Comparison of Landsat MSS Pixel Array Sizes for Estimating Water Quality*

Jerry C. Ritchie
Hydrology Laboratory, USDA Agricultural Research Service, Beltsville, MD 20705
Charles M. Cooper
Sedimentation Laboratory, USDA Agricultural Research Service, Oxford, MS 38655

ABSTRACT: A problem in the analyses of Landsat Multispectral Scanner (MSS) data is sampling pixels representative of the area being used for calibration. This study reports the analyses of different size pixel arrays for estimating water quality variables. Nested arrays of pixels with sizes of 5 by 5, 3 by 3, and 2 by 2, and the single center pixel of the 5 by 5 array were sampled at five different locations in the lake where water quality variables had been measured. Fourteen Landsat scenes for the period between January 1983 and June 1985 were analyzed. Analysis of variance (ANOVA) found no significant differences in mean pixel values due to the size of the pixel arrays. There were significant differences for mean pixel values with MSS band, sample date, and sample location. These were due to differences in water quality variables and sensor characteristics. A paired T-test of the mean of the differences between array pairs did show that the single center pixel and 2 by 2 pixel arrays may not be representative of larger pixel arrays. A comparison of different methods for reducing MSS variability in multidate and multisensor data showed that transformations of digital data to physical data proved best. Pixel values were significantly correlated with water quality variables (total suspended solids and chlorophyll-a) for all array sizes.

INTRODUCTION

SURFACE WATER QUALITY is a major problem around the world (Brown, 1984; Walling and Webb, 1983). Much time and effort has been spent in developing methods to monitor the quality of the Earth's surface water using *in situ* measurements (USGS, 1979a) and remote sensing techniques. Many examples of the use of remote sensing to estimate and map water quality variables in the surface water can be found in the literature (Middleton and Marcell, 1983) including both airborne (e.g., McKim *et al.*, 1984; Pionke and Blanchard, 1975) and satellite (e.g., Lindell *et al.*, 1986; Ritchie *et al.*, 1986; Verdin, 1985) sensors. A problem in the analyses of remote sensing data for comparison with *in situ* surface measurements is the selection of remote sensing data which are representative of the site of the surface data. The purpose of this study was to analyze multidate and multisensor Landsat multispectral scanner (MSS) data using different size pixel arrays for estimating water quality variables to determine if array size was important when all pixels were from the water area. The second purpose of the study was to compare different methods for transforming Landsat MSS multidate and multisensor data to estimate water quality variables.

METHODS

Digital Landsat MSS data were analyzed for 14 dates between January 1983 and June 1985. Data included scenes from Landsats 4 and 5. The Landsat data were purchased on magnetic disk compatible with the Remote Image Processing System (RIPS), a microcomputer based image processing system (Welch *et al.*, 1983). Data were purchased for a 256 by 240 pixel area surrounding and including Moon Lake (Landsat Path 23, Row 36) in Coahoma County in northwest Mississippi (90°30′ W - 34°25′ N). Moon Lake, approximately 0.5 km in width and 10.0 km in length, is an oxbow lake in an old channel of the Mississippi River. Water depth ranged from 3 to 9 metres in the lake. The lake is separated from the Mississippi River by a levee. Total suspended solids and chlorophyll-a were the water quality variables used in this study.

Each of the fourteen spectral data disks was analyzed to determine the minimum pixel value for each of the four MSS spectral bands for the 256 by 240 pixel area. Digital data for each of the four spectral bands were extracted for nested pixel arrays of 5 by 5, 3 by 3, and 2 by 2, and the single center pixel (row 3, line 3; see Figure 1). All pixel arrays were sampled to include the center pixel of the 5 by 5 array. The four possible 2 by 2 arrays were included in the analyses, giving a total of seven pixel array data sets (Table 1). Extracted data arrays were lo-

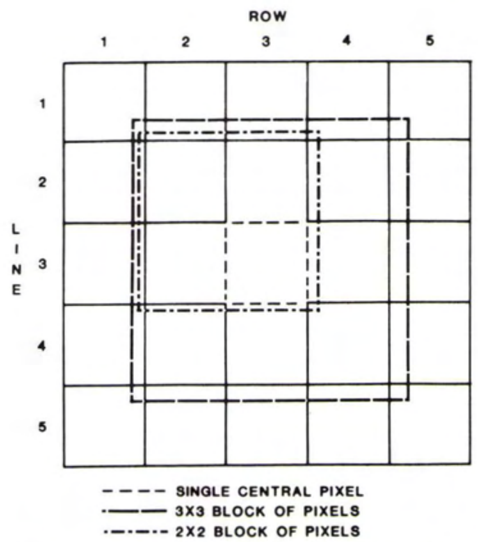

FIG. 1. Schematic diagram showing the relationship between the different pixel arrays.

TABLE 1. LIST OF ARRAY DATA SET EXTRACTED FROM LANDSAT MSS DATA DISKS.

Array size	Pixel row and line (see Figure 1)	Number of Pixels
Center	Row 3 Line 3	1
2 by 2A	Row 2-3 Line 2-3	4
2 by 2B	Row 3-4 Line 2-3	4
2 by 2C	Row 2-3 Line 3-4	4
2 by 2D	Row 3-4 Line 3-4	4
3 by 3	Row 2-4 Line 2-4	9
5 by 5	Row 1-5 Line 1-5	25

*Presented at the ASPRS/ACSM Annual Convention, March 1987, Baltimore, Maryland.

PHOTOGRAMMETRIC ENGINEERING AND REMOTE SENSING,
Vol. 53, No. 11, November 1987, pp. 1549–1553.

0099-1112/87/5311–1549$02.25/0

cated in Moon Lake so that at least one row of pixels was between the data array and any shoreline pixels.

Five different locations within Moon Lake were sampled on each scene, giving a total 70 samples for each MSS band. Location of the extracted pixel arrays was chosen to closely correspond to sites where *in situ* measurements of water quality variables had been made. Water samples for analysis were collected in the surface 3 cm of the water column. Water depth was at least 8 times secchi depth on each sample date (Cooper *et al.*, 1984). Field sample sites were located in conjunction with prominent landmarks visible on the Landsat image. Sites for pixel extractions were located interactively on computer generated 256 by 240 pixel video images of the Landsat data. The average pixel value and standard deviation were calculated for each of the seven pixel array data sets for each sample location and date. Analysis of variance (ANOVA) and a paired T-test were used to determine if there were significant differences between arrays and array pairs (SAS, 1985). Only least-squares regression techniques were used to determine the relationship between different pixel size arrays and the water quality variables.

Transformations were made to the average value of the 5 by 5 pixel array data set which created eleven new MSS data sets (Table 2). One data set was calculated by subtracting the minimum pixel value for each scene and band minus one from the raw pixel values to give a (scene) corrected pixel value. This has been referred to as the dark pixel correction technique (Rochon and Langham, 1974). Two more Landsat data sets were calculated by correcting both the raw pixel and the corrected pixel data sets to appear as though they were obtained at the average sun elevation angle (49.2°) for the 14 Landsat scenes sampled (Richardson, 1982). For radiance data sets were calculated by multiplying the four pixel data sets (raw pixels, corrected pixels, raw pixels corrected for sun angle, corrected pixels corrected for sun angle) by the calibration factor for each satellite and date (Price, 1987; Robinove, 1982; USGS, 1979b). Then reflectance data sets were calculated for each of the four radiance data sets using the method described by Robinove (1982). This gave a total of 12 MSS data sets (Table 2) that were used to determine which transformation would provide the best estimation equation for total suspended solids or chlorophyll-a (Cooper *et al.*, 1984). Least-squares linear regression techniques were used to determine the relationship between the transformed Landsat MSS data sets and the water quality variables. Only the assumption of a linear relationship between the MSS data sets and the water quality variables was tested.

RESULTS

An analysis of the means for the seven different array data sets (Table 3) shows little differences when comparing the means of the 70 observations in each band. Analysis of variance (ANOVA) found no difference in the means for each band at the 0.01 level of probability. ANOVA did show a difference at the 0.01 level of probability between the means for the different MSS bands and for the sampling data. The means between sampling location in Moon Lake were different at the 0.05 level of probability. The differences between MSS bands are due to sensor characteristics and the water and atmospheric responses at different wavelengths measured by the individual MSS bands. The differences between sample locations and between sample dates were mainly due to differences in water quality variables. Water quality variables (total solids and chlorophyll-a) were also significantly different at the 0.05 level of probability between sample locations and sample dates.

A parametric paired T-test was used to determine if the mean of the differences between one pixel and 2 by 2, 3 by 3, and 5 by 5 Landsat MSS pixel array pairs was different from zero. The assumption is that, if the two arrays represent the same area, then the mean of the differences of the individual pairs should be zero. With seven different MSS array data sets (Table 1), there were, by combinatorics, 21 possible pairs per site for each MSS band, giving a total of 84 pairs per site possible for the four MSS bands. In four comparisons (Table 4), the mean of the differences between two array data sets was not equal to zero at the 0.05 level of probability. In eight other cases (12 total), the mean of the differences between two MSS arrays was not equal to zero at the 0.10 level of probability. Seven of those 12 cases involved comparisons with the single center pixel and the other five cases involved comparisons with four pixels (2 by 2 arrays). Twenty-nine percent of the possible comparisons (24) between the center pixel and another array data set were significantly different from zero at the 0.10 level of probability or less. The mean of the differences between nine pixels (3 by 3 arrays) and 25 pixels (5 by 5 arrays) was not significantly different from zero for any comparisons.

The arrays were sampled so that all arrays were at least one

Table 2. Methods of Transforming the Data Sets Used in these Analyses. Calculations Were Done for each of the Four Landsat Multispectral Scanner Bands.

Data set	Calculation	Units
Raw pixel	Average of MSS pixels in the 5 by 5 data array	digital value of pixels
Corrected pixel	Raw pixel value-(minimum pixel in the 256 by 240 pixels-1)	digital value of pixels
Raw pixels corrected for sun angle	Raw pixel value corrected to sun elevation angle of 49.2° (Richardson, 1982)	digital value of pixels
Corrected pixels corrected for sun angle	Corrected pixel value corrected to sun elevation angle of 49.2°	digital value of pixels
Radiance 1	Raw pixel value * Landsat MSS calibration factor (Robinove, 1982)	$mWcm^{-2}sr^{-1}$
Radiance 2	Corrected pixel value * Landsat MSS calibration factor	$mWcm^{-2}sr^{-1}$
Radiance 3	Raw pixel corrected for sun angle * Landsat MSS calibration factor	$mWcm^{-2}sr^{-1}$
Radiance 4	Corrected pixel corrected for sun angle * Landsat MSS calibration factor	$mWcm^{-2}sr^{-1}$
Reflectance 1	Radiance 1 * $\pi/(E \sin a)$ where E = irradiance at top of atmosphere; a = solar elevation	unitless
Reflectance 2	Radiance 2 * $\pi/E/ \sin a$	unitless
Reflectance 3	Radiance 3 * $\pi/E \sin a$	unitless
Reflectance 4	Radiance 4 * $\pi/E \sin a$	unitless

TABLE 3. MEANS AND STANDARD DEVIATIONS OF THE RAW PIXEL VALUES FOR THE DIFFERENT SIZE PIXEL ARRAYS. N = 70.

Array	Mean	Standard deviation	Standard error of mean
	Landsat MSS Band 1 (500 to 600 nm)		
Center	34.09	9.29	1.11
2 by 2A	34.02	9.39	1.12
2 by 2B	33.94	9.20	1.10
2 by 2C	33.89	9.37	1.12
2 by 2D	33.93	9.25	1.11
3 by 3	33.87	9.30	1.11
5 by 5	33.83	9.22	1.10
	Landsat MSS Band 2 (600 to 700 nm)		
Center	38.04	15.11	1.81
2 by 2A	38.13	15.19	1.82
2 by 2B	38.06	15.16	1.81
2 by 2C	38.23	15.15	1.81
2 by 2D	38.07	15.03	1.80
3 by 3	38.11	15.09	1.80
5 by 5	38.09	15.16	1.81
	Landsat MSS Band 3 (700 to 800 nm)		
Center	28.04	12.58	1.50
2 by 2A	28.15	12.50	1.49
2 by 2B	28.04	12.49	1.49
2 by 2C	28.24	12.61	1.51
2 by 2D	28.26	12.64	1.51
3 by 3	28.20	12.55	1.50
5 by 5	28.24	12.56	1.50
	Landsat MSS Band 4 (800 to 900 nm)		
Center	13.10	6.57	0.79
2 by 2A	13.29	6.43	0.77
2 by 2B	13.25	6.41	0.77
2 by 2C	13.27	6.42	0.77
2 by 2D	13.34	6.37	0.76
3 by 3	13.30	6.41	0.77
5 by 5	13.36	6.52	0.78

TABLE 4. RESULTS OF T-TEST OF THE MEAN OF THE DIFFERENCE BETWEEN PAIRED ASSAYS.

Data set	Mean of differences	Standard error of mean	Probability
Band 1 2 by 2A - 5 by 5	0.20	0.08	0.02
Band 1 2 by 2A - 3 by 3	0.15	0.07	0.03
Band 1 Center - 5 by 5	0.26	0.13	0.05
Band 3 2 by 2B - 2 by 2D	−0.21	0.11	0.05
Band 1 Center - 3 by 3	0.20	0.11	0.06
Band 3 Center - 2 by 2D	−0.22	0.12	0.06
Band 4 Center - 5 by 5	−0.26	0.14	0.07
Band 4 Center - 2 by 2D	0.24	0.13	0.08
Band 1 Center - 2 by 2C	0.20	0.11	0.08
Band 3 2 by 2B - 3 by 3	−0.15	0.07	0.08
Band 4 Center - 2 by 2A	−0.19	0.10	0.08
Band 3 2 by 2B - 5 by 5	−0.20	0.12	0.10
All others			0.10

row of pixels away from the shoreline to assure that all pixels were water pixels. Visual examination of each image during the interactive pixel extraction indicated only gradual changes in visible surface water properties. No distinct boundaries or patchiness in the water areas were noted in any of the displayed images or during field sampling. The paired T-test would indicate that 3 by 3 or 5 by 5 pixel arrays provided similar information about the water at each sample site. When pixel arrays are 2 by 2 or a single pixel, there is a greater chance of getting a mean value that may not be representative of the area sampled by the larger pixel arrays. To insure sampling consistency in a water body, these analyses suggest that at least a 3 by 3 pixel array be sampled. Smaller arrays provide a greater chance that the mean pixel value may not be representative of a larger area.

One could, however, argue on-the-other-hand that, because *in situ* measurements are "point" measurements, single pixels would be more representative of a point measurement than the average of some larger pixel array.

Our field sampling does not allow us to determine the spatial distribution water quality variables around each sample site or to assign water quality values for each pixel in our extracted data arrays. Field observations on each sampling date and video displays of a 256 by 240 pixel image of each Landsat scene did not show any visual differences around each sample site that would explain the T-test results. Therefore, we cannot be certain that differences between the extracted arrays were due to changes in surface water quality across the arrays. Another possible cause for the differences could be due to MSS detector offsets and sensitivity (striping).

A comparison of correlation coefficients (r) determined by least-square linear regression techniques for the relationship between mean pixel values and water quality concentrations showed no differences in the correlation coefficients or the regression coefficients determined for the estimation equations for either total solids or chlorophyll-a regardless of pixel array size. So although a statistical difference could be calculated between some pixel array pairs, when comparing the end results for using MSS data to estimate water quality variables, the estimation equations calculated using any of the pixel arrays produced equations that were not significantly different from each other.

Many techniques have been used to transform Landsat MSS data for analyses (e.g., Lindell *et al.*, 1986; Nelson, 1985; Richardson *et al.*, 1980; Ritchie *et al.*, 1986; Robinove, 1982; Scarpace *et al.*, 1979; Verdin, 1985). Nelson (1985) listed changing sun angle, atmospheric conditions, and sensor differences as the three categories of factors which affected multidate Landsat MSS data. In this study, transformations of the Landsat MSS data were made that affected changes due to sun angle and sensor differences (Table 2). Clear water has been proposed and used to correct atmospheric differences (Richardson *et al.*, 1980; Scarpace *et al.*, 1979; Verdin, 1985). We do not think that water can be used to correct for atmospheric conditions because the change in response over water is an indication of water quality. Also, there are no clear lakes in our scenes. Because the Landsat measured signal from the study targets changed with time, analyses were made to determine which transformation provided the best correlation coefficient between the Landsat data and the water quality variables.

Least-squares linear regression analyses of the 12 Landsat MSS data sets (Figure 2) with the two water quality variables show a wide range of correlation coefficients (r) for the different transformations for the individual bands and between bands (Table 5). In general, any transformation of the raw pixel data tended

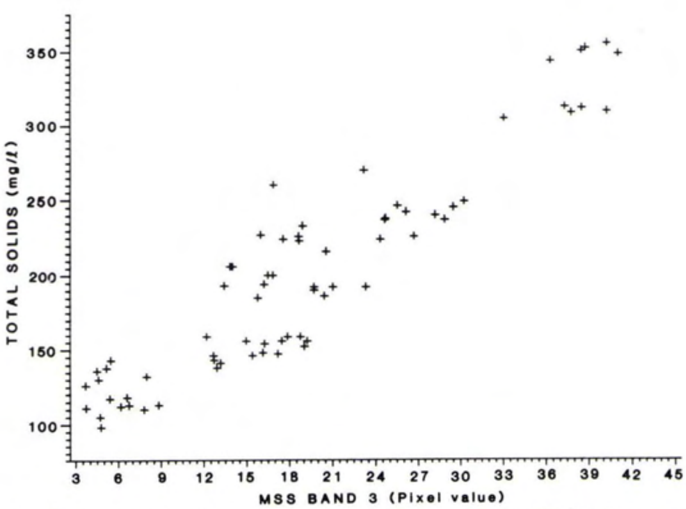

FIG. 2. The relationship between Landsat MSS Band 3 pixel values and total solids (mg l^{-1}).

TABLE 5. CORRELATION COEFFICIENT (R) FOR THE LINEAR RELATIONSHIP BETWEEN THE 5 BY 5 PIXEL ARRAY DATA SETS AND WATER QUALITY VARIABLES.

	Landsat MSS			
Data set	Band 1	Band 2	Band 3	Band 4
	Total solids (mg l^{-1})			
Raw pixels	0.67	0.83	0.81	0.58
Corrected pixels	0.90	0.91	0.93	0.78
Raw pixels sun angle	0.72	0.88	0.86	0.63
Corrected pixels sun angle	0.63	0.91	0.88	0.87
Radiance 1	0.69	0.84	0.82	0.59
Radiance 2	0.91	0.92	0.93	0.80
Radiance 3	0.76	0.87	0.90	0.65
Radiance 4	0.68	0.91	0.91	0.87
Reflectance 1	0.75	0.86	0.90	0.66
Reflectance 2	0.65	0.89	0.88	0.86
Reflectance 3	0.23	0.46	0.59	0.45
Reflectance 4	0.28	0.57	0.58	0.49
	Chlorophyll-a (mg m^{-3})			
Raw pixels	−0.40	−0.50	−0.45	−0.23
Corrected pixels	−0.68	−0.58	−0.52	−0.26
Raw pixels sun angle	−0.82	−0.77	−0.64	−0.34
Corrected pixels sun angle	−0.72	−0.75	−0.64	−0.40
Radiance 1	−0.40	−0.53	−0.42	−0.25
Radiance 2	−0.67	−0.59	−0.49	−0.28
Radiance 3	−0.74	−0.75	−0.62	−0.43
Radiance 4	−0.80	−0.77	−0.62	−0.37
Reflectance 1	−0.82	−0.81	−0.70	−0.45
Reflectance 2	−0.73	−0.76	−0.64	−0.48
Reflectance 3	−0.48	−0.65	−0.55	−0.44
Reflectance 4	−0.52	−0.61	−0.59	−0.46

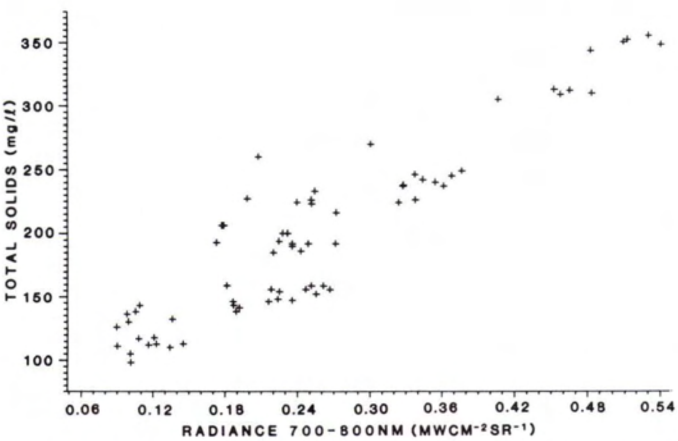

FIG. 3. The relationship between Landsat MSS Band 3 radiance and total solids (mg 1^{-1}).

to improve the correlation coefficient. However, transformation of transformed pixel data did not always improve correlation coefficients, and in some cases correlation coefficients were poorer from these second generation data sets.

The best single Landsat MSS band for estimating total solids in this analysis was band 3 using pixel values corrected for the minimum pixel value in the scene or radiance (Figure 3) calculated from this corrected pixel value. The best single band for estimating chlorophyll-a in this analysis was band 1 using raw pixel values corrected for sun angle or reflectance calculated from raw pixel values. Our regression analysis (Table 5) shows that, in general, bands 2 and 3 are almost equally correlated with total solids and that bands 1 and 2 are almost equally correlated with chlorophyll-a. Thus, in each case, either of the two bands could be used with almost equal results. These are the bands that have been shown to be useful in other studies of suspended sediment and chlorophyll (e.g., Ritchie *et al.*, 1986; Verdin, 1985; Scarpace *et al.*, 1979).

Transformations which change the digital Landsat MSS data to physical values were consistently the most useful for correcting the multidate Landsat scenes to improve correlation coefficients in this study. These transformations are based on the methods described by Robinove (1982) who argued that physically based data are essential if multiple images are to be compared. This study would tend to support Robinove's conclusions for multidate images.

Correlating the raw pixel data using the minimum pixel value (dark pixel technique) in each scene also proved useful in this study. This transformation is based on the assumption that there is a uniform absorber in the scene. Changes in pixel value measured over this uniform absorber would be due to changes in the atmosphere. This technique did provide improved data for estimating the concentration of total solids. However, we were not able to identify a single source or area for the dark pixel in the scenes. Therefore, although the dark pixel technique has proved useful in other studies, we cannot conclude that this technique will work based on our data set.

CONCLUSIONS

A T-test to determine if the mean of the difference between one pixel and 2 by 2, 3 by 3, and 5 by 5 Landsat MSS pixel array pairs was different from zero showed that one pixel and 2 by 2 pixel arrays may not be representative of the larger pixel arrays. No difference was found between 3 by 3 and 5 by 5 pixel arrays. However, ANOVA showed that the mean values of one pixel and 2 by 2, 3 by 3, and 5 by 5 pixel arrays were not significantly different if pixels were all from a water area. The correlation coefficients and the equations for estimating total solids or chlorophyll-a were the same regardless of pixel array size.

Transformation of the raw pixel data to physical values such as radiance or reflectance improved correlation coefficients for the calculated equations for estimating total solids or chlorophyll-a. These transformations should reduce variability between scenes when using multidate imagery such as used in this study.

REFERENCES

Brown, L.R., 1984. The global loss of topsoil: *J. Soil Water Conserv.* 39:162–165.

Cooper, C.M., E.J. Bacon, and J.C. Ritchie, 1984. Biological cycles in Lake Chicot, Arkansas: *Limnological Studies of Lake Chicot, Arkansas* (J.F. Nix and F.R. Schiebe, eds.), Quachita Baptist College, Arkadelphia, Arkansas, pp. 49–61.

Lindell, T., B. Karlsson, M. Rosengren, and T. Alfoldi, 1986. A further development of the chromaticity technique for satellite mapping of suspended sediment load: *Photogrammetric Engineering and Remote Sensing* 52:1521–1529.

McKim, H.L., C.J. Merry, and R.W. Layman, 1984. Water quality monitoring using an airborne spectroradiometer: *Photogrammetric Engineering and Remote Sensing* 50:353–360.

Middleton, E.M., and R.F. Marcell, 1983. *Literature Relevant to Remote Sensing of Water Quality*: NASA Technical Memo. 85077, Goddard Space Flight Center, Greenbelt, Maryland.

Nelson, R., 1985. Reducing Landsat MSS scene variability: *Photogrammetric Engineering and Remote Sensing* 51:583–593.

Pionke, H.B., and B.J. Blanchard, 1975. The remote sensing of suspended sediment concentration of small impoundments: *Water, Air, and Soil Pollution* 4:19–32.

Price, J.C., 1987. Calibration of satellite radiometers and the comparison of vegetation indices: *Remote Sensing of Environment* 21:15–27.

Richardson, A.J., 1982. Relating Landsat digital count values to ground reflectance for optically thin atmospheric conditions: *Applied Optics* 21:1457–1464.

Richardson, A.J., D.E. Escobar, H.W. Gausman and J.H. Everitt, 1980. Comparision of Landsat-2 and field spectrometer reflectance signatures of South Texas rangeland communities: *Proc. Sixth Symposium Machine Processing of Remotely Sensed Data*, LARS, Purdue University, West Lafayette, Indiana pp. 88–97.

Ritchie, J.C., F.R. Schiebe, and C.M. Cooper, 1986. Surface water quality measurements of Lake Chicot, Arkansas using data from Landsat satellites: *J. Freshwater Ecology* 3:391–397.

Robinove, C.J., 1982. Computation with physical values from Landsat digital data: *Photogrammetric Engineering and Remote Sensing* 227:781–784.

Rochon, G., and E.J. Langham, 1974. Teledection par satellite dans l'evaluation de la qualité de l'eau, *vehr. Internat. Verein. Limnol.* 19:189–196.

SAS, 1985. *SAS User's Guide: Basics.* SAS Institute Inc., Cary, North Carolina.

Scarpace, F.L., K.H. Holmquist, and L.T. Fisher, 1979. Landsat analysis of lake quality. *Photogrammetric Engineering and Remote Sensing* 45:623–633.

USGS, 1979a. *National Handbook of Recommended Methods for Water-Data Acquisition*, Office of Water Data Coordination, USGS, Reston, Virginia.

———, 1979b. *Landsat User's Handbook* (revised), USGS, Washington, D.C.

Verdin, J.P., 1985. Monitoring water quality conditions in a large western reservoir with Landsat imagery: *Photogrammetric Engineering and Remote Sensing* 51:343–353.

Walling, D.E., and B.W. Webb, 1983. Patterns of sediment yield: Background to Palaeohydrology: A Perspective (K. Gregory, ed.). Wiley, Cambridge, England, pp. 69–100.

Welch, R.A., T.R. Jordan, and E.L. Usery, 1983. Microcomputers in the mapping sciences: *Computer Graphics World* 6(2): 6 p.

(Received 23 March 1987; accepted 17 June 1987; revised 20 July 1987)

PUBLICATIONS AVAILABLE

PROCEEDINGS OF THE WILLIAM T. PECORA MEMORIAL SYMPOSIA

PECORA 1: First Annual William T. Pecora Memorial Symposium; 28–31 October 1975; Sioux Falls, South Dakota; Sponsored by American Mining Congress; Proceedings published by U.S. Govt. Printing Office (USGS Professional Paper 1015); 370 pages.

Order from:	*Cost:*	
U.S. Geological Survey	Member:	$7.50
Open-file and Books Section	Non-Member:	$7.50
Federal Center, Bldg. 41	Shipping:	(included)
Box 25425		
Denver, CO 80225		

PECORA 2: Mapping with Remote Sensing Data; 25–29 October 1976; Sioux Falls, South Dakota; Sponsored and published by American Society of Photogrammetry; Proceedings out of print.

PECORA 3: Application of Satellite Data to Petroleum and Mineral Exploration 30 October – 2 November 1977; Sioux Falls, South Dakota; Sponsored by American Association of Petroleum Geologists; Proceedings not published.

PECORA 4: Application of Remote Sensing Data to Wildlife Management; 10–12 October 1978; Sioux Falls, South Dakota; Sponsored and published by National Wildlife Federation; 397 pages.

Order from:	*Cost:*	
National Wildlife Federation	Member:	$10.00
8925 Leesburg Pike	Non-Member	$10.00
Vienna, VA 22180	Shipping	$ 2.75
(703) 790-4329		

PECORA 5: Satellite Hydrology; 10–15 June 1979; Sioux Falls, South Dakota; Sponsored and published by American Water Resources Association; 730 pages.

Order from:	*Cost:*	
American Water Resources Association	Member:	$ 85.00
Suite 220	Non-Member:	$102.00
5410 Grosvenor Lane	Shipping:	$ 6.00
Bethesda, MD 20814		
(301) 493-8600		

PECORA 6: Integration of Remote Sensing into the Exploration Process; 13–17 April 1980; Sioux Falls, South Dakota; Sponsored by Society of Exploration Geophysicists; Proceedings not published.

PECORA 7: Remote Sensing: An Input to Geographic Information Systems in the 1980's; 18–21 October 1981; Sioux Falls, South Dakota; Sponsored by Association of American Geographers, National Council for Geographic Education, and American Society of Photogrammetry; Published by American Society of Photogrammetry; Proceedings out of print.

PECORA 8: Satellite Land Remote Sensing Advancements for the Eighties; 4–7 October 1983; Sioux Falls, South Dakota; Sponsored by NASA, NOAA, and USGS; Published by Augustana College, The Augustana Research Institute; Proceedings out of print.

(Continued on next page)