Annotated Bibliography of Techniques for Image Enhancement and Interpretation in Remote Sensing

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The purpose of this annotated bibliography is to provide the user of the Remote Sensing Information Subsystem (RSIS) with brief descriptions of recent research techniques of image enhancement and their applications to specific image interpretation problems. Table 2 of the May 1979 ASVT/RSIS Technical Report entitled Functional Design Narrative Descriptions listed digital image processing requirements of the RSIS. The references in this bibliography were chosen because they describe these processing requirements. The format of that table was modified slightly and used as the outline for Section One of this bibliography.

The bibliography is not intended to be an exhaustive compilation of all pertinent articles. Such a collection would be outdated as soon as it was printed. It does, however, contain a broad sampling of the recent remote sensing literature. We tried not to include multiple references to the same technique, but some repetition was necessary in order to fully describe some procedures of image enhancement and interpretation.

The bibliography is divided into two major sections. The first section contains articles which describe methods of image enhancement. This section is divided into three parts which outline the sequential steps of image enhancement from digital data on magnetic tapes to hardcopy film images.

Preprocessing comprises the machine manipulation of digital data. Some preprocessing is accomplished prior to the interactive stage of data handling, but there is some overlap between these steps. The user assumes a more active role in the interactive stage of processing. At this time he manipulates the data (for example, as it is displayed on a CRT) to suit his needs. The post-

processing stage is herein considered the CRT display of final results of the previous two stages, and the production of hardcopy film images.

The user who is familiar with these techniques and who is interested in the applications of these processes to his area of interest should refer to Section Two.

The theme of Section Two is image interpretation. Articles in this section describe the application of techniques explained in Section One to specific problems of image interpretation that are expected to arise during the analysis of the TNRIS/NASA Joint Project Test Sites. This section is divided into seven broad land cover/land use categories. Within each category, articles are arranged by the technique described, such as density slicing, band-ratioing and the like.

The source of these annotated references was Geo Abstracts, Section G, Remote Sensing, Photogrammetry and Cartography, 1976-1979. We gratefully acknowledge the permission granted by that publication to use their annotations. Some of the annotations were edited to conserve space and eliminate information not directly relevant to the heading under which they were grouped.

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I. Image Enhancement

A. General

Haralick, R.M., 1976, Automatic remote sensor image processing, in Topics in applied physics, 11, pp 5-63.

Two methods of automatic image processing are described. The first one requires special instruments and the input of analog tapes. The second method consists of more complicated processing and requires corresponding software and the input of digital tapes. Automatic identification methods are applied by some authors to the division of cultivated land, urban areas, forests and water. Automatic processing includes tape recording of the imagery, normalization of half-tones, marking out of details, choice of the decisive rule and error determination. The processing is discussed from the point of view of both future development and of instruments and software.

Levinson, R.A.; Marrs, R.W.; and Grantham, D.G., 1976, Rapid low-cost image analysis through video processing, University of Wyoming, Remote sensing laboratory, open file report, GJBX-37(76), 54 pp.

A new, more economical, video system capable of performing complex image analysis has been developed. This report describes the functions, components, and operation of that system. Processing capability of the new video image analysis system includes many of the tasks previously accomplished with optical projectors and digital computers. Video capabilities include: color separation, color addition/subtraction, contrast stretch, dark level adjustment, density analysis, edge enhancement, scale matching, image mixing (addition and subtraction), image ratioing, and construction of false-color composite images. Rapid input of non-digital image data, instantaneous processing and display, relatively low initial cost, and low operating cost gives the video system a competitive advantage over digital equipment. Complex pre-processing, pattern recognition, and statistical analyses must still be handled through digital computer systems. The video system at the University of Wyoming has undergone extensive testing, comparison to other systems, and has been used successfully in practical applications ranging from analysis of X-rays and thin sections to production of color composite ratios of multispectral imagery.

Rosenfeld, A., and Kak, A.C., 1976, Digital picture processing, (Academic Press; Computer science and applied mathematics. A series of monographs and textbooks), 457 pp.

After a general introduction (chapter 1) and a review of various useful mathematical tools for digital picture processing (chapter 2) a brief introduction is presented to visual perception (chapter 3). Chapter 4 is devoted to the theory of picture digitization, while chapter 5 treats picture compression. In chapters 6 and 7 techniques for picture enhancement

and restoration are discussed. Chapter 8 deals with methods of segmenting pictures into significant parts, while chapter 9 discusses the measurement of geometrical properties of picture parts. Chapter 10 considers non-geometrical picture properties (e.g. texture) and gives a description of pictures in terms of parts, properties, and relationships.

B. Preprocessing

1. Radiometric corrections

Rohde, W.C.; Lo, J.K.; and Pohl, R.A., 1978, EROS Data Center LANDSAT digital enhancement techniques and imagery availability, 1977. Canadian journal of remote sensing, 4(1), pp 63-76.

The US Geological Survey's EROS Data Center (EDC) is experimenting with the production of digitally enhanced LANDSAT imagery. Advanced digital image processing techniques are used to perform geometric and radiometric corrections and to perform contrast and edge enhancements. The enhanced image product is produced from digitally preprocessed LANDSAT computer compatible tapes (CCT's) on a laser beam film recording system. Bad data lines or line segments with more than 150 contiguous bad pixels are corrected by inserting data from the previous line in place of the bad data. Striping, caused by variations in detector gain and offset, is removed with a destriping algorithm applied after digitally enhancing the data. Image enhancement is performed by applying a linear contrast stretch and an edge enhancement algorithm. The edge enhancement algorithm is designed to enhance boundaries between terrain features that exhibit subtle differences in brightness values along edges of features.

2. Geometric corrections

Ballew, G.I., and Lyon, R.J.P., 1977, The display of LANDSAT data at large scales by matrix printer. Photogrammetric engineering and remote sensing, 43(9), pp 1147-1150.

Lineprinter images of digital LANDSAT multispectral data may be conveniently and economically displayed on standard line-printer paper by using a matrix printer, DOTPRINT images at nominal scales of 1:24,000 and 1:50,000, and 1:62,500 are produced. More precise geometry is obtained by using control points and regression equations which permits features to be located to the nearest half-pixel over an area the size of a 15-minute quadrangle. Color infrared images and color classifications may be produced from several DOTPRINTs by overprinting channel- or ratio-images of different colors on the same piece of paper.

Rohde, W.C.; Lo, J.K.; and Pohl, R.A., 1978, EROS Data Center LANDSAT digital enhancement techniques and imagery availability, 1977. Canadian journal of remote sensing, 4(1), pp 63-76.

See Section I-B-1 for annotation.

3. Eliminating/reducing noise--bad scan line removal

Goetz, A.F.H., and Billingsley, F.C., 1973, Digital image enhancement techniques used in some ERTS application problems. University of Wyoming, Laramie, Contributions to geology, 12 (2), pp 7-21.

Enhanced images can be used alone or as inputs to classification routines. However, in some problems the spatial relationships are equal in importance to the classification results and enhancements can be designed to provide both types of information in one image. Enhancements discussed include contrast stretching, multi-ratio color displays, Fourier plane operations to remove striping and boosting MTF response to enhance high spatial frequency content. The use of each technique in a specific application in the fields of geology, geomorphology and oceanography is demonstrated.

4. Band ratioing

Goetz, A.F.H., and Billingsley, F.C., 1973, Digital image enhancement techniques used in some ERTS application problems. University of Wyoming, Laramie, Contributions to geology, 12 (2), pp 7-21.

See Section I-B-3 for annotation.

5. Contrast Stretch

Goetz, A.F.H., and Billingsley, F.C., 1973, Digital image enhancement techniques used in some ERTS application problems. University of Wyoming, Laramie, Contributions to geology, 12 (2), pp 7-21.

See Section I-B-3 for annotation.

Rohde, W.C.; Lo, J.K.; and Pohl, R.A., 1978, EROS Data Center LANDSAT digital enhancement techniques and imagery availability, 1977. Canadian journal of remote sensing, 4 (1), pp 63-76.

See Section I-B-a for annotation.

6. Edge enhancement

Faller, K.H., 1977, A procedure for detection and measurement of interfaces in remotely acquired data using a digital computer. US National Aeronautics and Space Administration, Lyndon B. Johnson Space Center, Houston, Texas, NASA-TR-R-472, JSC-S-467, 32 pp.

A technique developed and evaluated for the detection and measurement of

surface feature interfaces in remotely acquired data is described. A computer implementation of this technique has been effected to automatically process categorized data derived from various sources such as the LANDSAT multispectral scanner and other scanner type sensors.

Rohde, W.C.; Lo, J.K.; and Pohl, R.A., 1978, EROS Data Center LANDSAT digital enhancement techniques and imagery availability, 1977. Canadian journal of remote sensing, 4 (1), pp 63-76.

See Section I-B-1 for annotation.

7. Texture analysis

Haralick, R.M.; Shanmugam, K.; and Dinstein, I., 1973, Textural features for image classification. IEEE Transactions on systems, man and cybernetics, SMC-3 (6), pp 610-621.

Texture is one of the important characteristics used in identifying objects or regions of interest in an image, whether the image be a photomicrograph, an aerial photograph, or a satellite image. This paper describes some easily computable textural features based on graytone spatial dependencies, and illustrates their application in category-identification tasks of three different kinds of image data: photomicrographs, 1:20,000 panchromatic aerial photographs, and ERTS MSS imagery. We use two kinds of decision rules: one for which the decision regions are convex polyhedra (a piecewise linear decision rule), and one for which the decision regions are rectangular parallelpipeds (a min-max decision rule). In each experiment the data set was divided into two parts, a training set and a test set. Test set identification accuracy is 89 percent for the photomicrographs, 82 percent for the aerial photographic imagery, and 83 percent for the satellite imagery. These results indicate that the easily computable textural features probably have a general applicability for a wide variety of image-classification applications.

Thomas, J.O., 1977, Texture analysis in imagery processing, in British pattern recognition association and remote sensing society joint meeting on texture analysis, Oxford, April 19, 1977, Proceedings, ed J.O. Thomas and P.G. Davey, (J.L. von Genderen, Remote sensing society, Fairey Surveys Ltd., Maidenhead), pp 1-44.

Texture analysis is increasingly applied in automatic digital imagery processing systems in remote sensing. A variety of techniques for providing textural measures suitable, for example, for use as features to be extracted in software data classifiers are available. The most widely used employ first order grey level statistics, or, involve measures based on co-occurrence matrices (2nd order statistics). Other variants include transform methods - for example, 'rings' or 'wedges' based on Fourier measures of texture. In this paper, attention is concentrated on the use of second order statistics, and some simple 'model' images are used to illustrate how texture measures computed from the p-matrices work. The paper concludes with a discussion

of the use of texture analysis in remote sensing imagery evaluation. Simple classifiers based on textural feature extraction alone are capable of better than 85% accuracy in a wide range of applications particularly when combinations (e.g. pairs) of texture measures are used.

8. Table look-up procedure

Shlien, S., 1975, Practical aspects related to automated classification of LANDSAT imagery using lookup tables, Canada Centre for remote sensing, Department of Energy, mines and resources, research report, 75-2, 15 pp.

The computer time needed to classify LANDSAT data can be reduced by an order of magnitude by employing a table lookup scheme. The method is practical on any general purpose computer since it does not require special hardware or a great deal of core memory. This paper presents a description and illustration of a particular implementation of the table lookup scheme using hashing tables, and a mathematical model, relating the statistics of a LANDSAT image to the size of a lookup table, is examined.

C. Interactive processing

1. General

Henze, J., and DeZur, R., 1975, Interactive digital image manipulation system. in NASA earth resources survey symposium. Volume 1-B: geology, information systems and services, Houston, Texas, June 1975, (United States National Aeronautics and Space Administration, Lyndon B. Johnson Space Center, Houston, Texas; pp 1415-1435.

The system is designed for manipulation, analysis, interpretation, and processing of a wide variety of image data. LANDSAT (ERTS) and other data in digital form can be input directly into the system. Photographic prints and transparencies are first converted to digital form with an on-line high-resolution microdensitometer. The system is implemented on a Hewlett-Packard 3000 computer with 128 K bytes of core memory and a 47.5 megabyte disk. It includes a true color display monitor, with processing memories, graphics overlays, and a movable cursor. Image data formats are flexible so that there is no restriction to a given set of remote sensors. Conversion between data types provides a basis for comparison of the various data. Multispectral data is fully supported, and there is no restriction on the number of dimensions. In this way multispectral data collected at more than one time may be treated as data collected with twice (three times, etc.) the number of sensors. There are various libraries of functions available to the user: processing functions, display functions, system functions, and earth resources applications functions.

Morgan, O.E.; Balston, D.M.; and Custance, N.D.E., 1977, Interactive image processing techniques using the Plessey IDP 3000, in Proceedings 11th international symposium on remote sensing of environment, April 1977, (Center for remote sensing information and analysis, Environmental Research Institute of Michigan, Ann Arbor), pp 953-954.

The three modes of interactive operation, termed Alpha, Beta and Gamma Processing, reflect the need for a range of interactive processing techniques. Alpha processing is characterized by the instantaneous processing of a high quality TV image which can be live from a camera or stored on a number of the system's 16 digital image stores. The Alpha processing functions are highly interactive with pseudo-analogue control of piecewise linear contrast stretching, color compositing, tinting, level slicing, maximum emphasis display, ratioing and simple classification. Beta processing implements functions which cannot be easily performed at full TV rates by for which rapid response is essential in an interactive environment. The Beta functions may be one or two dimensional in nature and range from enhancement through multi-spectral classification with complex decision boundaries to spatial (texture) processing and analysis. The third processing mode, Gamma is totally software orientated and is used where it is inappropriate to implement the processing in hardware - e.g., feature optimization, and classifier training, or where the nature of the data makes software processing the natural function - e.g., ground truth data basing.

2. Density slicing

Dooley, J.T., 1976, Utility of scanning densitometer in analyzing remotely sensed imagery. US National Aeronautics and Space Administration, Lewis Research Center, Cleveland, Ohio, NASA-TM-X-73533, E-8955, 21 pp, refs.

The utility of a scanning densitometer for analyzing imagery was evaluated. Uses studied include: 1) quick-look screening of imagery by means of density slicing, magnification, color coding, and edge enhancement; 2) preliminary category classification of both low- and high-resolution data bases; and 3) quantitative measurement of the extent of features within selected areas.

Wang, S., 1977, Coastal thematic mapping by density slicing ERTS-1 imagery of western Taiwan. National Taiwan University, Department of Geography, science reports, 9, pp 53-68.

Thematic mapping by density slicing and color coding ERTS-1 satellite images can be accomplished by using an I^2S Digicol Density Analyzer. This is illustrated by extracting the following themes from either a Band 5 or Band 7 image: coastal wetlands; lakes and ponds; urbanized, industrial, and bare soil areas. This technique can be used to extract any particular theme which has a distinguishable tone on the images.

Wilmet, J., 1975, The use of density slicing for land use mapping. Bulletin trimestriel de la societe belge de photogrammetrie, 117-118, pp 33-43.

Density slicing may be achieved with the aid of masks from negatives or by numerical methods from digital data. Although the method allows the interpretation of features from their spectral signature, the signature may vary due to such factors as time and place of photography and the emulsion used. Two examples are given showing how the method may be used for land use mapping and the mapping of linear features and for thematic mapping from LANDSAT photography.

3. Band ratioing

Raines, G.L., 1977, Digital color analysis of color-ratio composite LANDSAT scenes, in Proceedings 11th international symposium on remote sensing of environment, April 1977, (Center for remote sensing information and analysis, Environmental Research Institute of Michigan, Ann Arbor), pp 1463-1472.

A new technique has been developed by which values of gray tones in three ratios being composited can be numerically transformed from three axes of an orthogonal coordinate system to values in a cylindrical coordinate system that approximates Munsell color space. Combined ratio values thus can be precisely and quantitatively defined in terms of distinct colors that would result from a color-compositing process, such as the diazo process. Applied to the Goldfield, Nevada, area, this new technique has been used to produce color composites that accurately discriminate altered ground, show variations within altered areas, and show limonitic alluvium transported from the Goldfield area, in different colors which could not be distinguished from altered ground in the diazo color-ratio composites previously used.

4. False-color image

Beer, J.S.; Sijmons, K.; and Weinreich, H., 1978, Intensity and color coding of relief and ground cover on PC transformed LANDSAT data, ITC journal, 78(2), pp 247-252.

Authors report on research to assess LANDSAT imagery as an aid in the production of relief maps by photo-mechanical methods. Using as original material black and white LANDSAT imagery showing relief and vegetation, the method of obtaining the simulation of continuous tone, in color, is described and the final results are presented.

Raines, G.L., 1977, Digital color analysis of color-ratio composite LANDSAT scenes, in Proceedings 11th international symposium on remote sensing of environment, April 1977, (Center for remote sensing information and analysis, Environmental Research Institute of Michigan, Ann Arbor), 1977, pp 1463-1472.

See Section I-C-3 for annotation.

Romijn, M.A., 1977, Primer for the production of LANDSAT color-composites, ITC journal, 77-3, pp 545-556.

This primer contains the basic technical information required for the production of LANDSAT color-composites, listing in note form the material and equipment needed, as well as the method of working.

5. "Unsupervised" or "clustering" analysis

Haskell, R.E., 1977, An interactive color display for multispectral imagery using correlation clustering, US National Aeronautics and Space Administration, Lyndon B. Johnson Space Center, Houston, Texas, 28 pp.

A method of and apparatus for processing multispectral data is provided which permits an operator to make parameter level changes during processing of the data. The system is directed to production of a color classification map on a video display in which a given color represents a localized region in multispectral features space. Interactive controls permit an operator to alter the size and change the location of these regions, permitting the classification of such regions to be changed from a broad to a narrow classification.

Narendra, P.M., and Goldberg, M., 1977, A non-parametric clustering scheme for LANDSAT, Pattern recognition, 9 (4), pp 207-216.

A 4-dimensional histogram is computed to reduce the large LANDSAT pixel data (up to 7.6 million pixels to a frame) to the much smaller number (6,000) of distinct vectors and their frequency of occurrence in the scene. The vectors are clustered by a recent non-parametric clustering algorithm, using the histogram count as a probability density estimate. Hashing is used to generate the histogram and also subsequent table look-up classification of the individual pixels in the image after the histogram vectors are clustered. The resultant clustering scheme is very efficient and a 512 x 512 LANDSAT scene can be clustered in less than 2 min of CPU time on a PDP-10 computer. Results of the application of the clustering scheme on representative LANDSAT scenes are included.

6. Change detection

Weismiller, R.A.; Kristof, S.J.; Scholz, D.K.; Anuta, P.E.; and Momin, S.M.; 1977, Evaluation of change detection techniques for monitoring coastal zone environments, in Proceedings 11th international symposium on remote sensing of environment, April 1977, (Center for remote sensing information and analysis, Environmental Research Institute of Michigan, Ann Arbor), pp 1229-1238.

An area of the Matagorda Bay estuarine system along the Texas coast was

selected as the principal study site. Initially, the study included individual data analysis of the area using the maximum likelihood classifier as implemented by LARSYS. The resultant inventory classifications included categories of agriculture, rangeland, high coastal marshes, wooded areas, swamp timber, brackish marshes, residential areas, grasslands, mud and sand flats, beach ridges, and at least 4 open water classes. Four candidate change detection techniques were designed with the understanding that other methods of change detection may function as well. The four techniques utilized were identified as: 1) post classification (direct change) method, 2) delta data change detection, 3) spectral/temporal change classification, and 4) layered spectral/temporal change classification.

7. Automated correlation of spectral "clusters" with surface information

Struve, H.; Grabau, W.E.; and West, H.W., 1977, Acquisition of terrain information using LANDSAT multispectral data. Report 2. An interactive procedure for classifying terrain types by spectral characteristics, US Army Engineer Waterways Experiment Station, Vicksburg, Miss., technical report, 140 pp.

This study developed a semiautomated procedure for classifying LANDSAT radiance data in terms of preselected land-use categories. The procedure is an interim solution to the problem of mapping very large areas in terms of relatively crude categories in very short periods of time.

D. Postprocessing

Best, R.G., and Smith, J.R., 1978, Photographic contrast enhancement of LANDSAT imagery, Photogrammetric engineering and remote sensing, 44 (8), pp 1023-1026.

An increase in photographic contrast (gamma) results in greater density differences among scene features and better radiometric resolution providing the maximum interpretation potential of LANDSAT imagery. The process involves selectively varying film type, developer, and development time to produce higher contrast in the reprocessed image. The technique has applications in any project which utilizes LANDSAT imagery.

II. IMAGE INTERPRETATION

A. Agricultural Land Use, Irrigation (See also Rangeland and Soils)

1. Table look-up

Richardson, A.J., and Wiegand, C.L., 1977, A table look-up procedure for rapidly mapping vegetation cover and crop development, in 4th annual symposium on machine processing of remotely sensed data, LARS, Purdue University, June 1977, ed D.B. Morrison and D.J. Scherer, (Institute of Electrical and Electronics Engineers), pp 284-296.

The LANDSAT data space surrounding the soil background line for MSS5 and MSS7 was divided into 10 decision regions corresponding to water; cloud shadow; low, medium, and high reflecting soil; cloud tops; low, medium, and dense plant cover; and a threshold region into which no LANDSAT data are expected to fall. Using a table look-up procedure, based on these 10 decision regions, LANDSAT scenes could be classified into meaningful vegetation density levels, soil brightness levels, and water from the raw satellite data without prior knowledge of local crop and soil conditions. These procedures deviate from current pattern recognition and remote sensing practice but should lead to faster and more automated machine processing of satellite MSS data for monitoring crop development, and for associating vegetation vigor and yield in large area crop yield prediction efforts.

2. False-color image

McMurtry, G.J.; Petersen, G.W.; and Wilson, A.D., 1974, Techniques for delineation and portrayal of land cover types using ERTS-1 data. Interim report. Pennsylvania State University, University Park, Office for Remote Sensing of Earth Resources, ORSER-SSEL-TR-23-74, 18 pp.

ERTS data were used to map land cover in agricultural areas, although in some parts of Pennsylvania, with small irregular fields, many of the pixels overlap field boundaries and cause difficulties in classification. Various techniques and devices were used to display the results of these land cover analyses. The most promising approach would be a user-interactive color monitor interfaced with a large computer so that classification results could be displayed on the CRT and these results output by a hard complete copier.

3. Radiometer, spectrometer applications

Ahern, F.J.; Goodenough, D.G.; Grey, A.L.; Ryerson, R.A.; and Vilbikaitis, R.J., 1978, Simultaneous microwave and optical wavelength observations of agri-

cultural targets, Canadian journal of remote sensing, 4(2), pp 127-143.

A 13.3 GHz scatterometer and a nadir-viewing radiometer measuring reflected radiance in the LANDSAT bands were flown simultaneously over fields containing eleven different forage crops. The coherent illumination and detection inherent in the scatterometer operation results in analysis techniques and statistical uncertainties which are quite different from those associated with the more traditional optical techniques. Confusion matrices were calculated for both the optical and the microwave data. Microwave and optical sensors provide complementary information which, when combined, permit the most accurate (88.4 $\pm$ 8.0 (s.d.) for 9 classes) classifications to be achieved. The most significant features derivable from the scatterometer data were the dual-polarized scattering co-efficients at nadir and the linear slopes of the scattering co-efficients as a function of observation angle.

Beers, J.N.P., 1975, Analysis of significance within crop-spectra: a comparison study of different multispectral scanners, Netherlands Interdepartmental Working Group on the Application of Remote Sensing, Delft, Publ-30, 46 pp.

In order to study the spectral signatures of vegetation canopies, reflectance data of 11 crops were gathered during the 1973 growing season using the NIWARS double beam type spectrometer. Using the spectra obtained, it was possible to determine for each crop or group of crops the part of the spectrum which is most significant. From this knowledge the use of the channels of different multispectral scanners is concluded in relation to the relative information content of the channels.

B. Forest Resources, Native Vegetation, Timber Survey
1. Digital analysis, general

Dethier, B.E.; Ashley, M.D.; Blair, B.O.; Caprio, J.M.; Hopp, R.J.; and Rouse, J.W., Jr., 1975, Satellite sensing of phenological events, Search, Agriculture, 6(1), 46 pp.

This study of the temporal and geographical progression of the plant life cycle reflected in variations in the spectral properties of plants at more than 3200 sites throughout the USA was based on 2 sequences; the green wave, which recorded the progression of foliage development over wide areas, and the brown wave, a record of vegetation senescence. The use and computer analysis of ERTS-1 (Earth Resources Technology Satellite) imagery and multispectral scanner digital tapes and data-handling and photo-interpretation techniques are described.

Hoffer, R.M., 1976, Techniques and applications for computer-aided analysis of multispectral scanner data, in Remote sensing in forestry. Proceedings of the symposium held during the XVI IUFRO World Congress, Oslo, 21 - 26 June, 1976, ed. G. Hildebrandt, (International Union of Forestry, Research Organizations, Subject Group S 6. 05 Remote Sensing, Freiburg), pp 103-113.

Several procedures for digitally processing and analyzing data from satellite scanner systems have been found to be useful. The techniques were applied to a mountainous test site of approximately 106 ha area. In spite of the vegetative and topographic complexity of this test site, coniferous and deciduous forest cover, as well as other major cover types, could be mapped with an accuracy of approximately 85% using both LANDSAT and SKYLAB data. Individual forest cover types were mapped with approximately 70% accuracy.

Kalensky, Z., and Scherk, L.R., 1977, Accuracy of forest mapping from LANDSAT computer compatible tapes, in Proceedings 10th international symposium on remote sensing of environment, October 1975, (Center for Remote Sensing Information and Analysis, Environmental Research Institute of Michigan, Ann Arbor), pp 1159-1168.

The obtained results confirmed usefulness of LANDSAT computer compatible tapes for automatic identification of forest and classification of broad forest types. This can be utilized in thematic mapping at 1:250,000 scale which is compatible with geometric accuracy of the LANDSAT scene corrected images.

Kan, E.P., 1976, A new computer approach to map fixed forest features and post-process multispectral data, in Proceedings of the American Society of Photogrammetry, Fall convention, Seattle, Washington, Sept. 28 - Oct. 1, 1976, pp 386-401.

Theory and application of a new computer approach for mapping mixed forest features (i.e. types, classes) from computer classification maps are presented. Because standard statistical pattern recognition techniques fail to detect mixed features in mixed stands defined by the Forest Service, a new approach is proposed by which features such as mixed softwood/hardwood stands are treated as admixtures of softwood areas and hardwood areas. This approach is accomplished by the iterative manipulation of the postprocessing algorithm that eliminates small connected sets. Computer-classified Land Satellite multispectral scanner data of the Sam Houston National Forest were used to demonstrate the approach.

Titus, S.; Gialdini, M; and Nichols, J., 1977, A total timber resource inventory based upon manual and automated analysis of LANDSAT-1 and supporting aircraft data using stratified multistage sampling techniques, in Proceedings 10th international symposium on remote sensing of environment, October 1975, (Center for Remote Sensing and Analysis, Environmental Research Institute of Michigan, Ann Arbor), pp 1093-1100.

The timber resource inventory proved to be cost-effective and timely in obtaining timber resource information. The parameters of interest had relative standard errors (RSE) within the range 6.31 to 8.19% with the exception of number of trees per hectare which was 12.19% (due largely to the difficulty of locating within the photo plots all trees of 127 mm DBH and larger). While the RSE for cubic meter volume, 7.82%, does not meet the specified sample precision level of five percent, the overall results are satisfactory.

2. Table look-up

Wiegand, C.L.; Gausman, J.W.; Leamer, R.W.; Richardson, A.J.; and Everitt, J.H., 1977, Soil, water and vegetation conditions in south Texas, Final report. 13 Jan. 75-13 Jun 77, (U.S. Department of Agriculture, Agricultural Research Service, Weslaco, Texas), 121 pp.

The best wavelengths in the 0.4 to 2.5 μm interval were determined for detecting lead toxicity and ozone damage, distinguishing succulent from woody species, and detecting silverleaf sunflower. A table look-up procedure was devised that permits rapid identification of soil background and green biomass or phenological development in LANDSAT scenes without the need for training data.

3. Density slicing

Kinash, K., Chyo, M., 1976, Monitoring forest environment with photo densitometer through successive sampling, in Remote sensing in forestry. Proceedings of the symposium held during the XVI IUFRO World Congress, Oslo, 21-26 June 1976, ed. G. Hildebrandt (International Union of Forestry, Research Organizations, Subject Group S 6 .05 Remote Sensing, Freiburg), pp 351-362.

One method of monitoring forest environment may be the measurements of the densitometer on the aerial photography of forests. Successive change of the two occasions will be estimated through successive sampling. Comparison of four basic methods of successive sampling is done and the change of forest percentage is estimated by the densitometer value.

Rodriguez-Bejarano, Dario, 1975, Density slicing applied to forest type delineation, Photogrammetric Engineering and Remote Sensing, 41(8), pp 1029-1037.

Printing aerial photographs of a forested area on Agfacontour film to achieve density slicing, and subsequently copying the density slices on very high contrast lith film, aided in the discrimination of conifers and broadleafed trees.

4. False-color image

Lee, Y J.; Towler, F.; Bradatsch, H.; and Finding, S., 1977, Computer-assisted forest land classification by means of several classification methods on the CCRS IMAGE-100, in 4th Canadian symposium on remote sensing, Quebec, May 16-18, 1977, (Canadian Aeronautics and Space Institute, Ottawa), pp 37-46.

This study reported the results of computer-assisted forest land classification

by means of principal components color enhancements, unsupervised, supervised classification and multidate digital analysis on the CCRS IMAGE-100 multispectral analyzer. The study was conducted on three test sites in British Columbia. Site one was selected for the study of forest land classification; site two for monitoring burned-over areas, and site three for monitoring logged-over areas. The results from principal components color enhancement were excellent.

5. Unsupervised classification

Lee, Y.J.; Towler, F; Bradatsch, H.; and Finding, S., 1977, Computer-assisted forest land classification by means of several classification methods on the CCRS IMAGE-100, in 4th Canadian symposium on remote sensing, Quebec, May 16-18, 1977, (Canadian Aeronautics and Space Institute, Ottawa), pp 37-46.

See Section II-B-4 for annotation.

6. Clustering

Fleming, M.D., and Hoffer, R.M., 1977, Computer-aided analysis techniques for an operational system to map forest lands utilizing LANDSAT MSS data, Purdue University, LARS Technical Report, 112277, 236 pp.

The objective of this research was to define an effective and efficient computer-aided analysis technique that can be utilized to map natural resources, particularly forest lands in areas of rugged terrain using digital multispectral scanner data collected from satellite altitudes. Six alternative procedures for developing training statistics were defined and tested. The results indicated that the 'Multi-Cluster Blocks' approach was optimal since it required the smallest amount of support data, required relatively few man-hours of analyst time, reduced computer (C.P.U.) time, and resulted in the highest overall classification accuracy.

7. Change detection

Baker, N.K., and others, 1976, An interactive minicomputer image processing system for remote sensing applications, in Proceedings of the American Society of Photogrammetry, Fall convention, Seattle, Washington, Sept. 28-Oct. 1, 1976, pp 373-385.

An inexpensive digital image processing and display system was developed by the U.S. Forest Service. The system has been designed to support a wide range of earth resource applications including: land use analysis, vegetation (species) identification, inventory of forests and rangelands,

and detection and analysis of insect and disease infestations. Results are presented for a typical application of change detection and forest stand impact analysis for Mountain Pine beetle infestations in the Ponderosa Pine ecosystem of the Black Hills National Forest in western South Dakota.

8. Mapping, manual interpretation

Witmer, Richard E., 1972, Some forest interpretation potentials of hyper-altitude photography and ERTS-A imagery applications and prognostications, Tennessee Valley test site; final report, (East Tennessee State University, Johnson City, Department of Geography), 23 pp.

Forest cover of an area in northern Alabama was mapped using 1:120,000-scale photography. Maps drawn from a mosaic, and one drawn from the original transparency, proved the increased accuracy of the map prepared from the transparency. Seven basic forest patterns were created by relating characteristic slopes, topographic positions, and drainage networks to the forest cover. The ability to produce a valid catalog of repeatable patterns that could be applied to specific case situations over a larger area was demonstrated.

9. Reflectometer, spectroradiometer applications

Drewett, R.J., 1977, Use of a remote reflectance and digital data analysis to study phosphate deficiency in spruce trees, in Proceedings 10th international symposium on remote sensing of environment, October 1975, (Center for Remote Sensing Information and Analysis, Environmental Research Institute of Michigan, Ann Arbor), pp 1123-1132.

A series of measurements was made during 1974 on 2 and 3 year Sitka Spruce with known levels of phosphate dosing ranging from severely deficient to a toxic overdose. Spectral reflectance was measured under a range of conditions in the pre-growth and full-growth seasons using a special-purpose remote reflectometer. This instrument scans a selected number of ground areas in rapid succession at each wavelength, and records the radiance from each target in digital form. One target is normally a reference panel, while the remaining targets (up to 9 is feasible) are the areas of measurement. A number of different targets may be reliably measured without difficulty from a tower or vehicle roof. A suite of programs is available to display and analyze the data.

Kalensky, Z., and Wilson, D.A., 1976, Spectral signatures of forest trees, in Third Canadian symposium on remote sensing, Edmonton, Alberta, September 1975, ed Thompson, (Canadian Aeronautics and Space Institute, Ottawa), pp 155-171.

Described are field measurements of daylight radiation reflected upwards from the crown of six tree species in visible and near-infrared frequencies of the electromagnetic spectrum. Each site was measured on at least two

dates between late June and early September to account for variations in species phenological stages during the summer season. In addition, some of the species were measured in two different locations to account for differences in site conditions. Presented are the reflectance data of tree species and their variations calculated from the field spectroradiometric data measured in the 1974 season.

Kreibel, K.T., 1978, Average variability of the radiation reflected by vegetated surfaces due to differing irradiations, Remote sensing of environment, 7(1), pp 81-83.

The average variability of the reflected field due to differing distributions of irradiation are given for three surfaces: bog, pasture land, and coniferous forest. Because the results are rather similar, mean values for vegetated surfaces can be derived. They indicate a change of reflected radiance by ± 1% per degree change of the solar zenith angle and per 10% change of the optical depth of the atmosphere.

Odle, W.C., 1976, Remote sensing of St. Augustine decline (SAD) disease, Texas A & M University, College Station, Remote Sensing Center, TR-RSC-77, 177 pp.

Laboratory and field spectral reflectance measurements of healthy and infected St. Augustine's grass were made using several different instruments. Spectral difference between healthy and infected grass occurred in the visible and near infrared regions.

C. Geology, Mineral Resources
1. Digital analysis, general

Hord, R.M., 1977, Digital enhancement of LANDSAT MSS data for mineral exploration, in Remote-sensing applications for mineral exploration, ed W.L. Smith, (Dowden, Hutchnison and Ross Inc., Pennsylvania; distributed by John Wiley and Sons), pp 235-250.

Review of published reports suggests that LANDSAT imagery has become established as a research tool despite the widespread use of less than optimal techniques for interpretation and presentation of the imagery. A developed technology exists to improve the utility of image data. When important decisions are to be made in the resource area, exploitation of this technology to maximum advantage is essential. Some of the more common examples illustrated in pictures are: digital linear contrast enhancement; density slicing; digital photomosaic construction; logarithmic ratioing; and combinations of these techniques on a single image.

Lyon, R.J.P., 1977, Mineral exploration applications of digitally processed LANDSAT imagery, in Proceedings of the 1st annual William T. Pecora memorial symposium, October 1975, Sioux Falls, South Dakota, ed. P.W. Woll and W.A. Fischer, (United States Geological Survey Professional Paper, 1015), pp 271-292.

Enhancement processing of LANDSAT CCT digital data can markedly increase its application in mineral exploration. The use of computers in geological analysis of these images is complicated because of the inability of the creative photogeologist to specify mathematically the decisionmaking process by which he arrives at an analysis. Algorithms can be created for some of the steps, but by using an interactive computer display system, under the control of the geologist personally familiar with the problem and area being studied, the man-machine interaction can extract the benefits of both. This paper describes the use of such a system (STANSORT) to mineral exploration problems, in zero vegetation cover (Yerington; Goldfield, Nev.), mixed cover of pinon pine and juniper (Pine Nut Mtns., Nev.), heavy birch forest (Karasjok, Norway), and full tropical cover (Tifalmin, New Guinea).

Robinson, J.E., and Carroll, S., 1977, Software for geologic processing of LANDSAT imagery, Computers and geosciences, 3(3), pp 459-464.

The effective delineation of rock boundaries and other geologic features from LANDSAT imagery usually requires the use of scenes that have been processed digitally to optimize information content and presentation. Geological processing programs correct for atmospheric distortions and standardize reflectances to uniform ranges for within and between scene continuity. The ideal geological software system for LANDSAT processing is a combination of programs that can be ordered to produce the desired resolution of reflectance zones while retaining the structural and textural information that is vital to accurate interpretation.

Schmidt, R.G., and Bernstein, R., 1977, Evaluation of improved digital-processing techniques of LANDSAT data for sulfide mineral prospecting, in Proceedings of the 1st annual William T. Pecora memorial symposium, October 1975, Sioux Falls, South Dakota, ed. P.W. Woll and W.A. Fischer, (United States Geological Survey Professional Paper, 1015), pp 201-212.

A relatively simple method of digital computer classification of multispectral scanner data was tested at a porphyry copper deposit in a very arid part of Pakistan and was then successfully applied to mineral exploration in an adjacent region. The surface expressions of the already known porphyry copper deposit and the five new prospects discovered in this experiment are all characterized by abundant light-toned sulfate minerals and do not seem to contain much pigmentation by iron oxides. Digital multispectral classification was performed by using reformatted computer-compatible tapes of one scene. Our experiment indicates that simple methods of digital classification of LANDSAT data can aid in the location of mineral deposits in desert terrain.

2. Contrast stretch

Albert, N.R.D., and Chavez, P.S., Jr., 1977, Computer-enhanced LANDSAT imagery as a tool for mineral exploration in Alaska, in Proceedings of the 1st annual William T. Pecora memorial symposium, October 1975, Sioux Falls, South Dakota, ed P.W. Woll and W.A. Fischer, (United States Geological Survey Professional Paper, 1015), pp 193-200.

Recent work in Alaska indicates that computer-enhanced LANDSAT imagery shows many of the known mineral deposits and can help in the prediction of potential mineral occurrences. False color, 'simulated natural color,' and color ratio techniques, were used successfully in conjunction with a black and white, single band image mosaic of Alaska. Computer techniques involved 1) atmospheric and Sun-elevation corrections, noise removal, computer mosaicking, and change of the data format and 2) image enhancement, involving data manipulation for maximum discrimination of surface materials and structure. Application of a new technique called a 'sinusoidal' stretch gave information not available in other products having standard contrast stretches.

Offield, T.W.; Abbott, E.A.; Gillespie, A.R.; and Loguercio, S.O., 1977, Structure mapping on enhanced LANDSAT images of southern Brazil: tectonic control of mineralization and speculations on metallogeny, Geophysics, 42(3), pp 482-500.

Computer enhancement, particularly contrast-stretching, reveals a previously unnoticed east-west structural zone across a LANDSAT image of the southern Brazilian Precambrian shield. In this zone occur the only known economic or near-economic deposits of gold, tin, and copper. Such deposits are typically localized by small east-west structural elements. Non-economical copper occurrences elsewhere in the region appear to be related to major northeast- and northwest-trending lineaments mapped in LANDSAT images.

Rowan, L.C.; Goetz, A.F.H.; and Ashley, R.P., 1977, Discrimination of hydrothermally altered and unaltered rocks in visible and near-infrared multispectral images, Geophysics, 42(3), pp 522-535.

Mineralogical differences between altered rocks and most unaltered rocks in south-central Nevada cause visible and near-infrared (0.45 to 2.4 μm) spectral-reflectance differences which can be used to discriminate these broad categories of rocks in multispectral images. The most important mineralogical differences are the increased abundance of goethite, hematite, and jarosite, and the presence of alunite, montmorillonite, and kaolinite in the altered rocks. The technique developed to enhance these subtle spectral differences combines ratioing of the MSS bands and contrast stretching. The stretched ratio values are used to produce black-and-white images which depict materials according to spectral reflectance; ratioing minimizes the influence of topography and overall albedo on the grouping of spectrally similar materials. Color compositing of two or more stretched

ratio images to form color-ratio composites provides additional enhancement. The most effective color-ratio composite for discriminating between the altered and unaltered areas, as well as among many of the unaltered rocks in south-central Nevada, was prepared using the following diazo color and stretched ratio image combinations: blue for MSS 4/5, yellow for MSS 5/6, and magenta for MSS 6/7. Altered areas appear green and brown in this combination.

3. Band ratioing

Ballew, Gary I., 1977, Correlation of LANDSAT-1 multispectral data with surface geochemistry, in Proceedings 10th international symposium on remote sensing of environment, October 1975, (Center for Remote Sensing Information and Analysis, Environmental Research Institute of Michigan, Ann Arbor), pp 1045-1056.

LANDSAT-1 multispectral scanner digital data were compared to surface geochemical data from the Washington Hill mercury mining district in the north central portion of the Virginia City 15-minute quadrangle, Nevada. The four channel values and their six ratios, four logs and six logs of ratios were correlated with metal concentration and log of metal concentration for each of the six metals. Assuming the data are normally distributed, linear relationships with a probability of greater than 0.90 exist for channels or functions of channels and Hg, Pb, Cu, Bi, log Hg, log Ag, log Pb, log Cu and Bi concentrations.

Juneman, P.M.; Wheeler, S.G.; and Ingram, D.S., 1976, Use of an interactive processing system in a geological application, in International Earth Resources Management Symposium, January 27-29, 1976, Houston, Texas, pp 333-349.

Authors describe the use of LANDSAT data plus an interactive computer processing system to make a detailed study of lithology, rather than structure, of a relatively small, arid area with very limited vegetation and primarily igneous rock types. The system has been used to transform a set of LANDSAT data by channel ratioing, to display the transformed data for analysis, and finally, after introducing ancillary ground truth information, to map rock types within the area. The conclusion is drawn that the use of an interactive processing system for rock type discrimination is feasible and practical.

Merifield, P.M.; Lamar, D.L.; Keaton, J.R.; and Lamar, J.V., 1974, Enhancement of geologic features near Mojave, California, by spectral band ratioing of ERTS MSS data, California Earth Science Corp. (Santa Monica, California), technical report, 74-4, 21 pp.

A number of geologic features in the western Mojave desert were enhanced in spectral ratio images to ERTS MSS data, especially in the Band 5 to Band 4 ratio. Alluvial fans of different ages, which are indistinguishable

in single spectral band images, are readily differentiated. Other geologic features enhanced relative to their surroundings include an iron oxide gossan around the once productive Middle Butte mining area, and a marble unit presently being quarried for the manufacture of cement. Calcareous and alkaline soils of low fertility are also easily distinguishable because of their relatively dark appearance on the Band 5 to Band 4 ratio image.

Rowan, L.C.; Goetz, A.F.H.; and Ashley, R.P., 1977, Discrimination of hydrothermally altered and unaltered rocks in visible and near-infrared multispectral images, Geophusics, 42(3), pp 522-535.

See Section II-C-2 for annotation.

4. False-color image

Albert, N.R.D., and Chavez, P.S., 1977, Computer-enhanced LANDSAT imagery as a tool for mineral exploration in Alaska, in Proceedings of the 1st annual William T. Pecora memorial symposium, October 1975, Sioux Falls, Soth Dakota, ed P.W. Woll and W.A. Fischer, (United States Geological Survey Professional Paper, 1015), pp 193-200.

See Section II-C-2 for annotation.

Rowan, L.C.; Goetz, A.F.H.; and Ashley, R.P., 1977, Discrimination of hydrothermally altered and unaltered rocks in visible and near-infrared multispectral images, Geophusics, 42(3), pp 522-535.

See Section II-C-2 for annotation.

5. Mapping, manual interpretation

Brewer, W.A.; Erskine, M.C., Jr.; Prindle, R.O.; and Haenggi, W.T., 1974, Mineral exploration potential of ERTS-1 data, (United States NASA, ERTS Report; E74-10608), 94 pp.

ERTS-1 imagery of Arizona was interpreted for regional structure and tectonic units. Eight fault systems were identified by trend, of which two, northeast and northwest, are considered to be related to porphyry copper mineralization. Nine tectonic units can be identified on the imagery as distinct geological identities. The boundaries between these units can be correlated with theoretical shear directions related to the San Andreas stress system. Fourier analysis of the N 50 W fault trend indicates a fundamental spacing between Fourier energy maxima that can be related to distances between copper deposits.

Lee, K., and Raines, G.L., 1974, An evaluation of multiband photography for rock discrimination, (United States NASA, ERTS Report, E74-10410), 38 pp.

The ability of multiband photography to discriminate sedimentary rocks was examined. More than 8600 in situ measurements of band reflectance of the sedimentary rocks of the Front Range, Colorado, were acquired. Statistical analysis of these measurements showed that: 1) measurements from one site can be used at another site 100 miles away; 2) there is basically only one spectral reflectance curve for these rocks, with constant amplitude differences between the curves; and 3) the natural variation is so large that at least 150 measurements per formation are required to select best filters. The designed multiband photography concept for rock discrimination is not a practical method of improving sedimentary rock discrimination capabilities.

Morrison, R.B., and Hallberg, G.R., 1974, Evaluation of ERTS-1 imagery for mapping Quaternary deposits and landforms in the Great Plains and Midwest, (United States NASA, ERTS Report, E74-10614), 8 pp.

Maps at 1:1 million scale for the identification and mapping of landform and land use characteristics and surficial geologic materials directly from the ERTS-1 images were prepared. For areas that have not been mapped at 1:500,000 or larger scales, maps will provide the first moderately detailed information on landform features and surficial materials. Much of the information mapped is significant for exploration and for applications in engineering and environmental geology, including land use planning. Analysis of drainage patterns, stream-divide relations and land use patterns has revealed several possible moraine-controlled divides of middle and early Pleistocene age. One is an extension of the Cedar Bluffs moraine of southeastern Nebraska. Another of these divides may correspond to the terminus of Nebraska drift in the Kansas City study area. The trends of parts of various ancient filled valleys also have been identified by analysis of changes in width of the present stream valleys. The alignments of certain segments of stream valleys in Kansas and Missouri appear to be controlled by regional faults or other structural features.

Stow, S.H.; Price, R.C.; Hoehner, R.; and Wielchowsky, C., 1976, Use of remote sensing techniques for geological hazard surveys in vegetated urban regions. Final report 1 Jul 1973 - 30 Jun 1976, (Alabama University, Department of Geology and Geography), 170 pp.

The feasibility of using aerial photography for lithologic differentiation in a heavily vegetated region is investigated using multispectral imagery obtained from LANDSAT satellite and aircraft-borne photography. Delineating and mapping of localized vegetal zones can be accomplished by the use of remote sensing. An investigation was made to show that local plant zones are affected by altitude, topography, weathering, and gullying; but are controlled by lithology. Therefore, maps outlining local plant zones were used as a basis for lithologic map construction.

D. Mining, Detection and Monitoring
1. Digital analysis, general

Anderson, A.T., and Schubert, J., 1976, ERTS-1 data applied to strip mining, Photogrammetric engineering and remote sensing, 42(2), pp 211-219.

Two coal basins within the Potomac River Basin contain the largest strip-mining operations in western Maryland and West Virginia. These are at the Georges Creek and the Upper Potomac Basins, which lie within the Georges Creek (Wellersburg) syncline. The disturbed strip-mine areas were delineated with the surrounding geological and vegetation features by using ERTS-1 data in both analog (imagery) and digital form. The two digital systems used were 1) the ERTS-Analysis system, a point-by-point digital analysis of spectral signatures based on known spectral values, and 2) the LARS Automatic Data Processing System. Aircraft data, ground verification information, and geological field studies also aided in the application of ERTS-1 imagery in order to perform an integrated analysis that assessed the adverse effects of strip mining.

Durfee, R.C., and Edwards, R.G., 1975, Assignments of ERTS and topographical data to geodetic grids for environmental analysis of contour strip mining, Oak Ridge National Lab, Tenn., Conference, 55 pp.

Computer techniques are presented for converting ERTS classified landcover patterns, Defense Mapping Agency topographic data, and geographical variables from other sources onto a common geodetic grid composed of latitude-longitude cells. Spatial analysis techniques are then used to assess the environmental and aesthetic impact of coal surface mining in the New River Basin of East Tennessee.

United States National Field Investigations Center, 1975, An application of ERTS technology to the evaluation of coal strip mining and reclamation in the northern Great Plains. Final report, (Denver, Colorado), 120 pp.

A study was conducted of the coal mines in Wyoming, Montana, North and South Dakota using remote sensing data from ERTS. The study documents the size, shape and location of the actively mined area, untouched spoil piles, reclaimed or recontoured areas, newly vegetated areas and abandoned spoil piles within each of the 30 active, inactive or proposed coal mine sites. Land use or classification at each mine evaluated was defined by computer processing of ERTS data from digital magnetic tapes. In most cases the computer classification techniques were successful.

2. Geometric correction

Rogers, R.H.; Reed, L.E.; and Pettyjohn, W.A., 1974, Automated strip-mine and reclamation mapping from ERTS, (United States NASA, ERTS Report E74-10490), 15 pp.

Computer processing techniques were applied to ERTS-1 CCT data acquired in August 1972 on the Ohio Power Company's coal mining operation in

Muskingum County, Ohio. Processing results succeeded in automatically classifying, with an accuracy greater than 90%; 1) stripped earth and major sources of erosion; 2) partially reclaimed areas and minor sources of erosion; 3) water with sediment; 4) water without sediment, and 5) vegetation. Computer-generated tables listing the area in acres and Km^2 were produced for each target category. Processing results also included geometrically corrected map overlays. Each target category is assigned a distinctive color on the overlay to facilitate interpretation. The overlays, drawn at a scale of 1:250,000 when placed over an AMS map of the same area, immediately provided map locations for each target. These mapping products were generated at a tenth of the cost of conventional mapping techniques.

3. Density slicing

Gilbertson, B.P., 1975, Monitoring the growth or decline of vegetation on mine dumps, (Spectral Africa (Pty) Ltd., Randfontein), 150 pp.

Particular mine dumps throughout the entire test area can be detected and identified. Patterns of vegetative growth on the mine dumps can be recognized from visual analysis of photographic images. Because vegetation tends to occur in patches on many mine dumps it is unsatisfactory to classify complete dumps into categories of percentage vegetative cover. A more desirable approach is to classify the patches of vegetation themselves. The coarse resolution of conventional densitometers restrict the accuracy of this procedure, and consequently a direct analysis of ERTS CCT's is preferred. A series of computer programs were written to perform the data reading and manipulating functions required for basic CCT analysis.

Jordan, D.C.; Graves, D.H.; and Hammetter, M.C., 1978, Use of manual densitometry in land cover classification, Photogrammetric engineering and remote sensing; 44(8), pp 1053-1059.

Our study indicates that manual densitometry is a valuable tool for cover classification in regions that include surface-mined areas. Manual spot densitometers were used to obtain land cover signatures for 118 strata from multi-temporal 1:24,000 color infrared and multispectral aerial photographs. Distinction between coniferous and deciduous trees is good under prefoliated conditions. However, a combination of foliated and prefoliated conditions is superior to either alone. Undisturbed forest and surface-mined areas are accurately classified from imagery taken during foliated conditions.

4. Edge enhancement

Anuta, P.E., and Ri, B.M., 1975, ERTS multispectral image transformations for geological lineament enhancement, Purdue University, LARS Information Note, 022575, 19 pp.

A study was conducted to investigate the edge enhancement potential of Gradient and Laplacian transformations on ERTS-1 multispectral scanner data. This report describes initial effort to enhance linear features by application of two-dimensional derivative operators to the ERTS imagery. The enhancements also have direct applications to image registration by providing a means of enhancing temporarily invariant objects in the scene.

5. Band ratioing

Anderson, A.T.; Schultz, D.T.; and Buchman, N., 1975, LANDSAT inventory of surface-mined areas using extendible digital techniques, in NASA Earth Resources Survey symposium. Volume 1-A: agriculture, environment, Houston, Texas, June 1975, (United States National Aeronautics and Space Administration, Lyndon B. Johnson Space Center, Houston, Texas), pp 329-345.

Multispectral LANDSAT imagery was analyzed to provide a rapid and accurate means of identification, classification, and measurement of strip-mined surfaces in Western Maryland. Four band analysis allows distinction of a variety of strip-mine associated classes, but has limited extendibility. A method for surface area measurements of strip mines, which is both geographically and temporally extendible, has been developed using band-ratioed LANDSAT reflectance data. The accuracy of area measurement by this method, averaged over three LANDSAT scenes taken between September 1972 and July 1974, is greater than 93%. Total affected acreage of large (50 hectare) mines can be measured to within 1.0%.

6. False-color image

Russell, O.R.; Nichols, D.A.; and Anderson, R., 1977, Application of LANDSAT-2 data to the implementation and enforcement of the Pennsylvania Surface Mining Conservation and Reclamation Act. Final report March 1975-May 1977, (Earth Satellite Corp., Washington, D.C.), 78 pp.

Evaluation of LANDSAT imagery indicates severe limitations in its utility for surface mine land studies. Image stripping resulting from unequal detector response on satellite degrades the image quality to the extent that images of scales larger than 1:125,000 are of limited value for manual interpretation. Computer processing of LANDSAT data to improve image quality is essential; the removal of scanline stripping and enhancement of mine land reflectance data combined with color composite printing permits useful photographic enlargements to approximately 1:60,000.

7. Histogram generation

Rogers, R.H.; Reed, L.E.; and Pettyjohn, W.A., 1974, Automated strip-mine and reclamation mapping from ERTS, (United States NASA, ERTS Report, E74-10490), 15 pp.

See Section II-D-2 for annotation.

8. Mapping manual interpretation

Amato, R.V.; Russell, O.R.; Martin, K.; and Wier, C.E., 1975, Application of EREP, LANDSAT, and aircraft image data to environmental problems related to coal mining, in NASA Earth resources survey symposium, Volume 1-A: agriculture, environment, Houston, Texas, June 1975, (United States National Aeronautics and Space Administration, Lyndon B. Johnson Space Center, Houston, Texas pp 309-327.

Remote sensing techniques were used to study coal mining sites within the Eastern Interior Coal Basin (Indiana, Illinois, and western Kentucky), the Appalachian Coal Basin (Ohio, West Virginia, and Pennsylvania) and the anthracite coal basins of northeastern Pennsylvania. Many sensors and platforms have been used.

Hughes, T.; Dillon, A.C., III; White, J.R., Jr.; Drummond, S.E., Jr.; and Hooks, W.G., 1975, Assessment of practicability of remote sensing techniques for a study of the effects of strip mining in Alabama. Final report 1 July 1973-30 June 1975, Alabama University, (Department of Geology and Geography), 190 pp.

Two test sites, Cordova and Searles, representative of the various strip mining techniques and environmental problems, were chosen for intensive studies of the correlation between remote sensing and ground truth data.

Mamula, N., Jr., 1978, Remote-sensing methods for monitoring surface coal mining in the northern Great Plains. Journal of research of the United States Geological Survey, 6(2), pp 149-160.

Studies at a surface coal mine in Montana confirm that remote sensing is effective for gathering land-use and environmental data (spatial, dynamic, and seasonal) for large-scale surface mines in the northern Great Plains. The Western Energy Co.'s Rosebud mine near Colstrip, Montana, was selected as a test site because it typifies surface operations in the Powder River Basin of Montana and Wyoming and elsewhere in the northern Great Plains. Color infrared and black-and-white aerial photographs and a black-and-white band 5 LANDSAT image were used to identify 1) highwall and bench areas, 2) ungraded spoils, 3) graded and recontoured areas, 4) revegetated recontoured areas, 5) natural and impounded surface water, and 6) miscellaneous areas.

Moore, H.D.; Adams, J.H.; and Gregory, A.F., 1977, Mapping mine wastes with LANDSAT images, in 4th Canadian symposium on remote sensing, Quebec, May 16-18, 1977, (Canadian Aeronautics and Space Institute, Ottawa), pp 294-304.

Surficial materials at mine sites were subdivided into four classes of mine waste (overburden tailings, waste rock and slag), two classes of water, two classes of vegetational cover and two classes of mining facilities. 718 mine sites were studied and classifiable wastes were detected at 399 sites. Inventory sheets were prepared for all detectable disposal areas larger than one hectare and 1:50,000 maps were prepared for all such areas in excess of 10 hectares.

Wobber, F.J.; Russell, O.R.; and Deely, D.J., 1975, Multiscale aerial and orbital techniques for management of coal-mined lands, Photogrammetria, 31(4), pp 117-134.

LANDSAT-1 imagery and small-scale color-infrared aerial photography have unique advantages for performing a rapid regional inventory of disturbances in coal-mining areas. Large-scale photography is needed for comprehensive studies of acid mine drainage, and other mining-related water-quality control problems. A systematic analysis of nearly 50 mined-land features versus various scales of imagery has been tabulated for ease of reference by those involved in mined-land studies.

E. Rangeland and soils

1. Digital analysis, general

Kirschner, F.; Kaminsky, S; Hinzel, E.; Latowski, C,; and Weismiller, R., 1977, Quantification of soil mapping by digital analysis of LANDSAT data, in Proceedings 11th international symposium on remote sensing of environment, April 1977, (Center for Remote Sensing Information and Analysis, Environmental Research Institute of Michigan, Ann Arbor), pp 1567-1574.

Digital analysis of LANDSAT multispectral scanner (MSS) data provides a means of accurately describing and quantifying soil mapping unit composition. This paper examines three distinctly different soil mapping units and their composition as described by 1) field mapping and 2) digital analysis of satellite MSS data. A 4 ml^2 area located in Clinton County, Indiana was selected as the study area. The soils of this location developed from glacial till, loess and lacustrine materials, and are representative for much of this region. One soil representing each of these categories was selected for detailed study.

2. False-color image

Iyer, H.S., 1975, Use of additive color viewer for interpretation of ERTS imagery for soil mapping with respect to a part of north western India, in Remote

sensing of earth resources, volume 4, ed F. Shahrokhi, (University of Tennessee Space Institute), pp 293-299.

ERTS-1 color composites relating to an area in the north western part of India were interpreted with the aid of projections in an Additive Color Viewer, for the purpose of preparing soil maps. Satisfactory physiographic delineations could be made by this procedure; the soil composition of the units could be stipulated on the basis of the author's knowledge of the soils of the study area. Bands seven and five gave the best results for the interpretation of the black and white imagery for small scale soil mapping. The color composite product was found to be superior to the black and white imagery; a procedure involving the combination of the two seems to be the best approach for soil mapping.

3. Spectrometer applications

Genda, H., and Okayama, H., 1977, Field-averaging spectrograph camera for remote sensing applications and its characteristics, Applied optics, 16(3), pp 601-606.

The function of a field-averaging spectrograph camera is the same as a spectroradiometer, which is widely used for remote sensing applications at the present time. Moreover, it is more compact, portable, and lower priced than conventional instruments. The spectral reflectances of scenes were measured by photographic and spectroradiometer methods in field experiments. The spectral image of soil photographed by a beam split camera used with the field-averaging spectrograph camera is displayed in false color.

Schreier, H., 1977, Quantitative predictions of chemical soil conditions from multispectral airborne, ground, and laboratory measurements, in 4th Canadian symposium on remote sensing. Quebec, May 16-18, 1977, (Canadian Aeronautics and Space Institute, Ottawa), pp 106-112.

The potential of predicting chemical soil conditions from multispectral reflectance measurements is examined using correlation and regression techniques. The spectral reflection of soils from five different parent materials was measured from the air, on the ground and in the laboratory with a multichannel spectrometer. Characteristic spectral reflection curves over the 400-1000 nm wavelength range were obtained for each of the five groups, producing significantly different mean and range values. A comparison between the chemical conditions of the soils and their reflection values revealed that percent carbon, percent iron, and exchangeable magnesium were most significantly correlated with percent reflection. A curvilinear regression fitting an exponential function was found to be satisfactory for the prediction of carbon and exchangeable magnesium values, while a straight linear function sufficed for iron prediction. Using the above mentioned functions it was possible to determine the carbon, magnesium, and iron variation across several agricultural fields using the airborne measurements.

4. Mapping, manual interpretation

Cooley, M.E., and Turner, R.M., 1975, Applications of ERTS products in range and water management problems, Sahelian zone, Mali, Upper Volta, and Niger. Open file report on West Africa investigations, US Geological Survey, Reston, Va., Office of International Geology, IR-WA-4, 96 pp.

A field investigation during April and May 1974 evaluated application of ERTS imagery to range and water management problems in Mali, Upper Volta, and Niger. Specific applications of the ERTS imagery were identified in river-blindness control; tse-tse fly control; bush-burning evaluation; distinction of arable from non-arable lands; analysis of problems of accelerated erosion; the annual flood of the Niger River; and ground-water development in fractured rocks.

Houston, R.S., and Gordon, R.C., 1974, Range vegetation type mapping and aboveground green biomass estimations using multispectral imagery, (United States NASA, ERTS Report, E74-10493), 17 pp.

Range vegetation types have been successfully mapped west of Baggs, Wyoming, using ERTS-1 imagery. These types have been ascertained from field transects over a five year period. Comparable studies will be made with EREP imagery. Aboveground biomass estimation studies are being conducted utilizing double sampling techniques on two similar study sites. Information obtained will be correlated with percent relative reflectance measurements obtained on the ground which will be related to image brightness levels. This will provide an estimate of aboveground green biomass with multispectral imagery.

Massoud, F.I., 1978, The use of satellite imagery in detecting and delineating salt affected soils, in 1er colloque pedologie et teledetection, Rome, 1977, ed M.C. Girard, (International Soil Science Society), pp 77-84.

The feasibility of using satellite imagery in detecting and delineating salt affected soils is reported for three case studies. In the Indus Plain, Pakistan, the feasibility study showed the usefulness of ERTS imagery in salinity appraisal in cultivated zones subject to the availability of basic soil survey information as gound truth data. The use of ERTS-1 imagery to update the soil survey data of salt affected areas in California, USA, gave encouraging results where the soils are barren, and inconsistent identification where they are cultivated. The results of investigations to identify certain vegetated and barren salty areas in Texas, USA, with Skylab S 192 MSS revealed that the reflective infrared wavelengths are superior to the visible wavelengths for soil salinity detection and that soil salinity may not be readily estimated when using bare soil information alone.

F. Urban areas
1. Digital analysis, general

Jackson, T.J., 1976, The value of LANDSAT data in urban water resources planning, (Dissertation Abstracts International, B, 77-10, 406), 251 pp.

An investigation was conducted to determine the economic value of LANDSAT multispectral satellite remote sensing in urban water resources planning. Parameters of the hydrologic simulation model STORM were related to the watershed percent of impervious area. Hydrologic comparisons indicated that reliable flood frequency data could be developed using machine-aided classification of LANDSAT data to define the parameters of STORM. Bayesian Decision Theory provided the framework for determining the expected value of LANDSAT data. The specific problem studied was selecting the optimal level of detention storage for the Fourmile Run watershed.

Mausel, P.W.; Rodd, W.J.; and Baumgardner, M.F., 1976, An analysis of metropolitan land-use by machine processing of Earth Resources Technology Satellite data, Purdue University, Lafayette, Indiana, Lab. for Applications of Remote Sensing, LARS-Information Note, 031276, 12 pp.

A successful application of state-of-the-art remote sensing technology in classifying an urban area into its broad land use classes is reported. This research proves that numerous urban features are amenable to classification using ERTS multispectral data automatically processed by computer.

Odenyo, V.A.O., and Pettry, D.E., 1977, Land-use mapping by machine processing of LANDSAT-1 data, Photogrammetric engineering and remote sensing, 43(4), pp 515-524.

Data on computer-compatible tapes of LANDSAT-1 of August 30, 1973, were analyzed to generate a land-use map of Virginia Beach, Virginia. Bands 4, 5, 6, and 7 were used in the supervised approach with the LARSYS software system of Purdue University. A Land-Use/Land-Cover map at a scale of 1:24,000 was obtained. Major functional classes delineated were Urban, Agricultural, Wooded, Water, Wetland, and Bare Land. Twenty-four subdivisions of these classes were spectrally separable. Performances of 97.9% for training field, 93.9% for test field, 97.0% for training class, and 92.1% for test class were obtained. Construction activities caused some misclassifications.

Williams, D.L., and Borden, F.Y., 1977, A reduction in AG/residential signature conflict using principal components analysis of LANDSAT temporal data, US National Aeronautics and Space Administration, Goddard Space Flight Center, Greenbelt, Md, NASA-TM-X-71387, 14 pp.

Methods to delineate the types of land cover in the urban-rural transition zone of metropolitan areas were considered. The application of principal components analysis to multidate LANDSAT imagery was investigated as a means

of reducing the overlap between residential and agricultural spectral signatures. The statistical concepts of principal components analysis were discussed, as well as the results of this analysis when applied to multidate LANDSAT imagery of the Washington, D.C. metropolitan area.

2. Geometric corrections

Carter, P.; Gardner, W.E.; and Smith, R.F., 1976, The use of LANDSAT imagery for the automated recognition of urban development, in Land use studies by remote sensing, ed W.G. Collins and J.L. van Genderen, (Remote Sensing Society; Remote Sensing Unit, Dept. of Civil Engineering, University of Aston, Birmingham), pp 54-88.

The value of LANDSAT imagery for the automated determination of changes in urban land is discussed. This imagery is readily available and relatively inexpensive. The form of LANDSAT digital data, and the geometrical corrections which may be applied, are described in detail and the limitations of the data for characterizing urban land use categories are considered. Finally various processing algorithms are described which will be invaluable for classifying data.

3. Edge enhancement

Tapper, G.O., 1976, Edge enhancement for delimitation of suburban environments, in Third Canadian symposium on remote sensing, Edmonton, Alberta, September 1975, ed G.E. Thompson, (Canadian Aeronautics and Space Institute, Ottawa), pp 195-201.

The technique of edge enhancement of selected LANDSAT 1 imagery has proved to be useful for mapping variegated areal phenomena especially in suburban environments. Edge enhancement of small scale (spacecraft) imagery can allow cost effective monitoring of land use change for large regions and will be an extremely valuable tool in providing data necessary for effective regional planning.

4. Density slicing

Carter, P., and Jackson, M., 1976, The automated recognition of urban development from LANDSAT images, in Symposium on machine processing of remotely sensed data, June 29-July 1, 1976. Laboratory for Applications of Remote Sensing, Purdue University, West Lafayette, Ind., (Institute of Electrical and Electronics Engineers, Inc.), pp 1B.15 - 1B.24.

The problems and progress made in the development of automated methods for the recognition and extraction of urban land use features from LANDSAT digital data of the UK are described. In the data examined so

far density slicing in one waveband appears to be almost as effective as multiwaveband classification in selecting the urban areas. While absolute boundaries may be difficult to delineate, new developments may be recognizable which would be adequate for monitoring needs. It appears important to include the effects of seasonal change and make use of textural analysis in the classification process.

Colner, B.J., 1976, The use of LANDSAT imagery in urbanized area studies, in Proceedings of the American Congress on Surveying and Mapping, Fall convention, Seattle, Washington, Sept. 28-Oct. 1, 1976, pp 210-222.

This paper discusses the application of LANDSAT imagery to the delineation of urbanized area (UA) limits. The drawing of LANDSAT UA boundaries was aided by the utilization of the appropriate 1970 Bureau of the Census Metropolitan Map Series sheets. The Bureau of the Census Block Statistics Reports (1970) were used to determine the population within the observed LANDSAT boundaries. The LANDSAT UA's were measured using a density slicer's electronic planimeter. Comparisons were made between the Census UA's and the LANDSAT UA's relative to their areas and population densities.

5. Change detection

Alexander, R.H., and Milazzo, V.A., 1974, Some findings on the applications of ERTS and Skylab imagery for metropolitan land use analysis, (United States NASA, ERTS Report, E74-10630), 17 pp.

Work on a three-sensor land use data evaluation of the Phoenix area is reported. Analyses between land use data generated from 1970 high altitude photography and that detectable from ERTS and Skylab, especially in terms of changes in land use, indicate that ERTS and Skylab imagery can be used effectively to detect and identify areas of post-1970 land use change, especially those documenting urban expansion at the rural-urban fringe.

Christenson, J.W., and Lachowski, H.M., 1976, Urban area delineation and detection of change along the urban-rural boundary, in Proceedings of the American Congress on Surveying and Mapping, Fall convention, Seattle, Washington, Sept. 28-Oct. 1, 1976, pp 223-228.

LANDSAT digital multispectral scanner data (MSS), in conjunction with supporting ground truth, were investigated to determine their utility in delineation of urban-rural boundaries. The digital data for the metropolitan areas of Washington, D.C., Austin, Texas, and Seattle, Washington, were processed using an interactive image processing system. Processing focused on identification of major land cover types typical of the zone of transition from urban to rural landscape, and definition of their spectral signatures. Census tract boundaries were input into the interactive image processing system along with the LANDSAT single and overlayed multiple date MSS data.

Todd, W.J., 1977, Urban and regional land use change detected by using LANDSAT data, Journal of research of the United States Geological Survey, 5(5), pp 529-534.

The Atlanta Regional Commission and the Earth Resources Observation Systems Data Center participated in a demonstration of the use of LANDSAT digital data to detect land use change in the Atlanta, Ga., area. Temporal overlays combining LANDSAT band-5 data from October 1972 and 1974 were made by using the General Electric Image 100 system. The 1972 data were divided by the 1974 data, and low ratios indicate areas where land use and land cover had changed. These low ratios were classified into a land-use-change theme.

6. Mapping, manual interpretation

Place, J.L., 1974, Land use mapping and modelling for the Phoenix quadrangle. Progress report 1 July 1972 - 19 April 1974, (U.S. Geological Survey, Reston, Va.), 34 pp.

The mapping of generalized land use level 1) from ERTS 1 images was shown to be feasible with better than 95% accuracy in the Phoenix quadrangle. The accuracy of level 2 mapping in urban areas is still a problem. Updating existing maps also proved to be feasible, especially in water categories and agricultural uses: however, expanding urban growth was presented with accuracy. ERTS 1 film images indicated where areas of change were occurring, thus aiding focusing-in for more detailed investigation.

G. Water
1. Ground water
a. general

Moore, G.K., and Deutsch, M., 1975, ERTS imagery for ground-water investigations, Ground water, 13(2), pp 214-226.

ERTS imagery offers the first opportunity to apply moderately high-resolution satellite data to the nationwide study of water resources. This imagery is both a tool and a form of basic data. The main advantage of its use will be to reduce the need for field work. Some present and potential uses of ERTS imagery are to locate new aquifers, to study aquifer recharge and discharge, to estimate ground-water pumpage for irrigation, to predict the location and type of aquifer management problems, and to locate and monitor strip mines which commonly are sources for acid mine drainage.

b. digital analysis, general

Lidster, W.A.; Schmer, F.A.; Ryland, D.W.; and Moore, D.G., 1975, Remote-sensing techniques for determining water table depths in irrigated agriculture, in Proceedings of the fall convention, American Society of Photogrammetry, October 1975, Phoemix, Arizona, pp 821-838.

An effort to evaluate the applicability of remote sensing for determination of water table depths in an irrigated region in North-Central Kansas has been in progress since mid-1972. Areas having high water tables were visually located on the aircraft imagery and verified by USBR personnel at the study area. Aircraft and LANDSAT-1 imagery were digitized and the digital values correlated with water table depths. Multiple regression, mode seeking, and K-class classification analyses were applied to the data. Significant correlations were obtained between water table depths and LANDSAT-1 and aircraft data for the total area of study and for specific fields.

c. mapping, manual interpretation

Charron, J.E., 1976, Hydrogeological application of Earth Resources Technology Satellite LANDSAT-1 imagery/Utilisation des techniques du satellite LANDSAT 1 dans le domaine de l'hydrogeologie, Environment Canada, Inland Waters Directorate, Scientific Series, 62, 22 pp.

A correlation of LANDSAT-1 imagery with various hydrogeological and surficial geology features in the Winnipeg areas, Manitoba, and the Ottawa (Ontario)--Montreal (Quebec) area of Canada is presented. The study includes the identification of groundwater recharge and discharge areas and artesian zones; areas of freshwater discharge into surface-water bodies; and the identification and mapping of various types of surficial deposits.

El Shazly, E.M.; Abdel, M.A.; and El Shazly, M.M., 1977, Groundwater studies in arid areas in Egypt using LANDSAT satellite images, in Proceedings 11th international symposium on remote sensing of environment, April 1977, (Center for Remote Sensing Information and Analysis, Environmental Research Institute of Michigan, Ann Arbor), pp 1365-1372.

Various features are interpreted which have strong bearing on groundwater in the arid environment. These include the nature of geologic and lithologic units, structural lineaments, present and old drainage systems, distribution and form of water pools, geomorphologic units, weathering surfaces and other weathering phenomena, desert soils, sand dunes and dune sand accumulations, growths of natural vegetation and agriculture, and salt crusts and other expressions of salinization.

2. Surface water, inventory and mapping
   a. general

Gierloff-Emden, H.G., 1976, Manual of interpretation of orbital remote sensing satellite photography and imagery for coastal and offshore environmental features (including lagoons, estuaries and bays), Munchener Geographische Abhandlunge, 20, 176 pp.

The manual covers 1) general remarks about the use of orbital satellites for coastal studies, and 2) detailed case studies in coastal areas--boundary layer model, water clarity and turbidity, lagoon and oceanic water interaction, use of multispectral photography.

b. digital analysis, general

Boland, D.H.P., and Blackwell, R.J., 1975, The LANDSAT-1 multispectral scanner as a tool in the classification of inland lakes, in NASA Earth Resources Survey symposium. Volume 1-A: agriculture, environment, Houston, Texas, June 1975, (United States National Aeronautics and Space Administration, Lyndon B. Johnson Space Center, Houston, Texas), pp 419-442.

Relationships between LANDSAT-1 multispectral scanner (MSS) data and the trophic status of a group of lakes in the north-northeastern part of the United States were studied by predicting the magnitudes of two trophic state indicators, estimating lake position on a multivariate trophic scale, and automatically classifying lakes according to their trophic state. Initially, the principal component ordination was employed with 100 lakes. MSS data for some 20 lakes was then extracted from computer-compatible tapes using a binary marking technique. The output was in the form of descriptive statistics and photographic concatenations. Color ratios were incorporated into regression models for the prediction of Secchi disc transparency, chlorophyll a, and lake position on the trophic scale. Results indicate that the LANDSAT-1 system, although handicapped by low spectral and spatial resolutions as well as excessive cloud cover, can be used as a supplemental data source in lake survey programs.

Mausel, P.W.; Todd, W.J.; Baumgardner, M.F.; Mitchell, R.A.; and Cook, J.P., 1976, Evaluation of surface water resources from machine-processing of ERTS multispectral data, Purdue University, Lafayette, Ind., LARS-Information Note, 030576, 7 pp.

The surface water resources of a large metropolitan area, Marion County (Indianapolis), Indiana, are studied in order to assess the potential value of ERTS spectral analysis to water resources problems. The results of the research indicate that all surface water bodies over 0.5 ha were identified accurately from ERTS multispectral analysis. Five distinct classes of water siltiness; depth of water; presence of macro

and micro biotic forms in the water; and presence of various chemical concentrations in the water. The machine processing of ERTS spectral data used alone or in conjunction with conventional sources of hydrological information can lead to the monitoring of area of surface water bodies; estimated volume of selected surface water bodies; differences in degree of silt and clay suspended in water and degree of water eutrophication related to chemical concentrations.

c. band ratioing

Yarger, H., and McCauley, J.R., 1975, Quantitative water quality with LANDSAT and Skylab, in NASA Earth resources survey symposium. Volume 1-A: agriculture, environment, Houston, Texas, June 1975, (United States National Aeronautics and Space Administration, Lyndon B. Johnson Space Center, Houston, Texas), pp 347-370.

Correlation studies were completed between LANDSAT MSS band ratios derived from CCT and 170 water samples taken from three large Kansas reservoirs, coincident with 16 different LANDSAT passes over a 13 month period. The following conclusions were obtained: 1) LANDSAT MSS reflectance levels are useful for quantitative measurement of suspended solids up to at least 900 ppm, 2) MSS band ratios derived from CCT can measure suspended solids with 67% confidence level accuracy of 12 ppm over the range 0-80 ppm and 35 ppm over the range 0-900 ppm, 3) suspended solids contour maps can be easily constructed from CCT for water bodies larger than approximately 100 acres, 4) ratioing suppresses MSS reflectance level dependence on seasonal sun angle variation and permits measurement of suspended load the year round in the middle latitudes. Skylab imagery from a single pass over three reservoirs compares favorably to LANDSAT results up to 100 ppm.

d. false-color image

Boland, D.H.P., and Blackwell, Richard J., 1975, The LANDSAT-1 multispectral scanner as a tool in the classification of inland lakes, in NASA earth resources survey symposium. Volume 1-A: agriculture, environment, Houston, Texas, June 1975, (United States National Aeronautics and Space Administration, Lyndon B. Johnson Space Center, Houston, Texas), pp 419-442.

See Section II-G-2-b for annotation.

e. mosaicking

May, G.A., and Petersen, G.W., 1978, Use of LANDSAT-1 data for the detection and mapping of saline seeps in Montana, Pennsylvania State University, University Park, Office for Remote Sensing of Earth Resources, ORSER-SSEL-TR-4-76, 87 pp.

Saline seeps can be efficiently and accurately mapped, within resolution capabilities, from merged May and August LANDSAT-1 data. Seeps were mapped by detecting salt crusts in the spring and indicator plants in the fall. These indicator plants were kochia, inkweed, and foxtail barley. The total hectares of the mapped saline seeps were calculated and tabulated. Saline seeps less than two hectares in size or that have linear configurations less than 200 meters in width were not mapped using the LANDSAT-1 data. Saline seep signatures developed in the Coffee Creek test site were extended to map saline seeps located outside this area.

f. mapping, manual interpretation

Frank, T.D.; McCoy, R.M.; and van Pelt, N.S., 1977, The application of remotely-sensed data to regional drainage basin analyses, in Great Plains--Rocky Mountain geographical journal, 6(2), pp 220-227.

The Center for Remote Sensing and Cartography at the University of Utah is presently evaluating remote sensing techniques useful in inventorying and monitoring surficial features of sparsely-vegetated perennial desert environments. A vast data base previously unavailable has been generated for certain drainage basin variables for a semiarid region of south-central Utah.

Gilmer, D.S., and Work, E.A., Jr., 1977, Application of LANDSAT system for improving methodology for inventory and classification of wetlands, (United States Bureau of Sport Fisheries and Wildlife, Jamestown, N. Dakota, Northern Prairie Wildlife Research Center), 13 pp.

Processing of LANDSAT MSS data for detection of prairie ponds and lakes was completed. Data coverage included a 36,876 sq km area in southeastern North Dakota during May and July. Cloud coverage limited the May coverage to 87% of the total area. Data analysis was accomplished using three software programs. Wetland identification by MSS sensors were compared to visual counts obtained by observers in low flying aircraft. Pond numbers identified by LANDSAT averaged about 20% of those counted visually. The discrepancy was attributed to the fact that approximately 75% of the ponds in the glaciated prairie region are less than 0.4 ha in size. It is significant, however, that LANDSAT counts accurately reflect trends.

Hancock, K.J., and Schlosser, E.H., 1976, Water mapping from satellite data: an automated procedure, in International earth resources management symposium, January 27-29, 1976, Houston, Texas, pp 279-301.

Death and destruction caused by failure of unrecorded dams led the U.S. Congress to require a national inventory and inspection of water impoundments. To aid in compiling the inventory, the Corps of Engineers and the State of Texas requested support from NASA's Johnson Space Center in Houston. As a result the DAM (Detection and Mapping) package was developed

to provide accurate, up-to-date economical and properly formatted maps of surface water using LANDSAT earth resources satellite digital data. This easy to use package has helped several Corps of Engineer districts update and check their impoundment inventories. Accuracies obtained for both water detection and location have exceeded the design criteria.

Work, E.A., and Gilmer, D.S., 1976, Utilization of satellite data for inventorying prairie ponds and lakes, Photogrammetric engineering and remote sensing, 42(5), pp 685-694.

By using data acquired by LANDSAT-1, studies were conducted in extracting information necessary for formulating management decisions relating to migratory waterfowl. Management decisions are based in part on an assessment of habitat characteristics, specifically numbers, distribution, and quality of ponds and lakes in the prime breeding range. This paper reports on a study concerned with mapping open surface water features in the glaciated prairies. Emphasis was placed on the recognition of these features based upon water's uniquely low radiance in a single near-infrared waveband. The results of this recognition were thematic maps and statistics relating to open surface water.

Wyatt, A.W.; Ellis, M.L.; and Bell, A.E., 1975, The application of remote sensing technology to the inventory of playa lakes in the High Plains of Texas, in NASA Earth resources survey symposium. Volume 1-D: water resources, Houston, Texas, June 1975, (United States National Aeronautics and Space Administration, Lyndon B. Johnson Space Center, Houston, Texas), pp 2523-2530.

The project will use the detection and mapping (DAM) package developed at NASA-Johnson Space Center. The economy of the High Plains region is dependent on ground water for irrigation and the Ogallala aquifer is being depleted faster than it is being recharged. The playa lakes represent a potential source of artificial recharge for the aquifer and an inventory is the first step in that direction.

3. Water quality, including salinity, turbidity
   a. digital analysis, general

Alfoldi, T.T., and Munday, J.C., Jr., 1977, Progress toward a LANDSAT water quality monitoring system, in 4th Canadian symposium on remote sensing, Quebec, May 16-18, 1977, (Canadian Aeronautics and Space Institute, Ottawa), pp 325-340.

The analysis of color or 'chromaticity' of LANDSAT scenes is providing a mechanism for the quantitative monitoring of water quality. Recent progress in the implementation of the chromaticity transform on the IMAGE 100 now offers the speed and flexibility of this digital analysis system. Data extracted from over 40 LANDSAT images of Canada, the U.S. and Nigeria have defined the locus of chromaticities on a chromaticity diagram for

a variety of water conditions. Discrete loci are identified for suspended sediment, chlorophyll and bathymetry. Moreover, contaminating shifts of these loci by sunglint, whitecaps, thin clouds, haze and air pollution may be detected on the diagram, and removed. Multidate suspended sediment sampling in the Minas Basin, Nova Scotia has produced correlation to LANDSAT data of r=0.95, after atmospheric adjustment.

Bukata, R.P.; Bruton, J.E.; and Jerome, J.H., 1977, Determination of water quality by means of remotely-sensed and locally-acquired optical data, in Environmental analysis, ed G.W. Ewing, (Academic Press), pp 13-28.

Spectro-optical techniques for determining water quality of inland lakes by means of both remotely-sensed and locally-acquired data are discussed. Results of pattern recognition studies are presented in which the mathematically cohesive patterns observed in the spectro-optical digital data of LANDSAT-1 are related to the water quality, physical, and biological aspects of lake behavior. Correlations are shown for the suspended solids concentrations (inorganic turbidity) and near-surface chlorophyll-a concentrations (organic turbidity) with the digital satellite data. A semi-empirical optical model is also described from which the suspended organic and inorganic concentrations of a water mass can be determined by simultaneous measurements of the transmission and volume reflectance of the water column at any wavelength.

Gervin, J.C., and Marshall, M.L., 1976, A LANDSAT study of water quality on Lake Okeechobee, in Proceedings of the American Society of Photogrammetry, Fall Convention, Seattle, Washington, Sept. 28-Oct. 1, 1976, pp 451-476.

This paper uses multiple regression techniques to investigate the relationship between LANDSAT radiance values and water quality measurements. For a period of over one year, the Central and Southern Florida Flood Control District sampled the water of Lake Okeechobee for chlorophyll, carotenoids, turbidity, and various nutrients at the time of LANDSAT overpasses. Using an overlay map of the sampling stations, LANDSAT radiance values were measured from computer compatible tapes using a GE Image 100 and averaging over a 22-acre area at each station. These radiance values in four bands were used to form a number of functions (powers, logarithms, exponentials, and ratios) which were then compared with the ground measurements using multiple linear regression techniques. Individual correlations were presented for the various water quality parameters and best fit equations were examined for chlorophyll and turbidity.

Rogers, R.H., and McKeon, J.B., 1977, Application to LANDSAT to mapping inland lake water quality and watershed land use, in Proceedings 11th international symposium on remote sensing of environment, April 1977, (Center for Remote Sensing Information and Analysis, Environmental Research Institute of Michigan, Ann Arbor), pp 1239-1240.

Bendix has tested a number of different approaches to mapping water quality from LANDSAT. The best approach is as follows: 1) Categorize LANDSAT CCTs on NDAS. Use available surface truth (water quality parameter measurements) only as a guide to assure that a wide range of lakes

are entered as training sets. 2) Plot spectral curves of each training-set lake (10-15 typically). 3) Compare curves, or transparencies thereof, and group according to shape and relative position (5-7 groups typically). 4) Re-assign colors so that each group of lakes has a different color. 5) Film complete study area. 6) Compare color of all lakes mapped in study area with surface truth and establish color key to relate each water quality parameter to each map color. Watershed land cover inventories which include color-coded maps and overlays, at various scales, tabular data, and digital cover files were produced from LANDSAT CCTs for a price of 0.1 to 1.0 cents per acre depending upon size of test area and map scales. Similar products produced from any other source would have cost two to ten times more. The land cover data is now being used by the State of Michigan and three state regional planning agencies to develop relationships between categorized land use and lake water quality.

Scherz, J.P., and van Domelen, J.F., 1977, Water quality indicators obtainable from aircraft and LANDSAT images and their use in classifying lakes, in Proceedings 10th international symposium on remote sensing of environment October 1975, (Center for Remote Sensing Information and analysis, Environmental Research Institute of Michigan, Ann Arbor), pp 447-460.

The first step in subtracting the noise from total signal is to determine the proper relationships between incoming energy, different water factors, and what the sensor sees. The next step is to mathematically manipulate these values such that everything is subtracted except the energy returned from the material in the water. In the laboratory this is performed by obtaining the proper signal from distilled water. While in the field the signal is obtained from a very clear water lake. In either case by properly subtracting the clear water signal from the dirty water signal the residual signal is caused solely by the material in the water. By applying such techniques to lab samples and LANDSAT tapes analyzed at Bendix Computers, it is possible to separate lakes into general groups, such as: clear water, silt, algal and tannin-water lakes.

Wezernak, C.T.; Tanis, F.J.; and Bajza, A., 1976, Trophic state analysis of inland lakes, Remote sensing of environment, 5(2), 147-165.

The formulation of a trophic state index using remote sensing data is discussed. A multivariate analysis technique is applied to the data to formulate a trophic state index which combines selected indicators of eutrophication into a single numerical expression. Results are presented for a group of inland lakes in Southern Michigan. The relationship between phosphorus loading to the lakes, and the derived numerical index is examined.

b. density slicing

Brown, D., and Skaggs, R., 1974, Remote sensing applications to hydrology in Minnesota, in A study of Minnesota forests and lakes using data from Earth Resources Technology Satellites: 24 Month progress report, (Minnesota University, Minneapolis, Space Science Center), pp 81-196.

The studies include: 1) the investigation of surface cover data to develop surface runoff coefficients for noninstrumented watersheds; 2) the detection of surface water and seasonal surface water changes with ERTS imagery; 3) the application of ERTS-1 MSS imagery to the detection of peaty wetlands; 4) the application of high altitude aerial photography and manually interpreted and density sliced ERTS-1 images to the development of an urban hydrologic model for the Twin Cities Metropolitan area; and to the investigation of multi-seasonal ERTS-1 imagery for classification of lake quality in Minnesota.

Lawrence, G.T., and Graham, C.W., 1976, Remote sensing applied to algal problems in lakes, in Third Canadian symposium on remote sensing, Edmonton, Alberta, September 1975, ed G.E. Thompson, (Canadian Aeronautics and Space Institute, Ottawa), pp 309-314.

In comparison to the restricted field of view obtained during in situ investigations, remote sensing provides a complete overview for the mapping of surface distribution of algae blooms and for the selection of sampling areas. The spectral reflectance of surface algae in the near-infrared portion of the spectrum provides the necessary signature for photographic analysis. A case study of Lake of the Woods (Ontario) is presented. High surface concentrations of algae on this lake provide spectral signatures that have been recorded by the multispectral scanner of the LANDSAT-1 satellite. Electronic density analysis of this imagery distinguished relative algae concentrations and distributions that are substantiated by low-altitude color infrared photography.

Scarpace, F.L., and Wade, R.E., 1974, Monitoring the trophic status of inland lakes: a quantitative application of ERTS imagery, in Proceedings American Society of Photogrammetry, fall convention, Sept. 10-13, 1974, pp 232-239.

The feasibility of using photographic representations of the ERTS imagery to classify lakes in the State of Wisconsin as to their trophic level was studied. Densitometric readings of bands 5 and 7 were taken for all the lakes in Wisconsin greater than 100 acres (approximately 1100 lakes). An algorithm has been developed from ground truth measurements to predict an indicator for trophic status.

c. band ratioing

Harris, G.P.; Bukata, R.P.; and Bruton, E.J., 1976, Satellite observations of water quality, Transportation engineering journal, ASCE, 102(TE3), Proceedings paper, 12300, pp 537-554.

LANDSAT-1 observations of water quality indicate that hydrography, suspended solids, and chlorophyll a can be measured with MSS bands 4, 5, and 6, respectively. As a summary of work performed at CCIW and McMaster University in the pattern recognition studies of the LANDSAT-1 digital data collection over the Laurentian Great Lakes, results are reviewed of the physical interpretation ascribed to data of the pattern observed in various combinations of the radiance bands while absent in others. Band-by-band limnological interpretations of the patterns observed in the digital print-outs of the LANDSAT-1 apparent radiance data are given.

Rogers, R.H., 1975, Application of LANDSAT to the surveillance and control of eutrophication in Saginaw Bay, (Bendix Corp., Ann Arbor, Michigan Aerospace Systems Div.), 13 pp.

LANDSAT digital data and ground truth measurements for Saginaw Bay (Lake Huron), Michigan, for 3 June 1974 can be correlated by stepwise linear regression technique and the resulting equations used to estimate invisible water quality parameters in nonsampled areas. Correlation of these parameters with each other indicates that the transport of Saginaw River water can now be traced by a number of water quality features, one or more of which are directly detected by LANDSAT. Five of the 12 water quality parameters are best correlated with LANDSAT band 6 measurements. One parameter (temperature) relates to band 5 alone and the remaining six may be predicted with varying degrees of accuracy from a combination of two bands (first band 6 and generally band 4 second).

Rogers, R.H.; Shah, N.J.; Smith, V.E.; and McKeon, J.B., 1976, Computer mapping of water quality in Saginaw Bay with LANDSAT digital data. Special report. Bendix Corp., Ann Arbor, Michigan Aerospace Systems Div., BSR-4213, 15 pp.

LANDSAT digital data and ground truth measurements for Saginaw Bay, Michigan for 31 July 1975 were correlated by stepwise linear regression and the resulting equations used to estimate invisible water quality parameters in nonsampled areas. Chloride, conductivity, total Kjeldahl nitrogen, total phosphorus, and chlorophyll a were best correlated with the ratio of LANDSAT Band 4 to Band 5. Temperature and Secchi depths correlate best with Band 5.

d. false-color image

Everett, L.G.; Leonhart, L.S.; and Lepley, L.K., 1973, An evaluation of ERTS-1 imagery in reservoir dynamics, in Proceedings 4th Annual Conference on Remote Sensing in Arid Lands, (University of Arizona, Tucson, College

of Earth Sciences, Office of Arid Land Studies), pp 259-274.

Implicit in the use of ERTS-1 imagery is the ability to locate stressed areas and to evaluate the seasonal and areal distribution of the aquatic problem. Evaluation of water quality parameters as they are interpreted through multispectral scanning by Bands 4 through 7 have indicated an applicability for locating: 1) seasonal and spatial plankton blooms, 2) areas of water upwelling and surface phenomena, and 3) sediment distribution from a controlled source (Glen Canyon Dam). The techniques of false color classification from computer analysis and multispectral additive color viewing are used to present elucidation of plankton dynamics and hydrodynamic variables in Lake Mead, Arizona.

McKeon, J.B.; Rogers, R.H.; and Smith, E., 1977, Production of a water quality map of Saginaw Bay by computer processing of LANDSAT-2 data, in Proceedings 11th international symposium on remote sensing of environment, April 1977, (Center for Remote Sensing Information and Analysis, Environmental Research Institute of Michigan, Ann Arbor), pp 1045-1054.

LANDSAT-2 computer compatible tapes for two consecutive scenes, acquired on 31 July 1975 (2190-15401), were processed on a Bendix MDAS (Multispectral Data Analysis System). Each water quality station was called up and located on the color TV monitor. A cursor was shaped around each of the 16 stations (those sampled the same day as the LANDSAT overpass) so as to include an average of 80 pixels per station area. The mean reflectance, in raw data counts, was extracted as the independent variable and applied to a linear regression program with nine water quality parameter surface measurements (temperature, Secchi depth, chloride, conductivity, total Kjeldahl nitrogen, total phosphorous, chlorophyll a, total solids and suspended solids). The correlation coefficients ranged from 0.73 for Secchi depth to 0.94 for temperature, nitrogen, and phosphorus.

Rogers, R.H.; Reed, L.E.; and Smith, E.V., 1975, Computer mapping of turbidity and circulation patterns in Saginaw Bay, Michigan from LANDSAT data, (United States NASA, ERTS Report, E75-10321), 16 pp.

LANDSAT was used as a basis for producing geometrically-corrected color-coded imagery of turbidity and circulation patterns in Saginaw Bay, Michigan (Lake Huron). This imagery shows nine discrete categories of turbidity, as indicated by nine Secchi depths between 0.3 and 3.3 m. The categorized imagery provided an economical basis for extrapolating water quality parameters from point samples to unsampled areas.

Rogers, R.H.; Smith, V.E.; Scherz, J.P.; Woelkerling, W.J.; Adams, M.S.; and Gannon, J.E., 1977, Application of LANDSAT to the surveillance of lake eutrophication in the Great Lakes basin. Final report March 1975--September 1977, (Bendix Corp., Ann Arbor, Michigan, Aerospace Systems Div.), 193 pp.

A step-by-step procedure for establishing and monitoring the trophic status of inland lakes with the use of LANDSAT data, surface sampling, laboratory analysis and aerial observations were demonstrated. The biomass was related to chlorophyll a concentrations, water clarity,

and trophic state. A procedure was developed for using surface sampling, LANDSAT data, and linear regression equations to produce a color-coded image of large lakes showing the distribution and concentrations of water quality parameters, causing eutrophication as well as parameters which indicate its effects. Cover categories readily derived from LANDSAT were those for which loading rates were available and were known to have major effects on the quality and quantity of runoff and lake eutrophication.

Taylor, M.M., and Langham, E.J., 1976, The use of maximum information color enhancements in water quality studies, in Third Canadian symposium on remote sensing, Edmonton, Alberta, September 1975, ed G.E. Thompson, (Canadian Aeronautics and Space Institute, Ottawa), pp 359-366.

There is usually a strong correlation between the four spectral bands of LANDSAT images. This means that any corresponding color composite using three of the bands as primary colors is not optimum for presenting the information contained in the images. Moreover, since only three bands may be used in the preparation of color composites an unknown amount of information is lost. The technique described here is a development of previous work and it enables noise to be minimized while the information from all four bands is concentrated sequentially into synthesized images. This procedure has wide application but it is particularly interesting for the study of lakes where there are gradients in the amplitude of one or several superimposed spectral signatures. Its use in the study of Lac St-Jean is described by way of illustration.

e. radiometer use

Moore, D., and Haertel, L., 1975, Remote sensing of water quality in prairie lakes. Completion report, (South Dakota State University, Brookings, Water Resources Institute), 72 pp.

Twelve different remote-sensing estimates were taken from LANDSAT-1 imagery, low-altitude aerial photographs, ground-based radiometer, and ground-level photographs. These were correlated with prairie lake water transparency and algae abundance. For predictive purposes multiple regression analyses were performed using the three water quality parameters as dependent variables and the remote sensing parameters as independent variables. The correlations between the three water quality parameters and physical factors and nutrient levels were also investigated using multiple regression analyses.

4. Water resources
   a. digital analysis, general

Henninger, D.L.; Stauffer, M.L.; Petersen, G.W.; and McMurtry, G.J., 1975, Flood-plain delineation using LANDSAT-1 digital data. Technical report, Pennsylvania State University, University Park Office for Remote Sensing of Earth

Resources, ORSER-SSEL-TR-20-75, 64 pp.

A continuous floodplain boundary was drawn on the basis of the computer classification of selected LANDSAT-1 digital MSS data. Within the agricultural and developed portion of the study area, this floodplain correlated favorably with the USACE 100-year return period floodplain, which is based on the conventional engineering parameters of streamflow and basin configuration. Within the forested portion of the study area, correlation of the floodplain limits was not as satisfactory. Since the floodplain limit established by remote sensing in the forested area consistently overestimated the USACE 100-year return period floodplain, there is an indication that it could represent the limit of a flood with a return period of more than 100 years.

b. density slicing

Hollyday, E.F., 1976, Improving estimates of streamflow characteristics by using LANDSAT-1 imagery, Journal of research of the United States Geological Survey, 4(5), pp 517-532.

Imagery from LANDSAT-1 was used to discriminate physical features of drainage basins in an effort to improve equations used to estimate streamflow characteristics at gauged and ungauged sites. Records of 20 gauged basins in the Delmarva Peninsula of Maryland, Delaware, and Virginia were analyzed for 40 statistical streamflow characteristics. Equations relating these characteristics to basin characteristics were obtained by multiple linear regression. A control group of equations contains basin characteristics derived from maps. An experimental group of equations contains basin characteristics derived from maps and imagery. Characteristics from imagery were forest, riparian (streambank) vegetation, water, and combined agricultural and urban land use. These basin characteristics were isolated photographically by techniques of film-density discrimination. The area of each characteristic in each basin was measured photometrically. Comparison of equations in the control group with corresponding equations in the experimental group reveals that for 12 out of 40 equations the standard error of estimate was reduced by more than 10%.

c. edge enhancement

McCoy, R.M., 1973, Enhancement of imagery for water resources studies, in Proceedings 4th annual conference in remote sensing in arid lands, (University of Arizona, Tucson, College of Earth Sciences, Office of Arid Land Studies), pp 220-226.

Describes several methods of enhancement, and goes on to describe the use of edge enhancement to define river networks and to facilitate the measurement of areas.

d. false-color image

James, W.P.; Woods, C.E.; and Blanz, R.E., 1976, Environmental evaluation of water resources development, Texas A & M University, College Station, Water Resources Inst. Technical Report, TR-76, 231 pp.

The environmental effects of channelization and surface impoundments are discussed for 12 physiographic regions of Texas as delineated on black and white satellite (LANDSAT-1) mosaic of band 7. With the aid of LANDSAT-1 imagery, representative or typical transects were chosen within each region. Profiles of each site were constructed from topographic maps and environmental data were accumulated for each site and related to low altitude aerial photography and enlarged LANDSAT-1 false color composites. Each diagrammatic transect, with accompanying data and photographs, provides significant information for input of environmental amenities on a local and regional scale into preliminary water resources development studies.

Owen, J.R., and Shown, L.M., 1976, Hydrology of arid and semiarid areas, United States Geological Survey professional paper, 929, pp 217-219.

A description of features shown on an ERTS color composite image showing the canyon lands of the Colorado Plateau and the confluence of the Green and Colorado Rivers in Utah.

e. mapping, manual interpretation

Higer, A.L.; Rogers. R.H.; Coker, A.E.; and Corder, E.H., 1975, Water—management models in Florida from ERTS-1 data. Final report, (U.S. Geological Survey, Miami, Fla., Water Resources Div.), 44 pp.

Twenty data collection platforms were established in southern Florida. Water level and rainfall measurements were collected and disseminated to users in less than 2 hours, a significant improvement over conventional techniques requiring 2 months. ERTS imagery was found to significantly enhance the utility of ground measurements. Water stage was correlated with water surface areas from imagery in order to obtain water stage-volume relations. Imagery provided an economical basis for extrapolating water parameters from the point samples to unsampled data.

Hollyday, E.F., and Pluhowski, E.J., 1976, Improving estimates of streamflow characteristics, United States Geological Survey professional paper, 929, pp 136-138.

Land-use data obtained from an ERTS image was used to improve estimates of mean monthly streamflow for July in the Delmarva Peninsula. As a result of using remotely sensed data, estimates of some characteristics of streamflow at ungauged sites have been significantly improved.