	0	0	0
02N04W	36	NWNE	40	0	0	0	0	0
02N04W	36	NWSW	42	0	0	0	0	0
02N04W	36	SENE	42	0	0	0	0	0
02N04W	36	SESW	40	0	0	0	0	0
02N04W	36	SWSW	37	1	0	0	0	0
02N04W	36	SWSE	42	3	0	0	0	0

corresponding orthophoto quadrangle maps, high altitude photography such as NHAP or NAPP, or, if necessary, by field verification. This process will allow IDWR to process routine, non-controversial claims quickly and efficiently while identifying those water right claims that most need the expensive attention of a field investigation.

ACCURACY EVALUATION

The accuracy of the Landsat classification for each county is evaluated by comparing the Landsat computed irrigated acreage to an independent estimate of the irrigated acreage, for a random sample of sections. The independently estimated acreage-totals are derived from large-scale, 35-mm, aerial slides taken by the USDA Agricultural Stabilization and Conservation Service (ASCS) in July 1986 – and in July 1984, for the portions of the three counties that fall within the 1984 Landsat scene.

ASCS data and Landsat data are combined to measure accuracy in the following way. First, a random sample equal to 5 percent of the total number of sections in the agricultural stratum is generated for each county. Then IIAF personnel travel to each ASCS county office with the list of randomly chosen sections to use the USDA/ASCS 1986 or 1984 compliance slides. These 35-mm aerial slides are taken every year and cover the agricultural land in each county. Next, the aerial slides covering each section on the list are projected and registered to 1:24,000-scale quad maps. The boundaries of each irrigated field in the section are drawn onto the quad map, and later digitized in IDWR using ESRI's ARC software. The resulting INFO report lists the irrigated acreage for each section produced from the ASCS slides.

The two acreage figures are compared using regression analysis in which Landsat-derived acreage predicts ASCS acreage. In this application, the ASCS acreage is considered to be a surrogate for true acreage, and therefore is the dependent variable. The Landsat acreage is the independent variable. The coefficient of determination (r^2) is used as the measure of classification accuracy. Table 3 shows the results of accuracy evaluation for the first five counties processed. The mean r^2 is 0.90, but this figure is only for the irrigated stratum. If the non-irrigated land of the county were included, the r^2 values would be higher.

The regression methodology is adapted from Sigman *et al.*, (1977). This method was chosen because it is efficient and revealing. The methodology is efficient because it uses section areas sampled from the irrigated stratum, rather than from the whole county. The sampling and the computations are focused

TABLE 3. ACCURACY FIGURES FOR THE IRRIGATED STRATUM OF THE FIRST FIVE COUNTIES PROCESSED. ACCURACIES ARE IN THE FORM OF COEFFICIENTS OF DETERMINATION (r^2), FOR LANDSAT ESTIMATED IRRIGATED ACREAGE VS. ESTIMATES COMPILED FROM USDA/ASCS SLIDES.

County	r^2
Adams	0.96
Clark	0.83
Lincoln	0.96
Gooding	0.88
Twin Falls	0.87

on the principal class of interest to this project, irrigated agriculture.

The method is revealing in two ways. First, as Card (1982) and Story and Congleton (1986) point out, accuracy figures should include both commission and omission errors. The r^2 values are computed from sums of squared errors, and thus are a function of both omission and commission error. Second, the sign of the Y intercept indicates whether the Landsat classification is over- or under-estimating irrigated acreage relative to the ASCS data. The project manager for the adjudication placed a smaller cost of misclassification on over-estimating than on under-estimating irrigated acreage. All results have shown negative Y intercepts, indicating that irrigated acreage is being consistently overestimated.

SUMMARY

This paper illustrated how a large-scale adjudication of water rights, an important regulatory process, can be facilitated by using remote sensing, image processing, and GIS technology. These tools allowed IDWR to process and combine information derived from a variety of sources and scales. These include satellite digital data, U-2 photography, 35-mm aerial slides, 1:100,000-scale clear Mylar maps, cadastral survey plats on microfiche, and 1:24,000-scale orthophoto quads. IDWR analysts used digital image processing and GIS technology to analyze and composite these data. The resulting products are land-cover overlays at 1:24,000 scale and a large database of land-cover information. These products are being used to help water consumers and the Idaho Department of Water Resources better manage Idaho's water.

ACKNOWLEDGMENT

The authors wish to acknowledge the work of Ben R. Britton, who wrote much of the software used in this project.

REFERENCES

- Card, Don H., 1982. Using Known Map Categorical Marginal Frequencies to Improve Estimates of Thematic Map Accuracy. *Photogrammetric Engineering and Remote Sensing* 48 (3):431-439.
- Chatfield, C., and A.J. Collins, 1980. *Introduction to Multi-variate Analysis*, Chapman and Hall, London.
- Cibula, W. G., and M. O. Nyquist, 1987. Use of Topographic and Climatological Models in a Geographic Data Base to Improve Landsat MSS Classification for Olympic National Park. *Photogrammetric Engineering and Remote Sensing*, 53(1):67-75.
- Costello, P. D., and P. J. Kole, 1985. Commentary on Swan Falls Resolution. *Western Natural Resource Litigation*. Summer, 1985. pp. 11-18.
- Forgy, E., 1965. Cluster Analysis of Multivariate Data: Efficiency vs. Interpretability of Classifications. *Abstract. Biometrics*, Vol. 21: p. 768.
- Hutchinson, C.F., 1982. Techniques for Combining Landsat and Ancil-

- lary Data for Digital Classification Improvement. *Photogrammetric Engineering and Remote Sensing* 48(1):123-130.
- Kauth, R.J., and G. S. Thomas, 1976. The tasseled cap--A graphic description of the spectral-temporal development of agricultural crops as seen by Landsat. *Proceedings of the Symposium on Machine Processing of Remotely Sensed Data*, West Lafayette, Indiana, pp.85-91.
- Logan, T. L., and A. H. Strahler, 1979. The Errors Associated with Digital Resampling of Landsat Forest Imagery for Multidate Registration. 8th Annual Remote Sensing of Earth Resources Conference, Tennessee Space Institute, Tullahoma, Tennessee.
- Morse, A., H. N. Anderson, and J. Peppersack, 1988. Spuds from space--using remote sensing/GIS in adjudicating Idaho water rights. *Proceedings of the Symposium on Water-Use Data for Water Resources Management*, Tucson, Arizona, pp.703-710.
- Sigman, R. S., C. P. Gleason, G. A. Hanuschak, and R. R. Starbuck, 1977. Stratified Acreage Estimates in the Illinois Crop-Acreage Estimate. *Proceedings of the 1977 Symposium on Machine Processing of Remotely Sensed Data*, IARS, Purdue Univ., West Lafayette, Indiana, pp.80-98.
- Schlein, S., 1975. *Practical Aspects Related to Automated Classification of LANDSAT Imagery Using Lookup Tables*. Research Report 75-2, Canadian Center for Remote Sensing, Ottawa.
- Story, M., and R. G. Congleton, 1986. Accuracy Assessment: A User's Perspective. *Photogrammetric Engineering and Remote Sensing*; 52(3):397-400.
- Wharton, S. W., 1983. A Generalized Histogram Clustering Scheme for Multidimensional Image Data. *Pattern Recognition* 16(2) :192-199.

In Memoriam

John Oran Eichler 1905 - 1989

Member Emeritus John O. Eichler died November 7, 1989, at his home in Marietta, Georgia. A longtime educator, John taught surveying, mapping and photogrammetry at The Georgia Institute of Technology, Atlanta, Georgia, until his retirement in 1973.

Eichler pursued his undergraduate studies at New York University, earning a B.S. degree in Civil Engineering in 1931. Later, while working on a Master's Degree at Syracuse University, granted in 1943, John was a teaching assistant to Earl Church, distinguished pioneer in education for Photogrammetry. The years spent at Syracuse were 1938 - 1947. John then joined the faculty at the Cooper Union for the Advancement of Arts and Sciences in New York City, serving as Associate Professor for surveying and photogrammetry. He directed surveying programs for engineering students at Green Camp in Passaic County, N.J., part of the Institute, an ideal practical laboratory for the students. While at Cooper, John was a Founder and one-time President of the Metropolitan New York Section of ASP, later incorporated in the present North Atlantic Region of the Society. The year was 1952. Also at Cooper Institute, in 1953, John co-authored, with Harry Tubis, then a part-time Instructor in Photogrammetry, a basic training manual, "Photogrammetry Lab Kit". (Now in its 4th edition and in use by schools and practicing engineers, Eichler continued as co-publisher, until his demise.)

In 1956, Eichler joined the faculty of Georgia Tech's Department of Civil Engineering. Again, surveying, mapping and photogrammetry were his teaching concerns. His summer surveying camps were renowned for their effectiveness and intense student participation. John served Georgia Tech in many non-teaching activities and committee work. He authored many papers and texts, and wrote and graded examinations for Surveyors' licensing in Georgia. In his professional affiliations, he served with distinction. He was a licensed professional engineer in the states of New York and Georgia. He was a Founder and first President of the Georgia-South Carolina Section of the American Society of Photogrammetry. He was presented a Presidential Citation by the Society in 1971. He held honorary memberships in the American Society of Professional Engineers, American Congress of Surveying and Mapping, the Mapping and Surveying Society of Georgia, and Sigma Xi and Chi Epsilon engineering fraternities. He also served on the Transportation Research Board of the National Academy of Sciences.

In leisure time, John and his wife Aldona, were avid "boat people", occupying one in a colony of houseboats at a Georgia lake in the area. In class and during leisure pursuits, John combined Astronomy with his longtime interest in mythology. These naturally rolled over into his interests in the Space programs. He often lectured on these subjects. John is survived by his wife, Aldona, sons Alan and Oran and two grandchildren.

—Harry Tubis