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APPLICATION OF LANDSAT TO THE SURVEILLANCE AND CONTROL OF LAKE EUTROPHICATION IN THE GREAT LAKES BASIN

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16. Abstract

This paper reports on the results achieved during the third three month period to establish cost benefits of LANDSAT for the surveillance and control of Lake eutrophication. This goal is being accomplished by producing LANDSAT products for an EPA modeling study of Saginaw Bay and inland lake surveys by the Michigan and Wisconsin DNR's. These user agencies are, in-turn, providing detailed ground truth on water quality and are participating in studies and evaluations to determine the cost benefits of LANDSAT.

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PREFACE

Program Objectives

The overall objective of this investigation is to establish the cost benefits of using LANDSAT on an operational basis in the surveillance and control of lake eutrophication. This objective is accomplished by supporting, with LANDSAT data products, bona fide users who will evaluate the data's usefulness to on-going programs concerned with the classification and control of lake eutrophication. The products supplied to the users will be made as applicable as possible to their data needs. The following therefore, are specific objectives to be addressed:

1. To identify the data requirements of the users and to relate these to LANDSAT data with respect to land-water categories, detail, scale, and frequency.

2. To identify water quality parameters which relate directly to eutrophication and to determine quantitative levels of these parameters by which lakes may be categorized as to trophic state.

3. To identify land-use patterns which relate to trophic state.

4. To develop and apply LANDSAT data imaging and interpretation techniques to categorize water and land-use features identified in order to produce information products of value to users.

Scope of Work

This investigation is supplying LANDSAT-derived information products to three federal and state agencies which are involved in the planning and management of lakes and watershed land use in the Great Lakes basin. Support is provided to the Environmental Protection Agency water quality survey and modeling study of lake eutrophication in Saginaw Bay; the State of Michigan Department of Natural Resources Survey of inland lakes and watersheds for the purpose of assessing the degree of eutrophocation in these lakes and the potential for further enrichment and pollution due to land-use practices; and the State of Wisconsin Department of Natural Resources lake survey to determine eutrophication status, causes, effects, and control treatments.

For each of these three programs, this investigation is analyzing and interpreting LANDSAT data to provide the three user agencies with land-use and lake water quality information about their specific test areas. The usefulness of LANDSAT data to each type of study and the cost benefits of its use over alternative data collection systems is being evaluated.

Conclusions

Chemical and biological water quality data collected June 3, 1974 at 27 stations within Saginaw Bay, Michigan, in concert with a LANDSAT overflight, have been processed to enable prediction of water quality in non-sampled areas. Measurements included; temperature, secchi depth, conductivity, chloride, chlorophyll $\bar{a}$, sodium, potassium, magnesium, calcium, total dissolved phosphorous, total kjeldahl nitrogen and total phosphorous. When these were treated as dependent variables and LANDSAT measurements as independent variables, and processed with a stepwise linear regression analysis, all but one parameter had correlation coefficients greater than that for the 95% level of significance.

Two recently completed investigations, for the Ohio-Kentucky-Indiana Regional Council of Governments (greater Cincinnati area) and the Triangle J Council of Governments (Raleigh, Durham and Chapel Hill, North Carolina area), demonstrate that successful land-cover map products can be rapidly produced from LANDSAT for less than a cent an acre. The distribution of urban (high, medium and rural-low density development), agricultural-grassland (cropland, pasture land, and tended grass cover), forest (upland and lowland hardwoods, pine, and mixed), and a variety of water categories, were mapped. Color coded map overlays, one per land-use category, color coded composite maps, percent-category-per-watershed-area tables, and rescanned and resampled computer tapes provided accurate inventory bases. This land-cover information is being combined with data on soils, rainfall, topography, cropping management and conservation practices to develop estimates of sediment and nutrient flows within regional watersheds.

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1. REVIEW OF PROGRAM AND RESULTS

This section reports on the work accomplished and results achieved during the third three month period of a program to establish the cost benefits of LANDSAT for the surveillance and control of lake eutrophication. To accomplish this goal, LANDSAT data products are being generated to support the Environmental Protection Agency (EPA) modeling study of lake eutrophication in Saginaw Bay; the State of Michigan's survey of inland lakes and watersheds for the purpose of assessing the effects of watershed land use on lake water quality; and the State of Wisconsin's lake survey to determine eutrophication status, causes, effects, and control treatments.

These user agencies are providing, at no cost to NASA, user needs which include desired data formats, data timeline requirements (i.e., how fast data are needed and how long it maintains its value before update is needed), and data accuracy requirements (i.e., geometric and classification accuracy). These agencies are also providing detailed ground truth on water quality and watershed land use in conjunction with LANDSAT overflights and are participating in studies and evaluations to determine the usefulness and cost benefits of the LANDSAT data products.

The remainder of this section is subdivided to report on the work accomplishments and results achieved to support the on-going water quality programs of the three user agencies.

1.1 SUPPORT FOR THE EPA STUDY OF WATER QUALITY IN SAGINAW BAY

Coordination meetings were held with the EPA in order to review LANDSAT data requirements and to develop plans to provide the needed aircraft and LANDSAT support.

The EPA is sponsoring a 36-month study of water quality in Saginaw Bay, which will terminate in June 1976. Important goals of this study are to describe, on a seasonal basis, the circulation and water masses in Saginaw Bay; to monitor inputs of nutrients from its watershed; and to develop and evaluate models for predicting water quality in the bays as a function of various control strategies.

To achieve these goals, the EPA is using LANDSAT data products produced by this investigation and surface/subsurface measurements obtained by the Cranbrook Institute of Science, under the direction of Dr. V. Elliott Smith (LANDSAT Co-Investigator). The surface measurement program has been underway since April of 1974. From each of 59 stations distributed over Saginaw Bay, some 30 water quality parameters are derived on an 18-day cycle that coincides with the LANDSAT overflights. On 1 April 1975, this measurement program was shifted from the LANDSAT-1 to the LANDSAT-2 schedule.

The first clear LANDSAT scene of the bay, coincident with surface measurements at the bay stations, was a 3 June 1974 scene. Techniques used in the computer processing of this scene and the results achieved were reported in the first Type II report. Of particular importance was the demonstration of a technique for editing LANDSAT measurements using the latitudes and longitudes of bay stations having known (measured) water quality parameters. At the time of the initial processing effort, the only parameter fully reduced for all bay stations which is a good indicator of turbidity was Secchi depth. Consequently this initial processing effort resulted in a geometrically-corrected color-coded image of Saginaw Bay showing nine discrete colors (categories) of turbidity, as indicated by nine Secchi depths between 0.3 and 3.3 meters.

To determine further relationships between LANDSAT measurements and water quality parameters the 3 June 1974 measurements from 27 bay stations of known chemical and biological parameters were edited and processed by a stepwise linear regression program. The water quality parameters included; temperature, secchi depth, conductivity, chloride, chlorophyll $\bar{a}$, sodium, potassium, magnesium, calcium, total dissolved phosphorous, total kjeldahl nitrogen and total phosphorous. When these parameters were treated as dependent variables and LANDSAT measurements as independent variables all but one water quality parameter had correlation coefficients greater than that for the 95% level of significance. The regression correlation coefficients varied from 0.99 for total phosphorus to 0.72 for chlorophyll $\bar{a}$ corrected. Five of the water quality parameters were best correlated with LANDSAT Band 6 alone. One parameter, temperature, related to Band 5 alone and only two bands were justified for mapping the remaining six parameters.

The regression analysis program applied to the 3 June 1974 LANDSAT data will be applied to 31 July 1975 data in order to include additional water quality parameters, determine whether similar correlations exist for different time periods, examine effects of atmospheric parameters, and to evaluate procedures to compensate for atmosphere if necessary. Color-coded (categorized) imagery will also be produced using the regression equations to provide a synoptic image of the various water quality parameters, their distribution, and circulation within Saginaw Bay.

1.2 SUPPORT FOR MICHIGAN'S SURVEY OF INLAND LAKES AND WATERSHEDS

To review the State of Michigan program, the Michigan Department of Natural Resources (DNR) is committed, under the State Federal Water Pollution Control Act (Act 92-5000), to a state-wide survey of public lakes and their watersheds for the purpose of assessing the degree of eutrophication in these lakes and the potential for further enrichment and pollution resulting from land-use development in the watershed. A requirement of the DNR program, as well as programs of other governmental agencies concerned with the maintenance and control of water quality, is to develop a knowledge of the interrelationships between the water quality parameters (turbidities, chlorophyll concentrations, etc.) and watershed land-use parameters (categories and coverage).

To obtain the needed information, the Michigan DNR has selected 19 test lakes whose watersheds contain various levels of urbanization. LANDSAT data acquired on July 30, 31, and August 1, 1975 will be used to inventory land cover within these watersheds. The land cover mapped by LANDSAT will be correlated with lake water quality measurements obtained by the DNR and the University of Michigan Biological Station. LANDSAT capability to map water quality parameters directly as done for Saginaw Bay will also be investigated.

Two recently completed investigations, for the Ohio-Kentucky-Indiana Regional Council of Governments (greater Cincinnati area) (Appendix B) and the Triangle J Council of Governments (Raleigh, Durham and Chapel Hill, North Carolina area) (Appendix C), demonstrates LANDSATs capability to inventory watershed land-use and the techniques that will be used for the Michigan inventory. The distribution of urban (high, medium and rural-low density development), agricultural-grassland (cropland, pasture land, and tended grass cover), forest (upland and lowland hardwoods, pine, and mixed), and a variety of water categories, were successfully mapped from LANDSAT data. Of particular importance is the technique for digitizing boundaries of watersheds from maps and extracting computer tabulations from these zones from the processed LANDSAT tapes. Color coded map overlays, one per land-use category, color coded composite maps, percent-category-per-watershed-area tables, and rescanned and resampled computer tapes provide the planner with accurate inventory bases. The land cover inventory data is combined with data on soils, rainfall, topography, cropping management and conservation practices to develop estimates of sediment and nutrient flows in the drainage areas.

1.3 SUPPORT FOR WISCONSIN'S SURVEY OF INLAND LAKES

As noted earlier, the Wisconsin DNR is also attempting to develop a method of lake classification by trophic level, as required by Section 314 of Federal Water Pollution Control Act Amendments (1972). Accordingly, the Wisconsin DNR is evaluating the utility of LANDSAT data products directed towards this goal.

The second Type II report described the techniques used by this investigation to categorize several hundred lakes in the Madison and Spooner, Wisconsin area for tannin and non-tannin waters and for the degree of algae, silt, weeds, and bottom effects present. The results of this categorization effect is being evaluated. When the lakes are categorized as having living algae or weeds, their concentration is related to the enrichment of eutrophication of the lake.

2. SIGNIFICANT RESULTS

(a) Computer techniques developed for mapping water quality parameters from LANDSAT data were demonstrated, using ground truth collected in an ongoing survey of water quality in Saginaw Bay (Lake Huron), Michigan sponsored by the US Environmental Protection Agency. Chemical and biological parameters were collected at 27 bay stations in concert with LANDSAT overflights. Application on stepwise linear regression to 12 of these parameters and corresponding LANDSAT measurements resulted in relationships that can be applied to map any one of the 12 water quality parameters over the entire bay. The regression correlation coefficients varied from 0.99 for total phosphorus to 0.72 for chlorophyll $\bar{a}$ corrected. Five of the water quality parameters are best correlated with LANDSAT Band 6 alone. One parameter, temperature, relates to Band 5 alone and only two bands are justified for mapping the remaining six parameters.

(b) LANDSAT CCTs were used as a basis for inventorying land use within each of the Ohio-Kentucky-Indiana Regional Commissions, 225 drainage areas, and nine counties. Computer tabulations were produced to obtain the area covered by each of 16 land-use categories within 225 drainage areas. The 16 categories were merged into ten categories and mapped at a scale of 1 in. = 5,000 ft, with detail to 0.44 hectares for the 2,700 sq. mi. region. These products were produced in less than 90 days, at a cost of one cent an acre. It is not uncommon to find single counties spending this much to map similar categories within a much smaller area.

(c) LANDSAT CCTs were used as a basis for inventorying land cover within the Triangle J Council of Governments 1,750 square mile 208 study area. Ten land cover categories were interpreted for the study area at a detail of 0.44 hectares (1.1 acres) and included 3 urban density categories, 4 forest types, agricultural-managed lands, bare soil-construction sites, and water. The resulting products included color-coded overlays for each of the 10 categories for a 1:96,000 scale base map, a color composite map of the same categories and scale, and a computer tape containing 54 quadrangles (7.5 minute) where each 50 meter grid cell was coded as to the ten land cover types. This taped data is being aggregated into 4 hectar (about 10 acres) grid cells and merged with soils and slope data to compute sediment and nutrient flows in the drainage areas. The complete inventory was accomplished within a period of 60 days at a cost of about one-half a cent per acre, a significant improvement in dollars and time over previously reported efforts.

3. PROBLEMS

No problems are impeding this investigation.

4. RECOMMENDATIONS

None

5. PUBLICATIONS

None

6. FUNDS EXPENDED

Total expenditures through 9 November of 1975 are $48,812.

7. DATA USE

A tabulation showing the total value of the data allowed and received through 29 October 1975 follows:

Value of Data Allowed	Value of Data Ordered	Value of Data Received
$5,550	$2,867	$2,867

8. AIRCRAFT DATA

By prior arrangement with NASA Johnson Space Center in Houston, supportive M^2S and photographic coverage of the test areas in Michigan was flown on August 18 (Flight No. 2, Mission 317). On this flight two of the MSS channels, 5 and 6, were out, and there was substantial cloud cover over almost all of the test lakes and/or their watersheds. The HDDT for this flight has been received. The mission has been rescheduled for mid-Summer of 1976.

APPENDIX A

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APPLICATION OF LANDSAT TO THE SURVEILLANCE AND CONTROL OF EUTROPHICATION IN SAGINAW BAY

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ABSTRACT

Computer techniques developed for mapping water quality parameters from LANDSAT data are demonstrated, using ground truth collected in an ongoing survey of water quality in Saginaw Bay (Lake Huron), Michigan sponsored by the US Environmental Protection Agency. Chemical and biological parameters were collected at 27 bay stations in concert with LANDSAT overflights. Application of stepwise linear regression to 12 of these parameters and corresponding LANDSAT measurements resulted in relationships that can be applied to map any one of the 12 water quality parameters over the entire bay. The regression correlation coefficients varied from 0.99 for total phosphorus to 0.72 for chlorophyll $\bar{a}$ corrected. Five of the water quality parameters are best correlated with LANDSAT Band 6 alone. One parameter, temperature, relates to Band 5 alone and only two bands are justified for mapping the remaining six parameters.

1. INTRODUCTION

In response to environmental requirements for large area surveillance of water quality and watershed land use, NASA's LANDSAT-2 investigation is establishing the cost benefits of LANDSAT to the surveillance and control of lake eutrophication in the Great Lakes Basin. To accomplish this objective, LANDSAT data products are being generated to support: the US Environmental Protection Agency (EPA) modeling study of eutrophication in Saginaw Bay, the State of Michigan's survey of inland lakes and watersheds for the purpose of assessing the effects of watershed land use on lake water quality; and the State of Wisconsin's lake survey to determine eutrophication status, causes, effects, and control treatments. One goal of this work is to determine which water quality parameters best correlate with LANDSAT measurements. This paper reports on preliminary results directed towards this goal using water quality parameters and LANDSAT data acquired 3 June 1974 on the Saginaw Ba· test area.

Several institutions and federal agencies in the United States and Canada are conducting a comprehensive survey of water quality and circulation in Lakes Huron and Superior (the Upper Lakes Reference Study, a part of the United States/Canadian Great Lakes Water Quality Agreement of 1972). In Saginaw Bay (Lake Huron), EPA is sponsoring a 36-month modeling study of water quality. EPA's program will develop a deterministic model that will describe water quality changes within the bay and their relationship to enrichment and pollution caused by man. The resulting model will be used to evaluate various strategies to control nutrient flow into the bay. Important goals in this project are to describe, on a seasonal basis, the circulation and water quality in Saginaw Bay, to monitor inputs of nutrients from its watershed, and, ultimately, to develop and evaluate models for predicting water quality in the bay as a function of various control strategies.

A number of investigators have recently reported on the feasibility of determining various water quality parameters from LANDSAT data. Klemas (Ref. 1)* has used Secchi depth and suspended sediment measurements as correlated with Band 5 image radiance to map turbidity and circulation patterns in Delaware Bay. Yarger (Ref. 2) has processed multidate digital data for reservoirs in Kansas to study the effects of sun angle change, and the 5/4, 6/4, and 7/4 band ratios to predict suspended solids (ppm) at unsampled areas from ground truth samples. Johnson (Ref. 3) has applied the equations for predicting suspended sediment derived from stepwise regression analysis of ground truth data from Delaware Bay to image data for Chesapeake Bay, and has found reasonable agreement with ground truth measurements for Chesapeake Bay.

This LANDSAT-2 investigation has reported (Ref. 4) on the applications of a supervised computer processing technique to produce geometrically corrected color-coded imagery of Saginaw Bay where the imagery shows nine discrete categories of turbidity, as indicated by nine Secchi depths between 0.3 and 3.3 meters. This work was limited to the consideration of the Secchi depth parameter as an indicator of turbidity and the application of the supervised processing technique to correlate the Secchi depth parameter to the LANDSAT measurements. This paper considers Secchi depth and 11 additional water quality parameters and their relationships to LANDSAT measurements as established by a "stepwise linear regression" program (Ref. 5).

Mapping nine Secchi depth ranges or any other water quality parameter by a supervised technique requires: subdividing the parameter of interest into discrete categories (i.e., nine Secchi depth ranges), locating and editing LANDSAT measurements (training measurements) corresponding to each category and applying the training measurements to categorize other LANDSAT picture elements ("pixels"). This technique is well established and is by far the most efficient procedure for mapping land-cover categories, i.e., urban, grassland, bare soil, water, etc., where the spectral characteristics of the categories are very different (uncorrelated). The application of this same processing technique to mapping the amount or concentration of a continuous water quality parameter, i.e., temperature, Secchi depth, chlorophyll concentration, etc., may not be justified as better estimates of the parameter may be obtained with less effort by a simpler technique. If a continuous equation can be established between the parameter and LANDSAT, e.g., the equation of a straight line with one independent and one dependent variable, then its solution would provide many more estimates of the desired parameter than would be practical by the supervised technique, which requires a training set for each discrete value of the parameter. This paper investigates this possibility by applying a stepwise linear regression program to 12 water quality parameters (Table 1) and LANDSAT measurements (Table 1) observed on 3 June 1974 at 27 stations in Saginaw Bay.

2. TEST AREA

Saginaw Bay is a shallow extension of Lake Huron and is bounded by five counties of southeastern Michigan (Figures 1 and 2). The bay has an area of some 2,960 km^2 and a maximum length and width of 82 km and 42 km, respectively. The mean depths are 4.6 m for the inner bay and 14.6 m for the outer bay. The Saginaw River enters the bay at its extreme southwestern end

*References, tables, and figures are located at the end of this paper.

and contributes approximately 90% of the pollutants found in the bay (Ref. 6). This river and its tributaries drain a watershed of more than 16,060 km^2, which contains four major cities and much agricultural land. Consequently, inputs of salts, nutrients, and pollutants to the bay have been increasing for many years. Levels of turbidity and algal production are consistently high, especially within the inner bay. Major declines in commercial fish yields, wildfowl populations, and esthetic values have resulted from this eutrophication. The natural movement of pollutants from the bay into southern Lake Huron may reduce water quality throughout the lower Great Lakes as well. While circulation within the bay is highly wind-dependent, the pattern is generally counterclockwise. Clear Lake Huron water enters mainly along the western shore; turbid bay water exists along the eastern shore. Significant but unknown quantities of sediment are resuspended regularly by wave action. The lower two-thirds of Saginaw Bay usually freezes over during January and February. These and other characteristics of Saginaw Bay have been documented by Freedman (Ref. 6).

3. GROUND TRUTH PROGRAM

The EPA measurement program in Saginaw Bay is creating a data bank of water quality information that will be used to develop and test models of circulation, nutrient loadings, and algal productivity. Since April 1974, surface and subsurface measurements have been obtained at the 59 bay stations shown in Figure 2, at 18-day intervals coinciding with LANDSAT overflights.

The first clear LANDSAT scene of the bay, coincident with surface measurements at the bay stations, was the 3 June 1974 scene in Figure 1. On both the day of the survey and the preceding day, water conditions such as circulation within the bay were stable, i.e., not wind-driven. The corresponding cruise tracks of the survey vessels obtaining measurements at the bay stations are shown in Figure 2. Typically, as in this 3 June mission, the western half of the bay (containing 31 stations) is sampled within a period of 3 hours before and 8 hours after a LANDSAT overflight. The remaining 28 stations are sampled on the following 2 days. LANDSAT measurements from 27 of the 31 bay stations monitored on 3 June were used in this investigation.

On-site measurements at each bay station include: temperature, pH, dissolved oxygen, conductivity, alkalinity, and water clarity. Clarity is indicated by Secchi depth and percent transmittance measurements. Variables measured in the laboratory include: soluble nutrients (nitrate-nitrite, orthophosphate, sulfate, silicate, and ammonia), organic materials (nitrogen, phosphorus, carbon, and chlorophylls), chloride and metals (sodium, potassium, calcium, magnesium, and six trace metals), and total suspended solids. Enumerations of phytoplankton and zooplankton are also made. Coordinated studies of current patterns, nutrient inputs, and bottom fauna are also underway by EPA.

4. COMPUTER PROCESSING OF LANDSAT DATA

The LANDSAT Computer-Compatible Tapes (CCTs) for this investigation were processed on the Bendix Multispectral Data Analysis System, M-DAS (Ref. 4). Three major processing steps were involved: (1) transforming the locations of the bay stations from navigation charts to LANDSAT CCT coordinates, (2) extracting the LANDSAT digital measurements from the CCTs for each of 27 bay station areas, and (3) applying stepwise regression to the water quality parameters and LANDSAT measurements derived from each bay station area.

Earth-to-LANDSAT Coordinate Transformation

Three basic steps were involved in the automatic referencing of ground coordinates to LANDSAT coordinates. The first step consisted of automatic retrieval of the latitude and longitude of carefully selected ground control points (GCPs) from a map through a digitizing process. The criteria for selecting these GCPs is that they can be easily and accurately identified on LANDSAT imagery. The second step consisted of converting the latitude and longitude of these GCPs to LANDSAT coordinates by using a theoretical transformation derived from known and assumed spacecraft parameters including: heading, scan rate, altitude, and a knowledge of earth rotation parameters. The LANDSAT coordinates and transformation matrices thus obtained are approximate, based on the use of the nominal spacecraft parameters. The approximately derived

LANDSAT coordinates and transformation are used, however, to identify the actual LANDSAT coordinates associated with the GCPs. To accomplish this, the coordinates of a GCP are input to the Bendix M-DAS. The approximate transformation computes the LANDSAT coordinates and displays the area on the TV monitor. Positional errors of the GCPs displayed to the operator are designated by a cursor to the computer, which uses the error measurement to derive an improved set of coefficients for the transformation matrix. This procedure is repeated on additional GCPs until the desired geometric accuracy is achieved. This investigation used 20 GCPs within the LANDSAT scene. The resulting bay station coordinates were transformed to LANDSAT coordinates with an accuracy of better than one picture element (pixel). A LANDSAT pixel corresponds to an area of 57 m x 79 m (0.44 hectares).

Extraction of Station Area Digital Characteristics

The M-DAS TV monitor was used to display the single pixel best corresponding to each bay station location. A cursor was then positioned, expanded, and shaped by the operator about each station site to designate a station area of 40 to 50 pixels in size. For some stations near coastal features, piers, or jetties, considerably fewer pixels were designated (Table 1). Once the station areas were designated, the M-DAS computer extracted the measurements from all pixels defined by the cursor and calculated the mean digital count in each band (Table 1). For the table shown, the digital counts from the standard LANDSAT CCT have been multiplied by two in Bands 4, 5, and 6 and by four in Band 7. The mean values of the digital counts in each LANDSAT band for each bay station were then stored in a disk file for use in the regression analysis.

Stepwise Regression Analysis

The LANDSAT measurements stored on the disk file were used in a stepwise linear regression program (Ref. 5) to investigate relationships between the LANDSAT measurements and each of 12 water quality parameters. The stepwise regression procedure first determined which single independent variable (one of the four LANDSAT bands) provided the best statistical correlation with the dependent variable (one of the water quality parameters). In successive steps, a second independent variable was added, if necessary, to improve the multiple correlation.

5. STATISTICAL RESULTS

The statistical results of the stepwise regression analyses are summarized in both tabular and graphical form at the end of the paper.

Part of the results of the regression analyses are presented in Table 2, which is best explained by reviewing the first row. If temperature in ^{o}C is considered as the dependent variable, then the best single independent variable is LANDSAT Band 5. The results for only one step of the regression are reported in this case, indicating that the correlation coefficient is not significantly improved by the addition of other bands. The regression correlation coefficient is a measure of the fit of the regression equation to the data with a maximum value of unity. The standard error of estimate has the same units as the dependent variable, in this example ^{o}C, and is the statistical standard deviation. Approximately 68% of the measurements are expected to be within one standard deviation of the mean. The estimated percent inaccuracy of the regression equation is 3.8% (standard error of estimate of 0.6759^{o}C divided by mean temperature of 17.73^{o}C).

The constants and coefficients for each of the 12 regression equations are shown in Table 3. For example, temperature may be predicted as follows:

$$\text{Temperature } (^{o}\text{C}) = 13.186 + 0.157 \text{ (Band 5 digital count)}$$

It should be pointed out that LANDSAT is not measuring temperature directly as temperature does not change the color or volume reflectance of the water, which LANDSAT measures directly. In June, however, Saginaw River water is effectively labeled by temperature as well as by turbidity and other chemical and biological factors.

Figure 3 presents graphs for six water quality parameters that have been determined to be best predicted by only one independent variable or LANDSAT band. Each plot shows the N sample points, the regression line and equation, and the regression correlation coefficient.

Figure 4 includes six examples of the 12 possible graphs which permit a visual evaluation of the overall fit of the regression equations. The regression equations and the appropriate samples and band(s) counts shown in Table 1 were used to arrive at predicted values of each water quality parameter. These predicted values were in turn plotted versus the measured values. If the regression equation resulted in a perfect correlation, then all points would fall on the 1:1 line.

6. DISCUSSION

Perhaps the most significant finding of this investigation is that Band 6, rather than either Band 4 or 5, is the single most important band for the prediction of almost all of the water quality parameters. Both Yarger (Ref. 2) and Johnson (Ref. 3) also found this to be true in Kansas reservoirs and Chesapeake Bay, respectively. It is suggested that atmospheric haze degrades the correlations in the two visible bands, 4 and 5.

Five of the six graphs shown in Figure 3 show a fairly even scatter of points both above and below the regression line. This suggests that, for these variables, a linear regression is sufficient to predict the water quality parameter plotted. The plot of temperature versus Band 5 counts shows a systematic departure of points from the straight line. If the straight line were used to estimate temperature from Band 5 counts, a large error would be incurred for temperatures below 17°C. Thus, it appears that a curve rather than a straight line should be used for this parameter.

Figure 4 permits a somewhat improved comparison between variables. It should be noted that both temperature and Secchi depth depart from the 1:1 line in a noticeably curvilinear pattern as explained above. Furthermore, the plot for chlorophyll $\bar{a}$ (corrected) has been included as an example of the poorest correlation fit of all 12 parameters, as is also indicated in Table 2.

Although the water quality parameters investigated here have been treated individually so far, there are apparent correlations between the parameters themselves. Table 4 presents the correlation coefficients for all parameters at 59 stations in Saginaw Bay during the second quarter of 1974. Although these relationships vary seasonally, some pairs of parameters consistently are well correlated. For example, distributions of the four major metals with chloride are highly correlated throughout the year. Thus, with a table such as this one, it may be possible to isolate the subset of water quality parameters whose distribution may be mapped or modeled as a unit.

The significance to water quality of each parameter measured in Saginaw Bay varies with the location and season. In general terms, however, the following applies to the June 1974 data. Temperature (also chemical and biological) gradients in the bay during the spring reflect the mixing of eutrophic Saginaw River water with oligotophic (and cooler) Lake Huron water. Thus, temperature may be used coincidentally to discriminate between waters of markedly different quality. Secchi depth estimates are used to approximate water transparency as affected by suspended particles and solutes. Chlorophyll $\bar{a}$ is also an approximate indicator of living algal biomass. Conductivity, which varies directly with the concentration of dissolved ions, is generally high in eutrophic or polluted waters. Similarly, chloride is used here as a conservative tracer of enriched Saginaw River water. The major metals (sodium, potassium, calcium, magnesium) are also important as principal ions derived partly from urban and agricultural pollution. Finally, the organic forms of phosphorus and nitrogen (TP, TDP, and KN) are major nutrients, derived largely from pollution, that stimulate algal productivity in Saginaw Bay.

As this investigation proceeds, it will seek to: (1) determine if data on suspended solids, which were lacking in 1974 but have been collected since April 1975, provide a better basis than Secchi depth for categorizing water masses using LANDSAT data, (2) determine if the use of a nonlinear regression analysis improves the correlations, (3) determine if the correlations can be improved by the use of one or more of the six nonredundant band ratios (such as 6/4, or 7/6, etc.) as the independent variables in the stepwise regression analysis, rather than single bands, so as to correct for local gradients in atmospheric haze, (4) analyze data from the remaining stations taken during the 2 days following the overpass to see how well they correlate, (5) determine the feasibility of using the regression equations as a means to produce color-categorized maps of the bay where each map would show a different water quality parameter and the color would denote its concentration or level, and (6) to determine if the regression equations can be applied to analyze LANDSAT data acquired at a different date to predict water quality parameters that agree with those obtained by boat on the same day.

7. CONCLUSIONS

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. The 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 studied are best correlated with LANDSAT Band 6 measurements alone. 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).

Water quality parameters mapped from the linear regression equations should indicate which water quality parameter(s) is most reliable as a tracer to identify Saginaw River water as it circulates throughout the bay and is diluted by Lake Huron water. The resulting regression equations can be used to predict the levels of water quality parameters throughout the bay, given the appropriate LANDSAT measurements. These parameters need not be directly detectable by LANDSAT, provided their distribution is correlated with some water characteristic that is detectable. The predicted values for each water quality parameter could be displayed on a TV monitor and color-coded and mapped onto film. Thus, LANDSAT monitoring, as an adjunct to conventional point-sampling, would provide an economical basis for extrapolating water quality parameters from point samples to unsampled areas and provide a synoptic view of water mass boundaries that no amount of point sampling could provide.

8. REFERENCES

1. Klemas, V., Otlery, M., Wetle, C., and Rogers, R., "Monitoring Coastal Water Properties and Current Circulation with ERTS-1," Third Earth Resources Technology Satellite-1 Symposium, Dec. 10-14, 1973, Vol I, pp. 1387-1411.

2. Yarger, H.L., McCauley, J.R., James, G.W., Magnuson, L.M., and Marzoff, A.R., "Quantitative Water Quality with ERTS-1," Third Earth Resources Technology Satellite-1 Symposium, Dec. 10-14, 1973, Vol I, pp. 1637-1651.

3. Johnson, R.W., "Quantitative Sediment Mapping from Remotely Sensed Multispectral Data," Fourth Annual Remote Sensing of Earth Resources Conference, Tullahoma, Tennessee, March 24-26, 1975.

4. Rogers, R.H., Reed, L.E., and Smith, V.E., "Computer Mapping of Turbidity and Circulation Patterns in Saginaw Bay, Michigan (Lake Huron) from ERTS Data," presented at the ASP-ACSM Convention, March 9-14, 1975, NASA-CR-142923, NTIS Order Number E75-10321.

5. Efroymson, M.A., "Multiple Regression Analysis" in Ralston, A., and Wilf, H.S. (eds.) Mathematical Methods for Digital Computers, John Wiley, pp. 191-203, 1960.

6. Freedman, P.L., "Saginaw Bay; An Evaluation of Existing and Historical Conditions," EPA Report 905/9-74-003, April 1974.

7. Smith, V.E., "Saginaw Bay (Lake Huron): Survey of Physical and Chemical Parameters," (draft), International Joint Commission, Windsor, Ontario, p. 49, 1975.

TABLE 1. WATER QUALITY AND LANDSAT DATA. For Saginaw Bay, 03 June 1974, Cruise 8. Measurements Made at Water Depth of One Meter.

	On-Site Measurements					Laboratory Analysis							Computer Processing of CCTs				
						Major Metals				Nutrients			LANDSAT Digital Data				
Station Number	Temperature °C	Secchi Depth m	Conductivity Micromhos	Chloride mg/l	Chlorophyll a (Corrected) µg/l	Sodium, Na mg/l	Potassium, K mg/l	Magnesium, Mg mg/l	Calcium, Ca mg/l	Total Dissolved Phosphorus P mg/l	Total Kjeldahl Nitrogen mg/l	Total Phosphorus P mg/l	Mean Reflectance for Station Area, Bands: 4 (Max: 254)	5 (254)	6 (254)	7 (252)	Number of Pixels to Station Area
41	18.8	0.4	764.	950.	55.50					0.043	1.00	0.186	46.8	32.1	21.9	7.1	17
9	19.0	0.3	827.	1070.	38.20								48.5	32.5	19.9	4.1	27
6	18.7	0.4	828.		27.90	42.	5.2	19.	104.	0.070	0.52	0.145	46.1	32.3	19.6	4.3	81
7	17.0	0.6	425.	364.	50.80								43.1	25.8	15.3	2.7	90
10	18.0	0.7	381.	287.	53.90	12.	2.1	13.	55.				42.8	25.3	15.0	3.6	67
14	18.4	0.8	309.	196.	29.00								45.1	27.4	14.0	2.9	63
18	17.7	1.3	293.	170.	9.46	9.	1.5	10.	45.	0.006	0.19	0.029	47.0	26.3	12.8	2.7	56
23	17.0	1.7	286.	172.	5.93								44.1	23.4	11.9	3.1	64
28	15.4	1.7	329.	194.	5.85								43.6	23.7	11.6	3.0	64
35	15.8	2.2	283.	147.	5.13					0.004	0.20	0.018	44.8	23.8	13.4	4.7	80
55	19.2	0.3	659.	759.	22.80	33.	4.0	19.	93.	0.071	0.73	0.195	53.7	41.3	27.3	8.3	12
54	19.0	0.3	736.	882.	26.80					0.071	0.94	0.213	53.0	40.7	27.2	9.0	8
1	19.8	0.3	772.	1118.	36.20	41.	5.3	19.	101.	0.054	0.81	0.200	50.2	38.0	23.8	6.8	10
21	17.3	0.5	466.	465.	69.30								44.9	29.5	18.5	5.0	72
5	18.0	0.6	492.	485.	59.70	20.	2.9	16.	70.				43.6	27.4	17.1	4.7	81
59	18.0	0.8	359.	265.	36.60	12.	2.1	12.	52.				46.8	29.5	16.7	3.9	64
2	17.5	1.0	320.	200.	17.00	10.	1.7	10.	44.	0.010	0.27	0.029	47.0	27.2	14.2	3.2	49
15	17.0	1.3	323.	160.	6.17	7.	1.2	9.	39.				46.7	25.8	13.0	2.8	42
16	18.2	0.8	315.	190.	12.10	9.	1.7	10.	46.				56.9	37.2	17.5	4.2	49
19	16.2	1.7	303.	157.	2.73								45.9	25.0	12.5	2.8	72
22	16.3	1.4	283.	163.	4.41								44.1	23.1	11.3	2.3	42
20	17.5	1.5	268.	159.	5.93					0.004	0.24	0.016	45.8	23.5	12.4	2.4	49
3	19.2	0.6	330.	207.	3.74	11.	1.8	11.	50.				62.8	42.0	18.6	4.3	56
30	18.7	1.2	285.	153.	6.74	8.	1.5	10.	42.				52.5	29.1	15.8	5.4	64
29	16.6	1.8	269.	140.	5.69					0.010	0.23	0.014	43.5	22.7	11.3	2.2	42
31	16.2	2.2	274.	137.	3.93								43.5	22.2	11.5	2.2	49
36	17.8	1.8	262.	124.	6.17								48.2	27.1	16.3	5.7	64
Mean	17.73	1.04	423.7	358.2	22.507	17.83	2.58	13.17	61.75	0.0343	0.513	0.1045	47.37	29.03	16.31	4.20	
Standard Dev.	1.15	0.62	196.0	316.6	20.651	13.15	1.45	3.97	24.12	0.0303	0.328	0.0896	4.73	6.03	4.61	1.85	
No. of Samples	27	27	27	26	27	12	12	12	12	10	10	10	27	27	27	27	

TABLE 2. RESULTS OF STEPWISE REGRESSION ANALYSIS

Dependent Variable	Units	Regression Step	Independent Variable Added (LANDSAT Band)	Regression Variables (LANDSAT Bands)	Standard Error of Estimate	Percent Inaccuracy	Regression Correlation Coefficient
Temperature	°C	1	5	5	0.6759	3.8	0.819
Secchi Depth	m	1	6	6	0.3839	38.9	0.791
		2	7	6, 7	0.2890	27.7	0.892
Conductivity	Micromhos	1	6	6	115.130	27.2	0.817
Chloride	mg/l	1	6	6	180.578	50.4	0.829
Chlorophyll ā (Corrected)	μg/l	1	6	6	18.715	83.2	0.459
		2	4	6, 4	14.905	66.2	0.721
Sodium	mg/l	1	6	6	8.5521	48.0	0.785
Potassium	mg/l	1	6	6	0.9696	37.6	0.772
		2	4	6, 4	0.7737	30.0	0.876
Magnesium	mg/l	1	6	6	2.4170	18.4	0.816
		2	4	6, 4	1.4331	10.9	0.945
Calcium	mg/l	1	6	6	14.9092	24.1	0.808
		2	4	6, 4	11.0980	18.0	0.909
Total Dissolved Phosphorus	mg/l	1	6	6	0.0121	35.3	0.926
Total Kjeldahl Nitrogen	mg/l	1	6	6	0.1429	27.9	0.912
Total Phosphorus	mg/l	1	6	6	0.0225	21.5	0.972
		2	4	6, 4	0.0155	14.8	0.988

TABLE 3. CONSTANTS AND COEFFICIENTS FOR REGRESSION EQUATIONS

Dependent Variable	Units	Constant	LANDSAT Coefficients			
			Band 4	Band 5	Band 6	Band 7
Temperature	°C	13.186		0.157		
Secchi Depth	m	3.370			-0.230	0.339
Conductivity	Micromhos	-143.269			34.762	
Chloride	mg/l	-555.378			56.450	
Chlorophyll	μg/l	99.388	-2.873		3.631	
Sodium	mg/l	-24.324			2.393	
Potassium	mg/l	2.534	-0.111		0.315	
Magnesium	mg/l	14.240	-0.350		0.925	
Calcium	mg/l	57.658	-1.847		5.439	
Total Dissolved Phosphorus	mg/l	-0.0472			0.0044	
Total Kjeldahl Nitrogen	mg/l	-0.358			0.047	
Total Phosphorus	mg/l	0.246	-0.010		0.019	

TABLE 4. CORRELATION COEFFICIENT MATRIX OF WATER QUALITY PARAMETERS FOR SAGINAW BAY, APRIL 1 - JUNE 30, 1974 (REF. 7)

Temperature (T)	1.000											
Secchi Depth (SD)	-.179	1.000										
Conductivity (CON)	.304	-.470	1.000									
Chloride (Cl)	.251	-.465	.958	1.000								
Chlorophyll ā (CH-ā)	.223	-.446	.733	.784	1.000							
Sodium (Na)	.324	-.468	.962	.973	.689	1.000						
Potassium (K)	.301	-.500	.960	.940	.752	.933	1.000					
Magnesium (Mg)	.372	-.586	.921	.920	.760	.879	.917	1.000				
Calcium (Ca)	.326	-.534	.942	.927	.751	.900	.940	.916	1.000			
Total Dissolved Phosphorus (TDP)	.214	-.158	.558	.077	.206	.683	.593	.509	.611	1.000		
Total Kjeldahl Nitrogen (TKN)	.285	-.484	.604	.617	.680	.683	.745	.738	.725	.275	1.000	
Total Phosphorus (TP)	.289	-.506	.609	.523	.531	.617	.649	.677	.689	.515	.485	1.000
	T	SD	CON	Cl	CH-ā	Na	K	Mg	Ca	TDP	TKN	TP

Figure 1.
LANDSAT Image (1680-15455, Band 5) of Lower Saginaw Bay Area for June 3, 1974

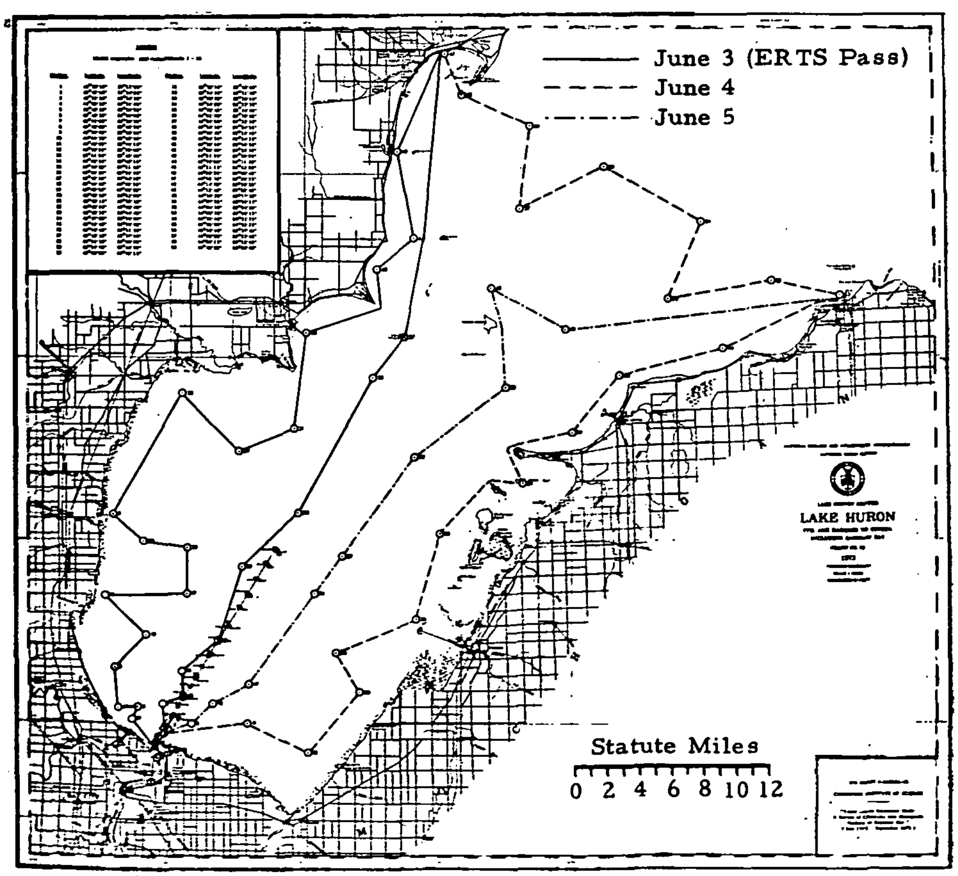

Figure 2.
Map of Saginaw Bay with Location of the 59 Bay Stations Denoted by ⊙ .

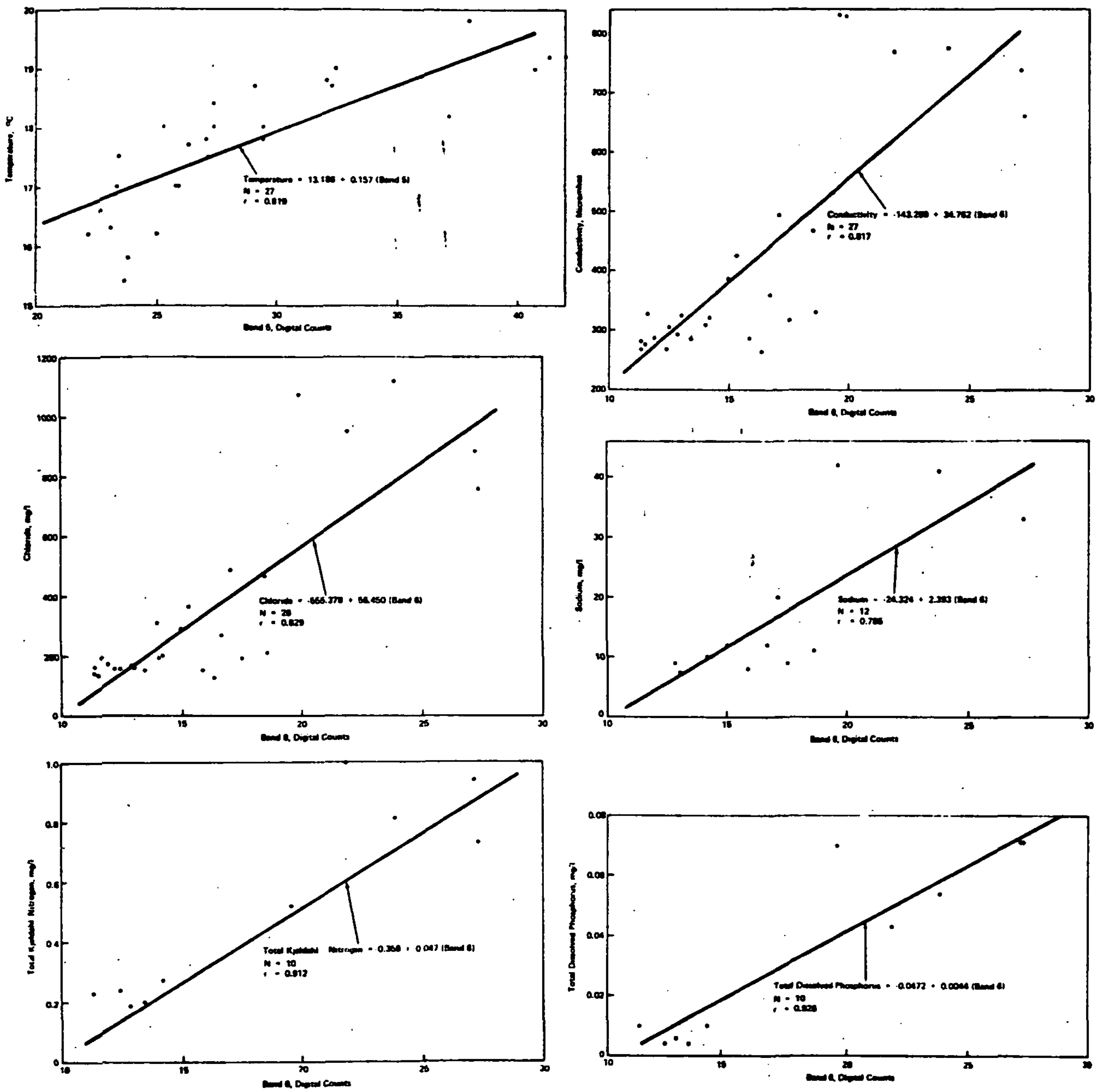

Figure 3. Water Quality Parameter Versus LANDSAT Measurements with Regression Line for Most Significant Single LANDSAT Band.

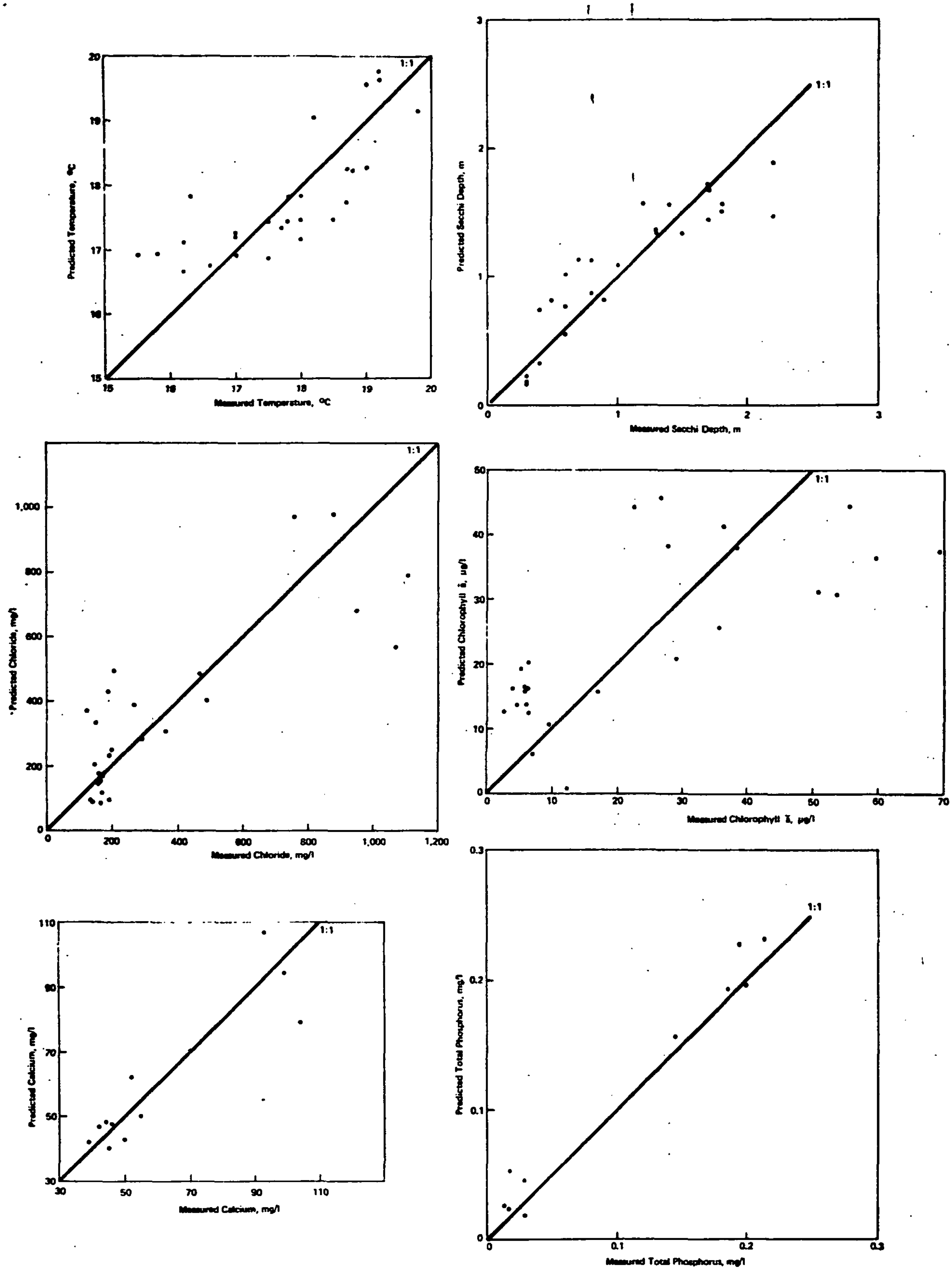

Figure 4. Predicted Versus Measured Values of Water Quality Parameters.

APPENDIX B

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle LANDSAT - 1; Automated Land-Use Mapping in Lake and River Watersheds		5. Report Date October 1975
		6. Performing Organization Code
7. Author(s) R.H. Rogers et. al.		8. Performing Organization Report No. BSR 4205
9. Performing Organization Name and Address Bendix Aerospace Systems Div. 3621 South State Road Ann Arbor, Michigan 48107		10. Work Unit No.
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15. Supplementary Notes

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16. Abstract

LANDSAT CCTs were used as a basis for inventorying land use within each of the Ohio-Kentucky-Indiana Regional Commissions, 225 drainage areas, and nine counties. Computer tabulations were produced to obtain the area covered by each of 16 land-use categories within 225 drainage areas. The 16 categories were merged into ten categories and mapped at a scale of 1 in. = 5,000 ft, with detail to 0.44 hectares for the 2,700 sq. mi. region. These products were produced in less than 90 days, at a cost of $20,000. It is not uncommon to find single counties spending this much to map similar categories within a much smaller area.

17. Key Words (Selected by Author(s))	18. Distribution Statement
Water Quality, ERTS, Computer Processing, Land Use.	

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
		10	

7

LANDSAT-1: AUTOMATED LAND-USE MAPPING IN LAKE AND RIVER WATERSHEDS

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BIOGRAPHICAL SKETCHES

Dr. Robert H. Rogers is a senior engineer at Bendix, where he is a Principal Investigator for NASA/LANDSAT and Skylab/EREP programs. Rogers received his BS from Tri-State College, his MS from Southern Methodist University, and his PhD in EE from Michigan State University. He is a member of the ASP, and has published many papers in the field of Remote Sensing. Larry E. Reed is a projects investigator for Bendix and is actively involved in the processing and analysis of data from ERTS, Skylab, and Bendix multispectral scanners. He has seven years experience as an Air Force image interpreter, using aerial photography, side-looking radar, and infrared imagery. Norman F. Schmidt is a senior staff engineer at Bendix where he is a systems engineer in the Earth Resources Data Center involved in production and system improvement. He received a BSE from the University of Illinois and MSE at the University of Michigan. Timothy G. Mara is an environmental planner for the Ohio-Kentucky-Indiana Regional Council of Governments. He received a BCP degree from the University of Cincinnati and has participated in several programs in the field of environmental planning.

ABSTRACT

As part of the national effort to deal with water pollution, Section 208 of the Federal Water Pollution Control Act Amendments of 1972 provides regional planning agencies with the opportunity and funding to undertake regional water quality planning. A common requirement of the 208 program is to develop a capability of predicting water quality in the rivers and lakes resulting from existing and potential land-use patterns. To achieve this capability, the Ohio-Kentucky-Indiana Regional Council of Governments (OKI) is developing a deterministic model capable of predicting sediment and nutrient flow into the waterways. An essential input to OKI's model is an accurate map of land use within the watersheds. This information was obtained by OKI through the machine processing of LANDSAT-1 digital tapes. Computer tabulations were generated to obtain the area covered by each of 16 land-use categories within 225 drainage areas. The 16 categories were merged into 10 catego-

ries and mapped at a scale of 1 inch = 5,000 feet with detail to 0.44 hectares (1.1 acres) for the 2,700-square-mile region. The map products and data were produced within a period of less than 90 days at a cost of $20,000, a significant improvement in dollars and time over conventional mapping techniques.

BACKGROUND

State and federal agencies are becoming increasingly alarmed over the loss in water quality in many of our public lakes and rivers. Much of this loss is a direct result of pollution generated by man and the increased sediment and nutrient runoffs into the rivers and lakes resulting from urbanization and intensive agriculture in the watersheds. It is now realized that our water resources are not inexhaustible. Land development must be planned and conservation practices must be used in connection with agricultural activities if the conflict between utilization of our water resources and maintenance of the quality of our lives is to be resolved.

To provide for this needed planning, the Federal Water Pollution Control Act Amendments of 1972 created several programs to fight water pollution. Under provisions of Section 208 of that act (EPA, 1974) regional planning agencies such as Ohio-Kentucky-Indiana (OKI) Regional Council of Governments were given the opportunity and the funding to undertake regional water quality planning. The new 208 program (OKI 1974) differs from past HUD-financed water and sewer planning in that this new EPA-administered program deals with all sources of pollution, not just pollution from municipal sewerage systems. Other sources of pollution for which planning responsibility is given are industrial discharges and what are termed "non-point" sources. These non-point sources include stormwater runoff from agricultural areas, urban runoff, erosion from construction sites, and leachates from septic tanks.

A common requirement of the 208 programs and programs of other governmental agencies concerned with the maintenance and control of water quality is the development of a knowledge of the interrelationships between the water quality parameters (suspended solids, total nitrogen, total phosphrus and organic wastes) and land-use parameters (land-use categories and coverage, etc.).

To obtain this information, OKI has developed a deterministic model capable of predicting water quality in rivers and lakes resulting from existing and potential land-use policies. The inventory of present land use together with population projections will provide OKI a basis for developing maps of anticipated land-use patterns. Given a future land use, the water quality model will be used to predict the impact of future development on water quality.

This analysis together with other detailed work with point sources will aid OKI in identifying critical areas where alternatives will have to be developed to minimize any deleterious impact on water quality. This may involve redirecting growth to other areas where the impact may not be as severe, or changing the character of the growth to minimize any harmful impact on water quality. The water quality plan will, in effect, contain a significant land-use planning element. The 208 water quality planning program will provide a rational basis for determining land use policy, especially as the policies may relate to water quality.

Accurate water and land-use parameters are essential in the development and application of the water quality model.

While many factors influence water quality, a dominating one is the use of land adjacent to and surrounding the lakes and rivers, the "drainage areas." During periods of rain or thaw, sediment and nutrients are washed directly into nearby water bodies. Each land-use category has its own special characteristic (Ref. 1)* which is important in the calculation of the quantity and quality of storm-water runoff. For example, urban lawns and streets discharge more nutrients, especially phosphorus, than do rangeland and forested land. Cropland is often tilled in the spring when rainfall is heaviest and absorbs much of the water, but erosion in the form of sediments, containing pesticides and fertilizer, are washed into nearby streams. This differs from what happens in a center city area where virtually all of the ground is covered by pavement and buildings and little or none of the water is absorbed into the earth. Instead, the water flows rapidly into storm sewers, carrying with it dirt from streets and buildings.

To establish sediment and nutrient flows from the drainage areas into the waterways, accurate information on drainage area land use is essential. Land-use information presently available to planning agencies is not adequate for water quality planning purposes. In almost every case, agricultural and vacant land has been lumped into one category labeled miscellaneous or undeveloped. Urban land uses often are not identified (categorized) in terms usable for water quality planning. Also, most 208 program planning areas are extremely large. The OKI Region covers 7,024 sq km (2,712 sq mi) and contains 225 drainage areas. For these reasons, OKI decided that the traditional techniques for land-use inventory - field inspection and interpretation of aerial photographs - are impractical in that they are too costly in terms of dollars and time. In its quest to evaluate new sources and techniques for obtaining the needed land-use information, OKI established and accomplished the following two goals: 1) Produced a 10-

* References and illustrations can be found at the end of the paper.

category land-use map of the OKI regional area showing; grassland, water, active cropland, two categories of forest land, core city/industrial, inner city, urban, and suburban. The smallest detail mapped was 0.44 hectare (1.1 acres) and the map scale was 1 inch = 5,000 ft., 2) Produced computer tabulation of area covered by 16 land-use categories for each of 225 drainage areas and nine counties.

OKI achieved its mapping goals within a period of 90 days at a cost of only $20,000, a significant improvement over conventional techniques.

OKI REGION

The OKI objectives were achieved through the machine processing of the 14 April 1973 LANDSAT-1 scene shown in Figure 1. The OKI region shown in this scene consists of the Ohio Counties of Hamilton, Clermont, Butler, and Warren; the Indiana Counties of Dearborn and Ohio; and the Kentucky Counties of Boone, Kenton, and Campbell. This 2,712-sq mi region centered around Cincinnati is expected to increase its population to over 2,000,000 by the year 2000, a 35% growth from its present figure of aboutl,600,000. The area is characterized by its many low hills and dense forest cover. The Ohio River and its tributaries drain the OKI region. The Ohio, Great Miami, Little Miami and Licking Rivers can also be seen in the LANDSAT image of the region. All of the rivers and lakes in the region are highly valued for recreational use and residential value. Increasingly heavy public use makes it vital that water quality considerations remain as one of OKI's highest planning priorities.

MACHINE PROCESSING OF LANDSAT DATA

The need for faster and more economical mapping of water quality and land use has led Bendix into evaluating computer target "spectral recognition" techniques as a basis for automatic target categorization and mapping. The categorization techniques (Ref. 2, 3) have been under continued development at Bendix for the past 10 years, primarily using aircraft multispectral scanner data. More recently, LANDSAT/MSS and Skylab/EREP-S192 data have been used.

Bendix Data Center

The elements of the Bendix Data Center used to process data for this study are shown in Figure 2 and include: a Bendix Datagrid® Digitizer System 100 for digitizing graphical data, a Bendix Multispectral-Data Analysis System (M-DAS) for the analysis of LANDSAT "computer-compatible tapes" (CCTs), and a Cal Comp Plotter for the production of land-water categorized maps from the processed LANDSAT tapes. A Gerber Series 40 Plotting Table is also used for this mapping function. M-DAS has been discussed (Ref. 4) in detail previously.

The nucleus of the M-DAS is a Digital Equipment Corporation PDP-11/35 computer with 28K words of core memory, one 1.5M-word disc pack, two nine-track 800 bit-per-inch (bpi) tape transports, and a DECwriter unit. Other units are an Ampex FR-2000 14-track tape recorder, a bit synchronizer and tape deskew drawers which can reproduce up to 13 tape channels of multispectral data from high-density tape recordings, a high-speed hard-wired special-purpose computer for processing multispectral data, a 9 1/2 in. drum recorder for recording imagery on film, and a color moving-window computer-refreshed display. M-DAS is the result of an evolutionary program initiated by Bendix in 1967 and is dedicated to the processing of remote sensing data.

Processing Steps

The data processing steps used and the results achieved in transforming LANDSAT CCTs into the desired land-use maps and data are briefly summarized in the following paragraphs.

Establish Map Categories

The first step in the development of the OKI land-use map was to locate and designate to the computer a number of LANDSAT picture elements or "pixels" that best typified the land-water categories of interest, the "training areas." These areas of known characteristics were established from aerial photographs and ground survey data, and were located on the LANDSAT CCTs by viewing the taped data on the M-DAS TV monitor. The coordinates of the training areas were designated to the computer by placing a cursor over the desired area and assigning a training area designation, category code, and color code. Several training areas, typically 20 to 50 pixels in size, were picked for each category, with each pixel corresponding to a ground coverage of 57 x 79 m. The color code was used in later playback of the tapes when the computer-categorized data are displayed in the designated colors.

Develop Processing Coefficients

The LANDSAT spectral measurements within the training area boundaries were edited by the computer from the CCT and processed to obtain a numerical descriptor (computer-processing coefficients) to represent the spectral characteristics of each target category. The descriptors (Ref. 2) included the mean signal and standard deviation for each LANDSAT band and the covariance matrix taken about the mean. The descriptors were then used to generate a set of processing coefficients for each category. In multivariate categorized processing the coefficients are used by the computer to form a linear combination of the LANDSAT measurements for each pixel. The variable produced has an amplitude which is associated with the probability that the unknown pixel measurements belong to the particular target category sought. In categorical processing, the probability of a LANDSAT pixel arising from each one of the different target categories of interest is computed for each pixel and a decision, based on these computations, is reached. If all the probabilities are below a threshold level specified by the operator, the computer will decide that the category viewed is unknown (uncategorized).

Evaluate Selection of Training Areas and Processing Coefficients

Before producing categorized data for the entire OKI region, a number of tests were applied to evaluate the computer's ability to perform the desired interpretation. The tests included generating categorization-accuracy tables and viewing the processed imagery on the M-DAS TV monitor. Selection of training areas, generation of accuracy tables, and evaluation of processing results through use of computer printouts and the TV monitor were iterative operations. The land-use categories listed below in order of their potential for discharging natural and human sources of nutrients, resulted from the LANDSAT processing and subsequent manual interpretation.

- Core City/Industrial - Most dense industrial and commercial area, asphalt, concrete, gravel, etc., 0% vegetation.
- Inner City - Second-most dense industrial and commercial area, almost no vegetation cover.
- Medium Density Urban - Older residential areas - 10% to 50% vegetation.
- Low Density Urban - New Suburban - New residential areas of varying density characterized by an almost total lack of trees but with large green lawn and low bush areas.
- Cropland - Active cropland limited to row crops such as corn, oats, tobacco and vegetables.
- Grasslands - Included are tended grass areas such as golf courses and cemeteries, untended pasture land and crops such as wheat and alfalfa.
- Forestland 1 - Most dense forest area (probably 25% or more canopy).
- Forestland 2 - Sparse forest and brushland.
- Surface Water - Various categories of depth and sediment concentration were combined.

- <u>Uncategorized</u> areas which did not pertain to desired categories or for which sufficient ground truth did not exist for identification.

Evaluation of processed results showed that some urban categories became confused with non-urban categories; i.e., older residential with forestland, new residential with grassland, core city with sand bars and beaches. However, the errors occur at random spots as "speckles" and, when viewed in context on a map grid, were corrected by manual interpretation. This points up the additional need to transfer LANDSAT categorized data to a base map where contextual information can also be used in interpretation.

Generate Categorized LANDSAT Tapes

When satisfied with the categorization accuracy achieved on the land-water categories, the processing coefficients were placed into the computer disk file and used to process that portion of the LANDSAT CCTs covering the OKI region. This step in the categorization processing resulted in new or categorized CCTs, where each LANDSAT pixel was represented by a code designating one of the 16 land-water categories. These 16 categories were merged into the primary categories noted previously and mapped at a scale of 1 in. = 5,000 ft for the OKI region. Computer tabulations were also extracted from the categorized tapes to obtain a quantitative measure of land use within the drainage areas.

Produce Categorized Map Overlays

To produce categorized data that will directly relate to a base map, the categorized CCTs were submitted to a second stage of processing. In this stage, new tapes were generated that had data corrected for earth rotation and a format compatible with a computer-driven CalComp Plotter. These tapes, when played back by the computer, caused overlays of a specified land-water category to be drawn by the plotter on mylar at a scale specified by the computer. Examples of these mylar drawings over a map of drainage areas near Cincinnati are shown in Figure 3. The examples show core city/industrial and forestland categories at the original scale of 1:120,000. The overlays were photographically enlarged to the final map scale of 1 in. = 5,000 ft. A diazochrome material was exposed through the black and clear category transparencies by a lithographic plate burner and ammonia developed to produce color-coded overlays. The color coding permitted multiple overlays to be used simultaneously over the base map.

A ten category color coded land-use map was developed for a 3,100 sq. mi. area including the OKI Region and vicinity, at the full LANDSAT resolution (0.44 hectare or 1.1 acre pixels) and at a scale of 1 in. = 5,000 ft. The cost for this map was approximately $2.20 per sq. mi.

Area Measurement Tables

Computer-generated area measurement tables were produced from the categorized data tapes to determine land use within the drainage areas. To accomplish this step, a procedure was developed by which the drainage area boundaries in earth coordinates (latitude and longitude) are first digitized from watershed maps. The resulting digital tape is processed on M-DAS to transform the earth coordinates to LANDSAT coordinates and to extract and tabulate land use from the categorized tape. The area measurement table provides the amount of land that falls within a particular category in terms of square kilometers, acres, and percentage of the total drainage area processed. Figure 4 illustrates two area tabulations of the urban watersheds in Cincinnati. The categories are listed in order of urban density where an additional High Density Urban category has been added. This category was randomly confused with plowed fields (cropland) in the initial machine processing but was corrected by manual interpretation of base map overlays.

The tabulated data provided a useful input to OKI's water quality model where each category is assigned a "loading function" or pollution equivalent (Ref. 5). Eventually, by multiplying the extent of land use acreage in an area by these loading functions, the water quality model will calculate the extent of pollution emanating from these non-point sources.

CONCLUSION

Computer processing of LANDSAT data provides a rapid and economical means of mapping land use in watersheds of lakes and rivers.

Although additional improvements can and are being made in processing techniques to increase mapping rates and accuracy and to reduce cost, OKI has demonstrated the techniques and utility of LANDSAT for mapping watershed land use on an operational basis.

As there is still some confusion between some urban and non-urban categories as indicated by random misclassification, additional processing refinements are needed to improve separability of these categories.

Machine-assisted interpretation of LANDSAT tapes was found to be very fast. The analysis phase required about one day per LANDSAT scene. Once the analysis was completed and the processing coefficients were computed, the categorized tape was produced for a full LANDSAT CCT (2,500 square nautical miles) in less than 30 minutes. Boundaries of water drainage areas were manually digitized from maps of the OKI area at a rate of about six per hour. The computer extracted and tabulated land use within these areas at a rate of one every 3 minutes. The major time-consuming step in the production of the LANDSAT products was the generation of the map overlays for the region, which required about 3 weeks. In the near future, a drum film recorder will replace the computer controlled plotter permitting this overlay production to be accomplished within a day.

The machine-processing techniques permitted the nine county OKI region to be mapped to 1-acre detail for $20,000. With application of conventional techniques, it is not uncommon for a county to spend this much or more to map similar categories within a much smaller area. Additionally, conventional techniques based on manual interpretation of photography and field checks typically require a year to obtain a mapping product similar to that obtained by OKI within 90 days.

REFERENCES

1. US Environmental Protection Agency, Office of Air and Water Programs, EPA-430/9-73-014, "Methods for Identifying and Evaluating the Nature and Extent of Nonpoint Sources of Pollutants," October 1973.

2. Dye, R. H. and C. S. Chen, "Divergence Analysis of Bendix Feature Extraction and Classification System," Proceedings of LARS Symposium on Machine Processing of Remotely Sensed Data, IEEE Catalog No. 75 CH 1009-0-C, June 3-5, 1975.

3. Rogers, R. H., "Environmental Monitoring from Spacecraft Data," Proceedings of LARS Symposium on Machine Processing of Remotely Sensed Data, IEEE Catalog No. 75 CH 1009-0-C, June 3-5, 1975.

4. Johnson, R. H., "M-DAS Multispectral Data Analysis System," Bendix Report BSR 4146B, September 1974.

5. US Environmental Protection Agency, Water Planning Division, (Draft) "Guidelines for Areawide Waste Treatment Management," May 1974.

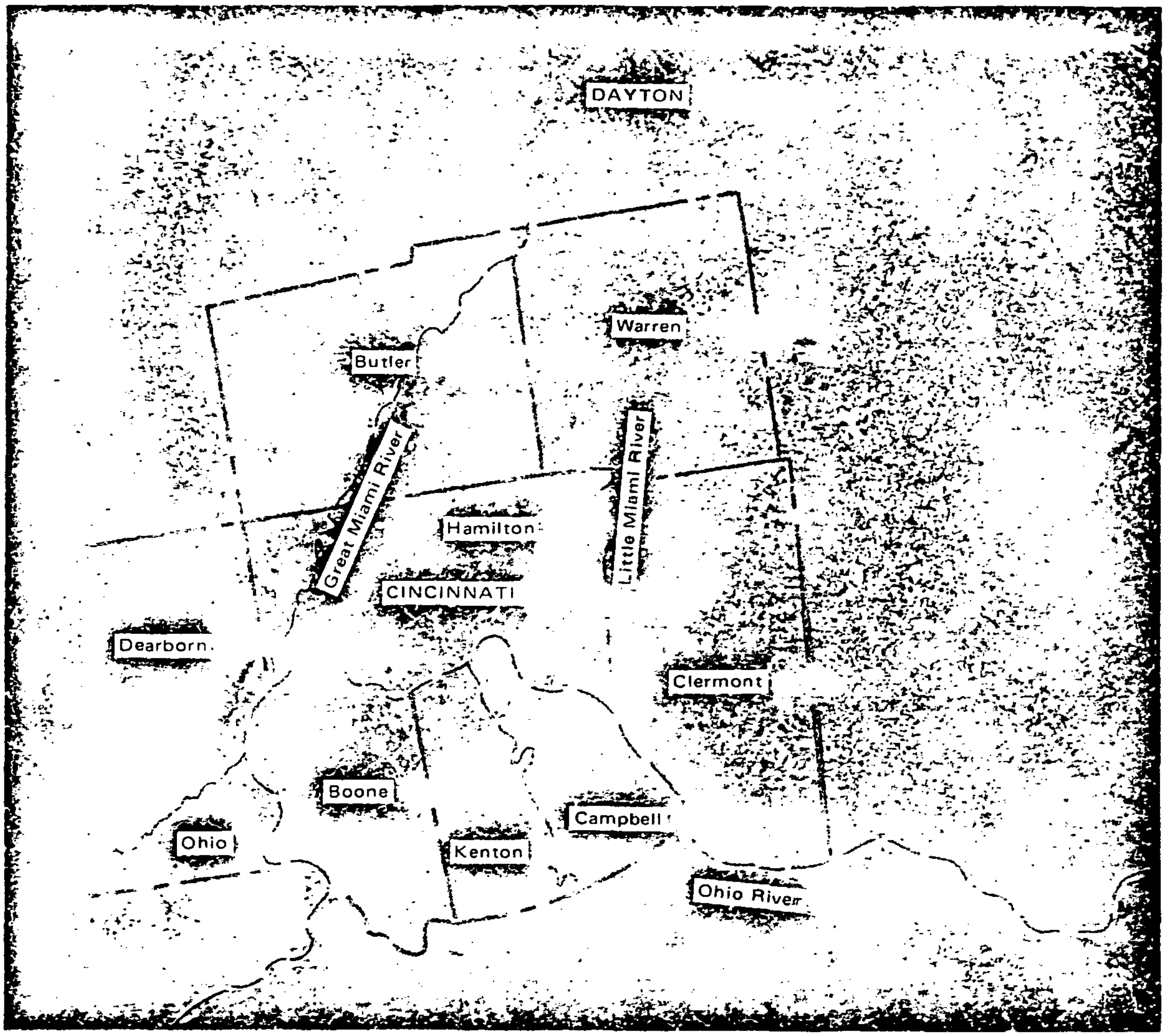
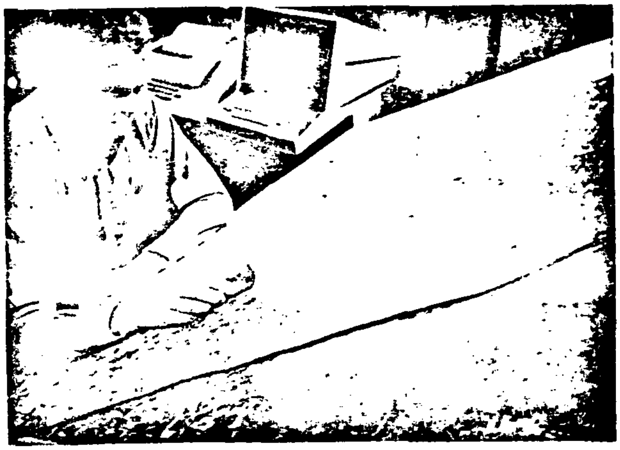


Figure 1. LANDSAT Band 5 Image (E-1265-15485) of 14 April 1973 Showing the Ohio-Kentucky-Indiana Regional Council of Government Area.

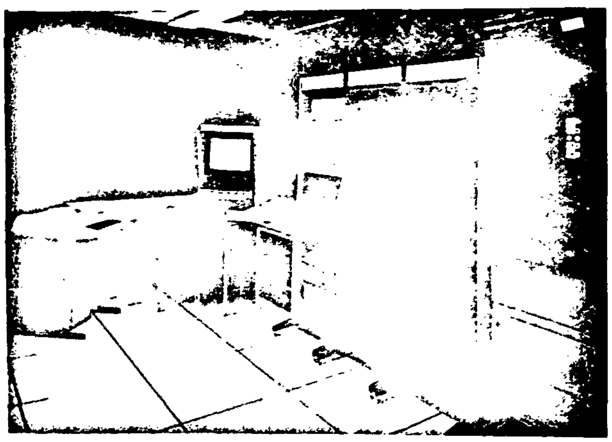
Datagrid Digitizer



Develop Earth to LANDSAT Coordinate Transformation

- Digitize Ground Control Points
- Designate Location of Training Areas
- Digitize Boundaries of Areas for which Area Printout Tables Are Required; Watersheds, Counties, Townships, etc.

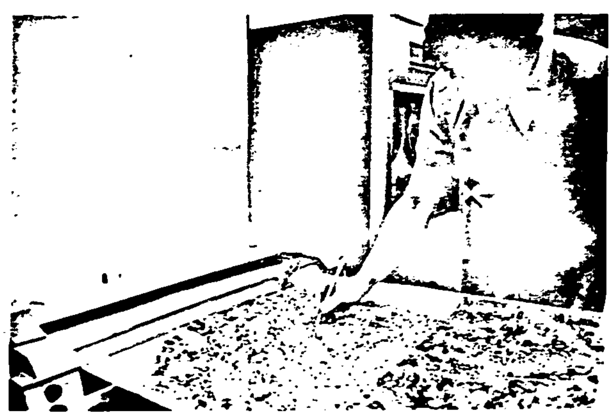
Multispectral-Data Analysis System (M-DAS)



Produce LANDSAT Categorized Tapes

- Define Land-Water Categories and Locate Corresponding Training Areas within LANDSAT Tapes.
- Compute Category Characteristics.
- Evaluate Training Area Selection.
- Transform LANDSAT Tapes into New Set of Tapes where Each Pixel Is Coded to Correspond to Interpreted Land-Water Categories.

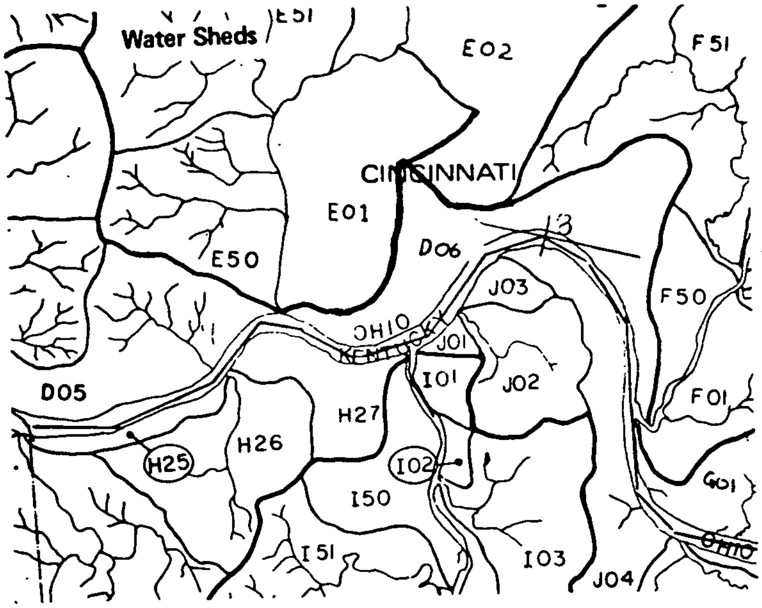
Cal Comp Plotter



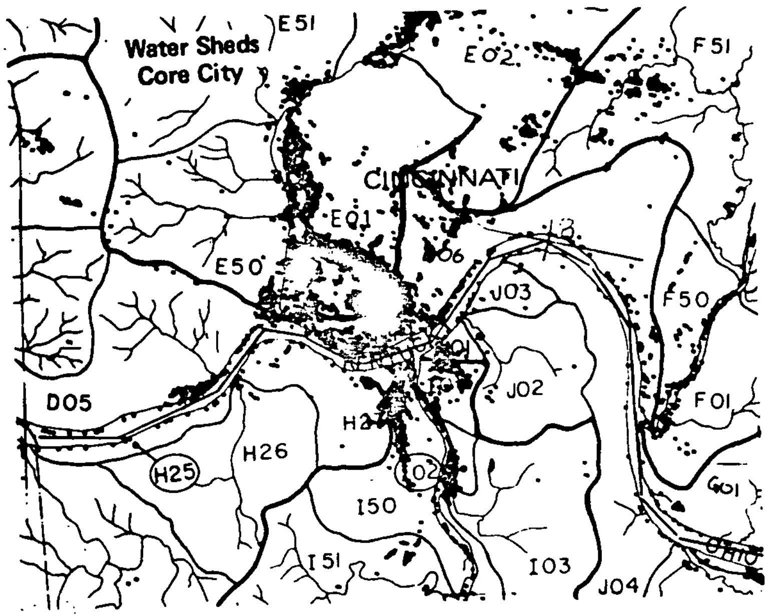
Generate Data and Map Products from LANDSAT Categorized Tapes

- Produce Transparent Color-Coded Overlay for Each Category; Typical Scales of 1:24,000, 1:62,500, and 1:250,000.
- Generate Color-Coded Imagery Where Color Is Used as a Code to Designate Categories.
- Produce Tabular Computer Printouts Listing Area Covered by Land-Water Categories within Specified Political and Geographic Boundaries in Percent Coverage per Category, Acres, and Square Kilometers.

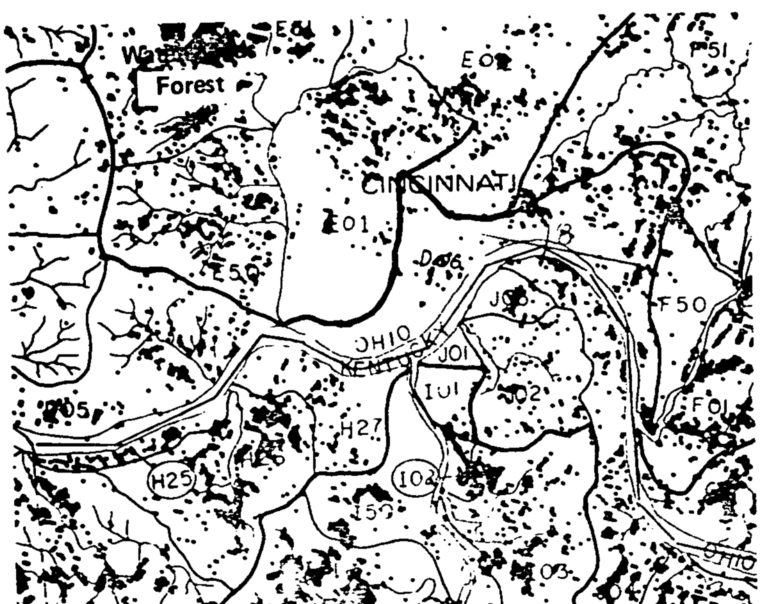
Figure 2. Computer Generation of Land-Use Maps from LANDSAT Data



Map Showing Watersheds Around Cincinnati

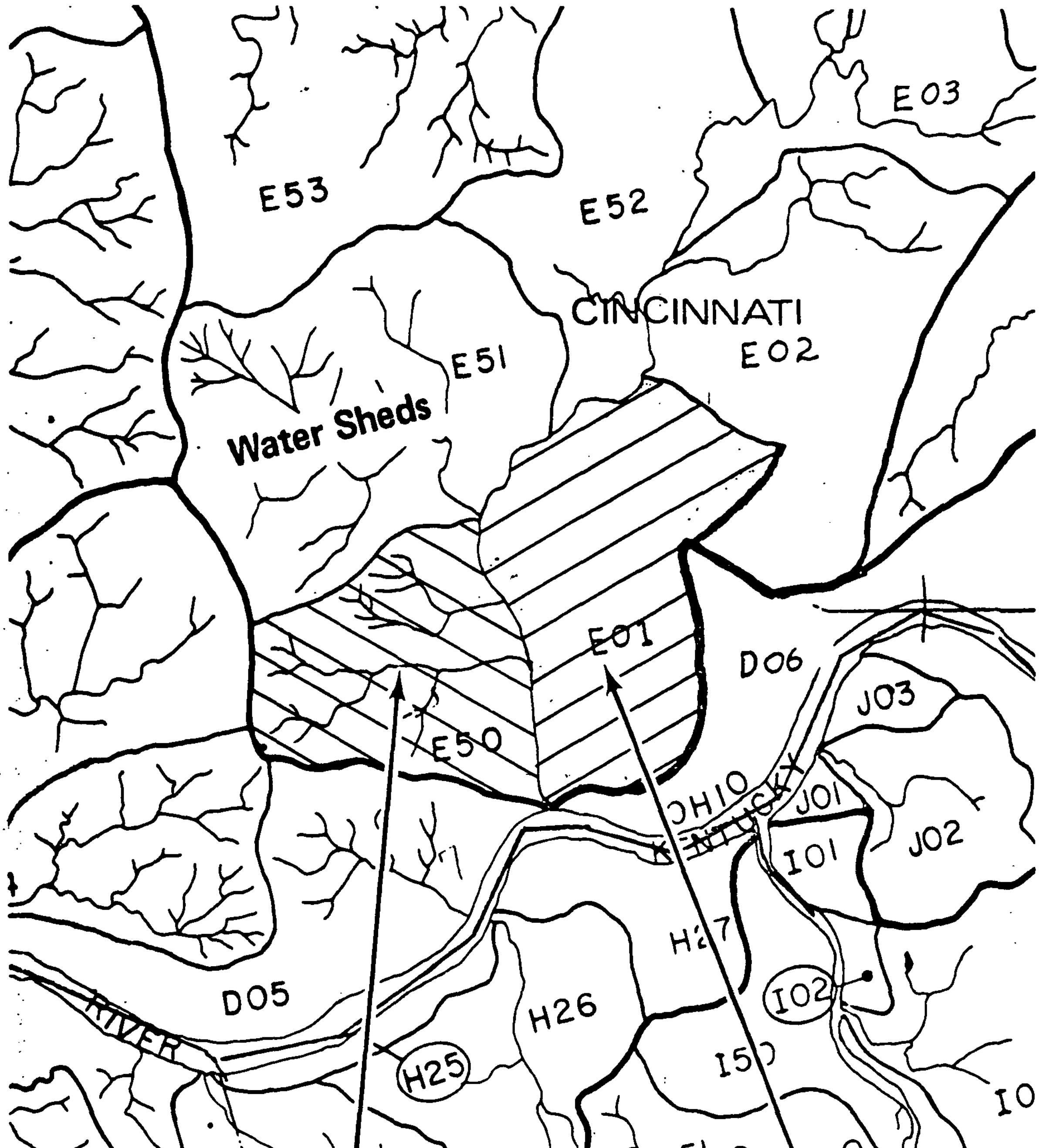


Core City/Industrial Category Mapped from LANDSAT Overlaying Watershed Map



Forestland Category Mapped from LANDSAT Overlaying Watershed Map

Figure 3. Examples of Watershed Land Use Maps Mapped from LANDSAT



	WATERSHED E-50			WATERSHED E01		
Category	Percent of Watershed	Acres	Square Kilometers	Percent of Watershed	Acres	Square Kilometers
Core City/Industrial	2.77	118.5	0.48	11.01	699.8	2.83
Inner City	4.60	196.75	0.80	11.95	760.17	3.08
High Density Urban	8.95	383.44	1.55	16.3	1037.29	4.19
Medium Density Urban	25.93	1110.07	4.49	20.04	1274.4	5.16
Low Density Urban	3.79	162.09	0.66	0.51	32.42	0.13
Grassland	25.46	1089.95	4.41	12.01	763.52	3.09
Forrestland	26.63	1140.26	4.62	20.43	1299.0	5.26
Water	0.19	7.83	0.03	6.25	396.85	1.61
Uncategorized	1.7	72.67	0.29	1.51	96.14	0.39
Total	100.00	4281.54	17.33	100.00	6358.59	25.73

Figure 4. Map of Watersheds Around Cincinnati, and Example of Tabular Printouts Produced from LANDSAT Data.

APPENDIX C

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.

4. Title and Subtitle Computer Mapping of LANDSAT Data for Environmental Applications	5. Report Date November 1975 6. Performing Organization Code
7. Author(s) Robert H. Rogers el. al.	8. Performing Organization Report No. BSR 4206
9. Performing Organization Name and Address Bendix Aerospace Systems Division 3621 South State Road Ann Arbor, Michigan 48107	10. Work Unit No. 11. Contract or Grant No. NAS 5-20942
12. Sponsoring Agency Name and Address Goddard Space Flight Center Greenbelt, Maryland 20771	13. Type of Report and Period Covered Special Report 14. Sponsoring Agency Code

15. Supplementary Notes

Presented at the Workshop for Environmental Applications of Multi-Spectral Imagery, November 1975, Ft. Belvoir, Va.

16. Abstract

LANDSAT CCTs were used as a basis for inventoring land cover within the Triangle J Council of Government's 1,750 square mile 208 study area. Ten land cover categories were interpreted for the study area at a detail of 0.44 hectares (1.1 acres) and included 3 urban density categories, 4 forest types, agricultural-managed lands, bare soil-construction sites, and water. The resulting products included color-coded overlays for each of the 10 categories for a 1:96,000 scale base map, a color composite map of the same categories and scale, and a computer tape containing 54 quadrangles (7.5 minute) where each 50 meter grid cell was coded as to the ten land cover types. This taped data is being aggregated into 4 hectar (about 10 acres) grid cells and merged with soils and slope data to compute sediment and nutrient flows in the drainage areas. The complete inventory was accomplished within a period of 60 days at a cost of less than one cent per acre, a significant improvement in dollars and time over previously reported efforts.

17. Key Words (Selected by Author(s))	18. Distribution Statement
Water Quality, LANDSAT, Computer Processing.	

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
		17	

COMPUTER MAPPING OF LANDSAT DATA FOR ENVIRONMENTAL APPLICATIONS

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BIOGRAPHICAL SKETCHES

Dr. Robert H. Rogers is a senior engineer at Bendix, where he is a Supervisor of the Earth Resources Interpretations Group. Rogers received his BS from Tri-State College, his MS from Southern Methodist University, and his PhD in EE from Michigan State University. He is a member of the ASP, and has published over 30 papers on the applications of Remote Sensing data. Dr. John B. McKeon, Larry E. Reed and Norman F. Schmidt are project investigators in the Interpretations Group and are involved in the computer processing and analysis of LANDSAT, Skylab, and Bendix Multispectral Scanner data. Dr. McKeon, a telegeologist, received a BA in natural sciences from Johns Hopkins University, degrees in geology from The University of Maine, MS, and The Ohio State University, PhD. Mr. Reed has seven years training and experience as an Air Force image interpreter. Mr. Schmidt received a BSE from the University of Illinois and MSE at the University of Michigan. Roger N. Schecter is Senior Environmental Specialist on the 208 staff in the Triangle J Council of Governments. He received a B.S. from East Carolina University and M.S. from the University of North Carolina at Greensboro. He has been actively involved with the relation of resource planning and evaluation to decision making processes in governmental and private sectors.

ABSTRACT

As part of the national effort to deal with water pollution, Section 208 of the Federal Water Pollution Control Act Amendments of 1972 (PL 92-500) provides regional planning agencies with the opportunity and funding to undertake regional water quality planning. A common requirement of the 208 program is to develop a capability of predicting water quality in the rivers and lakes resulting from existing and potential land-use patterns. To achieve this capability, the Triangle J Council of Governments is developing deterministic models capable of predicting sediment and nutrient flow into the waterways. An essential input to these models is an accurate inventory of land-cover within the watersheds of the region.

The needed inventory was obtained by Triangle J for its 1,750 square mile (1,120,000 acres) 208 study area through the computer processing of LANDSAT computer compatible tapes (CCTs). Ten land cover categories were interpreted for the study area at a detail of 0.44 hectares (1.1 acres) and included 3 urban density categories,

4 forest types, agricultural-managed lands, bare soil-construction sites, and water. The resulting products included color-coded overlays for each of the 10 categories for a 1:96,000 scale (1 inch = 8000 feet) base map, a color composite map of the same categories and scale, and a computer tape containing 54 quadrangles (7.5 minute) where each 50 meter grid cell was coded as to the ten land cover types. This taped data is being aggregated by Triangle J into 4 hectar (about 10 acres) grid cells and merged with soils and slope data to compute sediment and nutrient flows in the drainage areas.

The complete 208 inventory was accomplished within a period of 60 days at a cost of less than one cent per acre, a significant improvement in dollars and time over previously reported efforts.

BACKGROUND

It has become increasingly apparent to federal, state, and local agencies that the control of water pollution by single-step, short-ranged programs is not an approach that will produce noticeable results. Regulations which focus primarily on the end of a sewage discharge pipe do not address the many faceted and complex interactions which, in effect, result in polluted water. Billions of dollars have been expended solely for expensive treatment facilities without making an effort to understand overall causes and effects of water pollution or to look toward less expensive methods for controlling its impacts. Agriculture, silviculture, mining, construction, urbanization, and natural processes all contribute in different ways to pollution loads in lakes and streams. The use of the land, the environmental processes which are occurring, and the capacities of streams and rivers to withstand pollution are interactive forces. Planning for the utilization of valuable resources must focus on a range of causes, effects, and solutions to have meaningful impact on water quality.

The Federal Water Pollution Control Act Amendments of 1972 initiated a coordinative approach to the problem of water pollution. Under provisions of Section 208 of this Act (Ref. 1) federal, state, and areawide programs were established with financial backing from the Environmental Protection Agency. This 208 areawide water quality management planning effort, for the first time enabled sub-state regional agencies such as Triangle J to plan for improved water quality while concurrently addressing the land-use, environmental, managerial, and financial aspects which are directly related to solving the problem. Such a planning process deals with point sources of pollution and, perhaps more importantly, with non-point pollution. These non-point sources include storm-water runoff from agricultural areas, urban runoff, erosion from construction site, and leachates from septic tanks.

The Triangle J Council of Governments, in May of 1974, was the first regional planning agency to be granted EPA funds to conduct a water quality management program. As part of this pilot project, Triangle J spend eight months developing a comprehensive work plan for its program of study (Ref. 2). This work plan has since provided guidance for other agencies who have become involved in 208 water quality planning (Ref. 3). Of primary importance in the plan was the development and evaluation of relationships between water quality and land resources and use within the region. To accomplish this goal it was essential that Triangle J obtain a uniform base map of existing resources and a data base which could be used to relate existing and future land use to storm-water quality problems, and environmental impacts.

While many factors influence water quality, a dominating one is the use of land adjacent to and surrounding the lakes and rivers, the "drainage areas." During periods of rain or thaw, sediment and nutrients are washed directly into nearby water bodies. Each land-use category has its own special characteristic (Ref. 4) which is important in the calculation of the quantity and quality of storm-water runoff. For example, urban lawns and streets discharge more nutrients, especially phosphorus, than do rangeland and forested land. Cropland is often tilled in the spring when rainfall is frequent and absorbs much of the water, but erosion in the form of sediments, containing pesticides and fertilizer, are washed into nearby streams. This differs from what happens in a center city area where virtually all of the ground is covered by pavement and buildings and little or none of the water is absorbed into the earth. Instead, the water flows rapidly into storm sewers, carrying with it dirt from streets and buildings. In order to quantify the water quality impacts resulting from storm-water runoff from various land-uses Triangle J established six water quality monitoring stations and eleven water quality sampling stations. The monitoring stations continuously measure dissolved oxygen, water temperature, conductivity, and pH and are placed downstream from major population centers. The sampling stations are designed to take samples only during storm-water runoff events and measure biochemical oxygen demand, chemical oxygen demand, total organic carbon, total and suspended solids, and levels of nitrogen and phosphorus compounds. These sampling stations are located in such a manner that they measure storm-water quality from a specified land-use category in particular drainage areas. Land-use categories being monitored are: single family residential, multi-family residential, central business district, commercial, developed rural, and undeveloped rural. The remaining sampling stations sample large drainage areas with several land-use categories.

Water quality data from the monitoring and sampling stations are being used to develop pollution coefficients (Ref. 4) for particular land-use categories. Triangle J's approach requires a land-use and topographic map to delineate drainage areas throughout the region based on relatively homogeneous land-use. The pollution coefficients for the dominant land-use category along with other pertinent data (soils, slope, rainfall data, etc) is then used by the 'Storm-water Management Model' (Ref. 5) to estimate sediment and nutrient flow from the area.

The inventory of present land-use together with population projections was also required by Triangle J to form a basis for developing maps of anticipated land-use patterns. This analysis will use a 'Residential Allocation Model' (Ref. 6). By programming various constraints such as urban density, soil suitability, slope, and critical environmental areas, projected population will be allocated to undeveloped and developed areas in a series of alternative land use patterns. Anticipated storm-water runoff problems can be assessed for each drainage area and projected land-use category by applying the associated pollution coefficient. This analysis together with other detailed work with point sources will aid Triangle J in identifying critical areas where alternatives will have to be developed to minimize any deleterious impact on water quality. This may involve redirecting growth to other areas where the impact may not be as severe, or changing the character of the growth to minimize any harmful impact on water quality. The water quality plan will, in effect, contain a significant land-use planning element. The 208 water quality planning program will provide a rational basis for determining land use policy, especially as the policies may relate to water quality.

The land use inventory, as noted, is essential in the Triangle J 208 work plan. To accomplish the 208 effort Triangle J was faced with the requirement of having to inventory its relatively large study area, 1,750 square miles, within a short period of time; less than three months, with only a modest sum of money, under ten thousand dollars. Other 208 regions are most likely faced with this same dilemma.

The region had orthophoto 7.5 minute quadrangle maps prepared for the area in 1973 by the U.S. Geological Survey. The 208 area was included in parts of 40 to 50 of these quadrangles. The effort required to manually transform the land-use data from the quads into a uniform set of map overlays and into digitally coded tapes (for merging with other data) was determined to be too time consuming and expensive. For these reasons, Triangle J decided that the traditional techniques for land-use inventory - based on interpretation of aerial photographs or orthophoto quads and field inspections - were impractical on a regional level. To obtain the needed inventory Triangle J turned to LANDSAT data and computer assisted interpretation techniques.

TRIANGLE J 208 STUDY AREA

The Triangle J region is located in the eastern portion of the North Carolina Piedmont physiographic province. The designated 208 area is the central core of the region encompassing three counties (Orange, Durham, and Wake) and portions of two others (Chatham and Johnston) in the six-county region. The 208 area shown in the LANDSAT image of Figure 1 covers 1,750 square miles (over 1,120,000 acres). Three major population centers (Raleigh, Durham, and Chapel Hill) and fourteen other municipalities provide a variety of employment and residential opportunities within this area. The 208 area is within the watersheds of the Neuse and Cape Fear Rivers but because many of area's 5,000 miles of streams are headwater streams, water is not abundant and the small amount that is available is highly valued. Presently, there are only a few medium sized water supply reservoirs and numerous ponds. Two major reservoirs with a total surface area exceeding 74,000 acres are proposed for the area. Population in the 208 area increased 37% from 1950 to its 1970 level of 428,000. Conservative estimates indicate an anticipated population in the 208 area beyond 761,000 by the year 2000.

COMPUTER ASSISTED INTERPRETATION

To prepare for the LANDSAT data processing effort the 208 staff evaluated LANDSAT Band 5 images acquired October 25, 1973, February 10, 1974, February 14, 1975 in order to select the scene with least cloud cover, best resolution, and best coverage of the study area. These images were at a scale of 1:250,000 (1" = 3.9 miles). The selected image, that of October 25, 1973 shown in Figure 1, was ordered in the 9 track computer compatible tape (CCT) form. In addition to being the best scene, the date closely corresponded to that on the orthophoto 7.5 minute quadrangle maps acquired on the area in February 1973.

Bendix Data Center

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The first step in the development of the Triangle J land-use map was to locate and designate to the computer a number of LANDSAT picture elements or "pixels" that best typified each land-water category which was to be mapped, the "training areas." These areas of known characteristics were established by the Triangle J staff using the orthophoto quadrangle maps and their personal knowledge of the area. These training areas, about 16 hectares (40 acres) or more in size, were located on the LANDSAT CCTs by viewing the CCT data on the M-DAS TV monitor. The coordinates of the training areas were designated to the computer by placing a cursor over the desired area and assigning a training area designation, category code, color code and name. Several training areas, typically 20 to 50 pixels in size, were picked for each category, with each pixel corresponding to a ground coverage of 57 x 79 m. The color code was used in later playback of the tapes when the computer-categorized data are displayed in the designated colors.

Develop Processing Coefficients

The LANDSAT spectral measurements within the training area boundaries were edited by the computer from the CCT and processed to obtain a numerical descriptor (computer-processing coefficients) to represent the spectral characteristics of each land cover category. The descriptors (Ref. 8) included the mean signal and standard deviation for each of the four LANDSAT bands and the covariance matrix taken about the mean. The descriptors were then used to generate a set of processing coefficients for each category. In multivariate categorical processing (Ref. 8) the coefficients are used by the computer to form a linear combination of the LANDSAT measurements for each pixel. The variable produced has an amplitude which is associated with the probability that the unknown pixel measurements belong to each of the particular land cover categories sought. In categorical processing, the probability of a LANDSAT pixel arising from each one of the different land cover categories of interest is computed for each pixel and a decision, based on these computations, is reached. If all the probabilities are below a threshold level specified by the operator, the computer will decide that the category viewed is unknown, or "uncategorized".

Evaluate Selection of Training Areas and Processing Coefficients

Before producing categorized data for the entire 208 study area, a number of tests were applied to evaluate the computer's ability to perform the desired interpretation. The tests included generating categorization-accuracy tables and viewing the processed imagery on the M-DAS TV monitor. Selection of training areas, generation of accuracy tables, and evaluation of processing results through use of computer printouts and the TV monitor were iterative operations. The land cover categories listed below, approximately in order of their potential for discharging sediment and nutrients, resulted from the LANDSAT categorical processing.

- <u>Urban-High Density Developed</u> - Developed areas with high concentrations of impermeable surface and no vegetation, such as central business district and high density industrial, commercial, and residential areas.

- <u>Urban-Medium Density Developed</u> - Developed areas with medium concentrations of impermeable surface and limited vegetation includes low density commercial and low density single and multifamily residential areas.

- <u>Urban-Rural and Low Density Developed</u> - Developed areas with very low concentrations of impermeable cover and 30% to 40% vegetation, including single family residential and rural development.

- <u>Agricultural-Managed Lands</u> - Active cropland, tended pasture land, and managed areas with grass type cover such as golf courses and major highway interchanges.

- <u>Bare Soil-Construction Areas</u> - Areas with bare soil exposed such as plowed or working agricultural fields and areas undergoing construction. Would also include sand and gravel pits, bedrock quarries, and extractive sites.

- <u>Upland Hardwoods</u> - Forests dominated by oaks and hickories found in areas which have been relatively undisturbed for over 100 years.

- <u>Pine Forest</u> - Forests dominated by pine trees found in areas which have been cleared for use within the last 60 to 80 years.

- <u>Mixed Forest</u> - Forests with varying mixes of deciduous and evergreen trees in areas in successional transition from pine to hardwood.

- <u>Bottomland Hardwood</u> - Forests dominated by hardwoods including sycamore, birch, maple, and oak located in low-lying areas which are subject to periodic flooding.

- <u>Lakes and Ponds (Water)</u> - Various categories of depth and sediment concentration were combined.

- <u>Uncategorized</u> - Small areas which were not represented in the above ten categories. Less than 1.0% of the study area.

Generate Categorized LANDSAT Tapes

When satisfied with the categorization accuracy achieved on the land-water categories, the processing coefficients were placed into the computer disk file and used to process that portion of the LANDSAT CCTs covering the 208 study area. This step in the categorization processing resulted in new or 'categorized' CCTs, where each LANDSAT pixel was represented by a code designating one of the 11 land-water categories.

Geometric Processing

LANDSAT data in addition to categorical processing was submitted to geometrical processing in order to produce map overlays and coded taped data that were geometrically corrected and corresponded to a specified geographical area and scale. Geometrical processing included (1) establishing an earth to LANDSAT coordinate transformation, (2) developing a LANDSAT data file of a specified area, (3) rotating the orientation of the LANDSAT data to north-south, (4) removing the skew in the LANDSAT data due to earth's rotation, and (5) resampling the LANDSAT pixel to a desired cell size. Geometrical processing could have been accomplished before or after the categorical processing. For the Triangle J area the data was corrected after categorization.

The earth (latitude; longitude) to LANDSAT (pixel number) coordinate transformation was needed to locate the desired 208 area within the LANDSAT categorized CCT, and to establish the location and direction of the line used to scan the CCT data from west to east. The first step in developing the transformation was to digitize 25 carefully selected ground control points (GCPs) from the USGS 7.5 minute quad maps of the region. The GCPs were digitized using the Bendix Digitizer shown at the top of Figure 2. The criteria for selecting these GCPs was that they could be easily and accurately identified on the LANDSAT CCT data when viewed on the TV monitor. The second step consisted of converting the latitude and longitude of these GCPs to LANDSAT pixel coordinates by using a theoretical transformation derived from known and assumed spacecraft parameters including: heading, scan rate, altitude, and a knowledge of earth rotation parameters. The LANDSAT GCP coordinates and transformation matrices thus obtained were approximate, based on the use of the nominal spacecraft parameters. This transformation matrix was accurate enough to locate and display on the TV monitor the area containing the GCP. The exact GCP location was designated to the M-DAS computer by using a cursor. Once the operator had designated each of the GCPs on the M-DAS monitor an improved set of coefficients for the transformation matrix was computed. After an accurate LANDSAT to earth transformation matrix was obtained it was used to produce geometrical correct map overlays and coded tapes for the 208 study area. The error in transforming from earth coordinate to LANDSAT coordinates was found to be less than 1.0 pixel (rms).

Produce Categorized Map Overlays

The LANDSAT to earth transformation matrix and the categorized CCTs were used by M-DAS to drive a high speed Optronics film recorder (Type P-1500) to produce a geometrically corrected film negative for each of the 11 land cover categories. Inputs to the filming program included; transformation matrix, earth coordinates of corners of rectangle containing the 208 area, categorized LANDSAT tape, desired film scale, and filming aperture. A film scale of 1:576,000 (one sixth of the final map scale) was chosen with a film aperture of 50 x 50 microns. The M-DAS filming program located the categorized data on the study area and corrected it for earth rotation (skew) and scale to produce the desired film for each land-water category. The run time for this step was approximately 30 minutes per category (film). The negatives were photographically enlarged and printed as black and clear positives on mylar at a scale of 1:96,000. Examples of the transparent overlays over a portion of the Triangle J base map near Durham is shown in Figures 3, 4, and 5. On close observation a single LANDSAT pixel can be observed at this scale. The black and clear overlays were color coded by a Cromalin process to produce color Cromalin overlays, one per category, and to produce a color composite map of the study area. The color coding permitted multiple overlays to be used simultaneously over the Triangle J base map.

Produce Rescanned-Resampled Tape

Triangle J Council of Governments is tied into the Triangle Universities Computation Center and has the capacity to aggregate 50m x 50m land-use coded taped data into Statewide Planning and Land Use Management System (PLUM) grid cells (Ref. 9) for direct comparison with soils and slope data for the 208 area which are already coded on the basis of 4 hectare grid cells. Data aggregations are also possible on an area-wide, county, municipal, census tract, or watershed basis. To produce LANDSAT data that can be related directly to the PLUM cells the categorized tapes were submitted to a second stage of processing which produced a rescanned-resampled tape. A data file on this new tape was established for each of the 54-7.5 minute quads required to cover the 208 study area. Each quad file was identified on the tape by the quad name, an ID number, and the earth coordinates of its corners. The data in each file scanned the quad one line at a time from west to east (designated as a 'record') progressing a line at a time from the north to the south end of the quad. A data cell within the file covered a 50m x 50m square, had a north-south grid orientation, and was coded to designate one of the 11 land cover categories.

Inputs to the M-DAS rescanned-resampled tape program included the name and ID number for the quads, earth location of corners of quads, the earth to LANDSAT transformation matrix, and the categorized tape. The M-DAS program with help from the transformation matrix located the quads and established the location and direction of the line used to scan the categorized CCT data from west to east. When the categorization data was being scanned it was also resampled, using a nearest neighbor method, to produce the desired 50m x 50m grid cell.

The original categorized tape was transformed into the new land-cover map files at a rate of one 7.5 minute quad file every 2 minutes for a total run time of about 1.6 hrs.

FIELD VERIFICATION OF DATA

Field checks and close analysis of LANDSAT map and data products revealed the following:

1) Within an 80 acre site east of Raleigh which was under development in October, 1973, LANDSAT correctly identified areas; as Urban-High Density Developed where apartments and parking lots had been constructed, as Agriculture-Managed where construction had been completed and grass was planted, and as Bare Soil-Construction where land had been cleared for additional apartments.

2) At the North Carolina State University's Agricultural Research farm, two acres of Urban-Low Density Developed (three research buildings and lawn area) were correctly categorized from the surrounding cropland area of 150 acres.

3) Numerous farm ponds and construction sites with exposed soil were distinguished which were at the limits of LANDSAT resolution, 1.1 acres.

4) Distinctions between forest types were assessed to be particularly good for Upland Hardwood, Pine Forest, and Mixed Forest. Bottomland Hardwood, characteristically variable from site to site, was the least exclusive category, on occasions being classed as Mixed Forest and as Upland Hardwood. Checks on aerial photography of sites with known forest cover indicated that separations for the four forest types were extremely useful for the 208 applications.

5) Distinctions between levels of high, medium and low density urban development were particularly accurate when checked against aerial photography. Some areas of known low density, older residential development with thick tree cover were categorized as a forest type. Such areas however were easily recognized and corrected by staff members familiar with the region.

6) The amount of area uncategorized was very small. In the Chapel Hill 7 1/2' quad area only 1.5% of the total acreage was uncategorized. For the overall test area 1.0% or less was uncategorized.

7) The overall categorization accuracy was estimated by the Triangle J Staff to be better than 90%.

SUMMARY

The land-cover overlays and maps produced from LANDSAT are providing information on existing land-use and resources throughout the 208 study area. The overlays are being used to delineate drainage areas of a predominant land cover type. The information on cover type is also being combined with other pertinent data (soils, rainfall, topography, etc) to develop estimates of sediment and nutrients flows from the drainage area. The LANDSAT inventory of present land-cover together with population projects is providing a basis for developing maps of anticipated land-use patterns required to evaluate impact on water quality which may result from these patterns.

The overlays of forest types have been particularly useful for defining wildlife habitat and vegetational resources in the region. The extent and distribution of these forest types indicates the general availability of wildlife habitat, possible existence of rare and endangered species, and locations of unique or natural areas. A knowledge of the location and area covered by the four forest types is also a significant factor in planning potential control of storm-water run-off, which is significantly less from forested areas.

LANDSAT data and computer assisted interpretation was found to be a rapid cost-effective procedure for inventorying land-cover on a regional bais. The entire 208 inventory which include acquisition of ground truth, LANDSAT tapes, computer processing and production of overlays and coded tapes was completed within a period of 2 months at a cost of about 0.6 cents per acre, a significant improvement in time and cost over conventional photo interpretation and mapping techniques.

REFERENCES

1. US Environmental Protection Agency, Water Planning Division (Draft) "Guidelines for Areawide Waste Treatment Management," May 1974.

2. Moreau, David H., Field Level Planning for Areawide Waste Treatment Management", Department of City and Regional Planning, University of North Carolina, Chapel Hill, April 1975.

3. Triangle J Council of Governments, "Proposed Work Plan for Region J Areawide Waste Treatment Management Program," Research Triangle Park, North Carolina, May 1975.

4. US Environmental Protection Agency, Office of Air and Water Programs, EPA-430/9-73-014, "Methods for Identifying and Evaluating the Nature and Extent of Nonpoint Sources of Pollutants," October 1973.

5. Environmental Protection Agency, "Storm Water Management Model" Part of Water Pollution Control Research Series: Volumes I, II, III, IV, 1971.

6. Giblert, Gorman C., "Guidelines for Allocating Residential Growth in the Triangle J 208 Planning Region," Dept. of City and Regional Planning, University of North Carolina, Chapel Hill.

7. Rogers, R. H., "Environmental Monitoring from Spacecraft Date," Proceedings of LARS Symposium on Machine Processing of Remotely Sensed Data, IEEE Catalog No. 75 CH 1009-0-C, June 3-5, 1975.

8. Dye, R. H. and C. S. Chen, "Divergence Analysis of Bendix Feature Extraction and Classification System," Proceedings of LARS Symposium on Machine Processing of Remotely Sensed Data, IEEE Catalog No. 75 CH 1009-0-C, June 3-5, 1975.

9. Skinner, C. William, "Design Concepts for the North Carolina Planning and Land Use Management (PLUM) Information System," Office of State Planning, Department of Administration, North Carolina State University, July 1974.

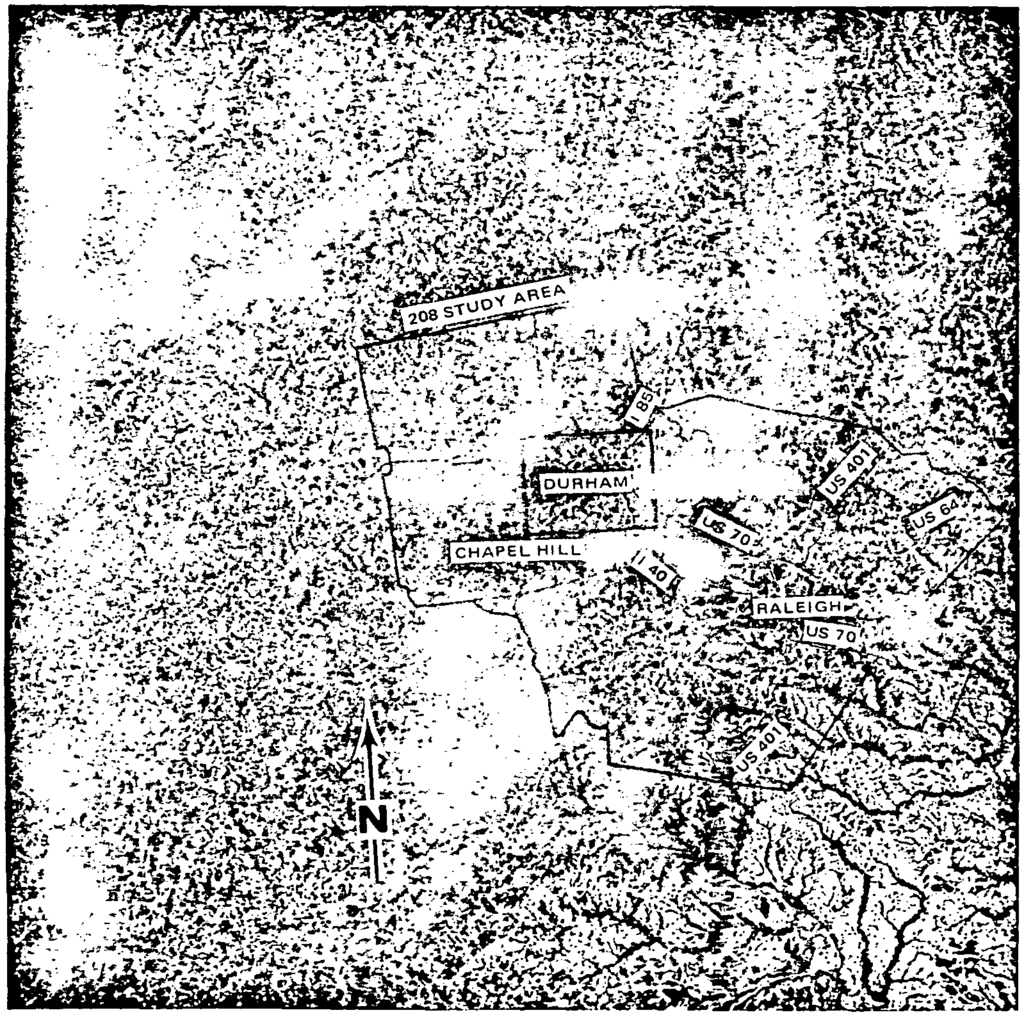
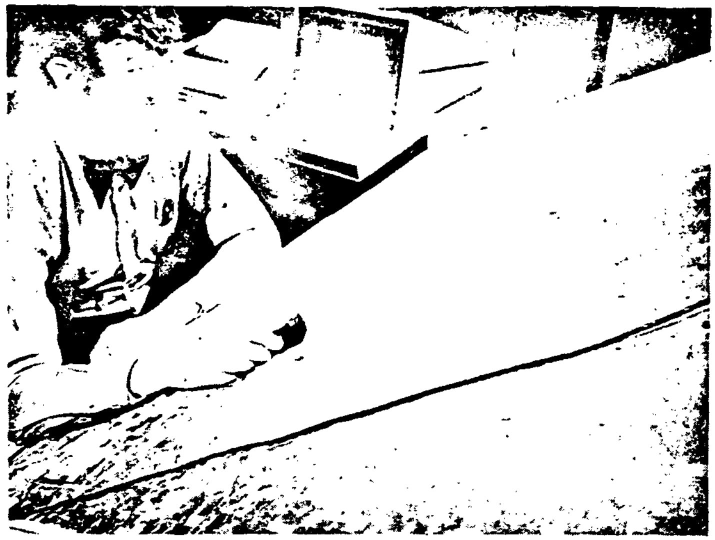


Figure 1. LANDSAT Band 5 Image (E-1459-15235) of 25 October 1973 Showing the 1,750 Square Mile Triangle J 208 Study Area. Small 8 by 10 mi Area Around Durham is Shown Processed in the Following Figures 3, 4, and 5.

Datagrid Digitizer



Multispectral-Data Analysis System (M-DAS)

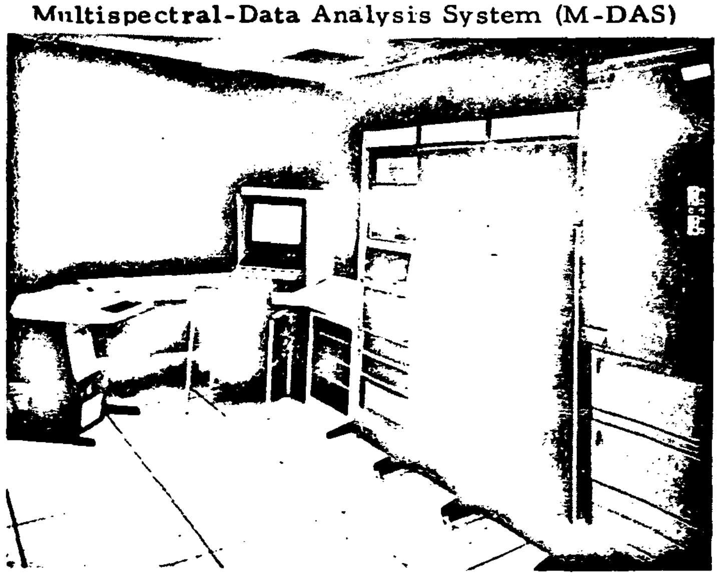
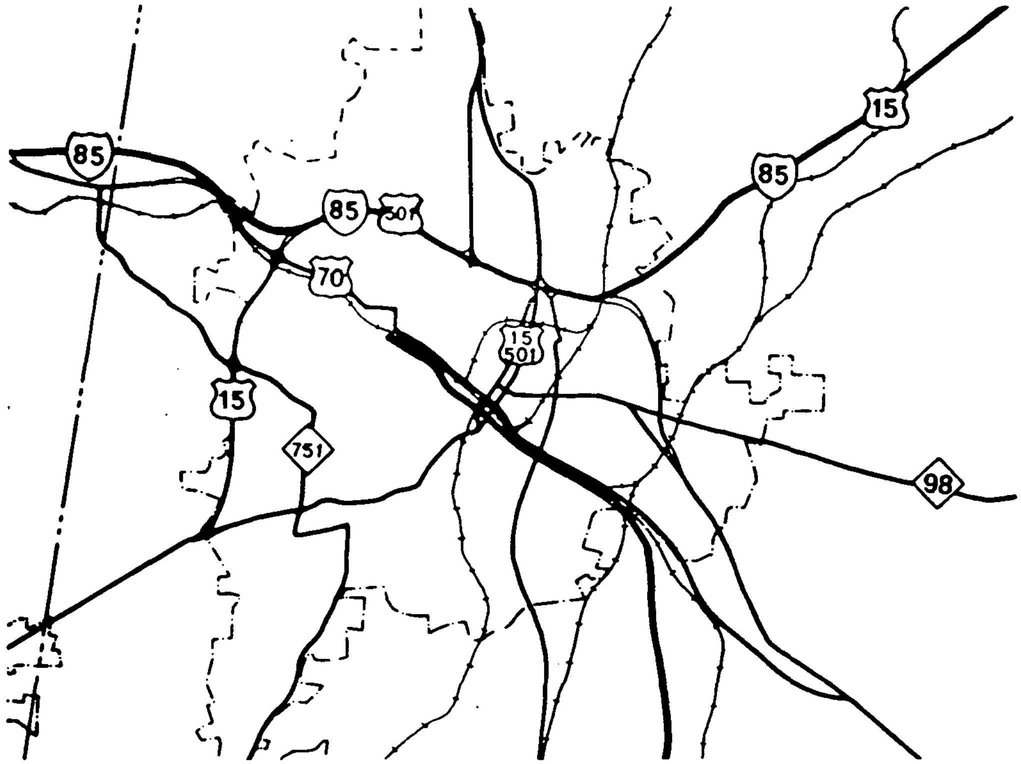


Figure 2. Computer Generation of Land-Use Maps from LANDSAT Data. The Datagrid is Used to Digitize Ground Control Points and Boundaries of Areas for Which Area Tables are Required. M-DAS Transforms the Datagrid and LANDSAT Computer Tapes into Area Tables, Categorized Map Overlays, Color-Categorized Imagery, and Rescanned-Resampled Tapes.

Base Map Original Scale 1:96,000



High Density Developed Category over Base Map. (Central Business District, Commercial, and High Density Residential)

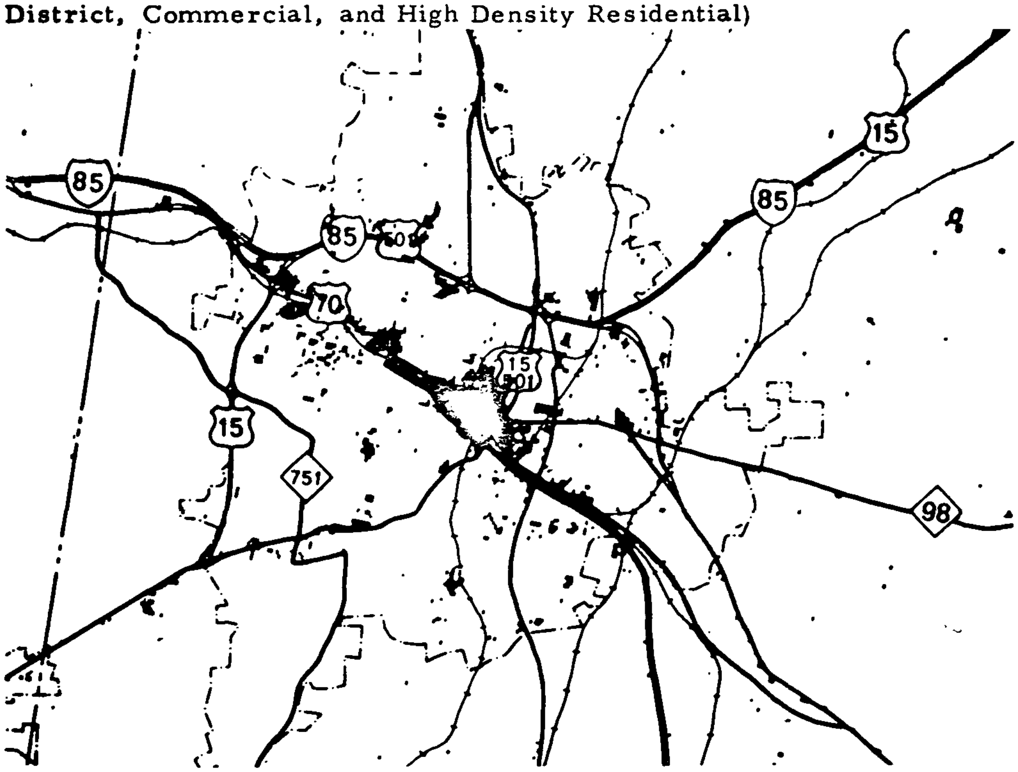


Figure 3. **Example of Urban Land Cover as Mapped from LANDSAT Categorized Tapes. View of 8 mi by 10 mi Area Centered on Durham N. C.**

Medium Density Developed Category Over Base Map(Less Dense Commercial and Residential Areas)

Low Density Developed Category Over Base Map(Single Family Residential and Developed Rural)

Figure 4. Additional Urban Land Cover Categories Mapped from LANDSAT Around Durham N. C.

Pine Forest

Upland Hardwoods (Oaks and Hickories)

Figure 5. Two of Four Forest Cover Categories Mapped From LANDSAT Around Durham N. C.