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Mapping Urbanized Area Expansion Through Digital Image Processing of Landsat and Conventional Data

Steven Z. Friedman

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FOREWORD

This research was carried out at JPL between January 1977 and November 1978 under the direction of Jerrold Christenson, Goddard Space Flight Center, and Jacob Silver, U.S. Bureau of the Census.

ACKNOWLEDGEMENTS

The author wishes to thank all individuals who have aided in the completion of this research. Albert Zobrist, the principal theoretician of IBIS, was most helpful in developing new programs. Jerrold Christenson of Goddard Space Flight Center supplied most Landsat imagery. Jim Davis of the Geography Division, U.S. Bureau of the Census, provided technical assistance and directed the task to meet Census Bureau needs. Len Gaydos of the Geography Program of the U.S.G.S. at Moffett Field provided Landsat imagery and a thematic classification of Seattle, Washington.

ABSTRACT

The Geography Division of the U.S. Bureau of the Census must determine the maximum potential extent of urbanized areas prior to conducting a Census of Population and Housing. Currently, the mapping task is cumbersome and time consuming, involving the manual integration of data obtained from many sources. As part of an ongoing research project for possible use in future censuses, new mapping approaches are being investigated by the Jet Propulsion Laboratory. The Geography Division has noted that several of the map products may be quite useful in future mapping exercises.

A new technology for indicating potential expansion of urbanized areas has been developed. Through implementation of the system, Landsat imagery and more conventional types of cartographic data have been integrated, and a data base has been produced from which various aspects of the urban environment can be represented. Thematic maps depicting areas of urban expansion have been derived for three major urban regions in the United States: Orlando, Seattle, and Boston. Tabular reports summarizing those themes have been produced as well.

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SECTION I

THE CENSUS-URBANIZED AREA PROJECT

A. INTRODUCTION

The primary focus of this report is the research conducted at NASA/JPL in support of the Census-Urbanized Area Project (Reference 1-1), part of NASA's Application System Verification and Transfer (ASVT) program. Basically, JPL was given the responsibility of developing an information system capable of integrating data derived from Landsat imagery with data currently available to the Bureau of the Census. Also, JPL had been developing image processing techniques that could be utilized to map the urban fringe from Landsat imagery.

Most image processing for this project was completed by implementing programs from the Video Image Communication and Retrieval (VICAR) Image Processing System (Reference 1-2). VICAR was developed in the early 1960s to support the imaging systems of JPL's unmanned planetary space program. Rather than a series of independent computer programs, VICAR is a fully-developed image processing system that includes a complete instruction set and a universal control card format.

The Image-Based Information System (IBIS), a subset of the VICAR program library, was used extensively for data processing. Through implementation of IBIS, Landsat data and conventional data were interfaced, and revised urbanized area maps were produced. In addition to revised urbanized area maps, statistical reports summarizing the results of the investigation were derived as well.

B. BACKGROUND

The U.S. Bureau of the Census has been mandated by the Federal Government to conduct a census of population and housing every five years beginning with the 1980 decennial census. As a consequence of this decision and associated legislation, the Census Bureau will have to process much more data during the next decade than in any previous decade. Furthermore, due to a steady increase in the population of the United States and a continued high mobility of the public, the enumeration process carried out by the Bureau of the Census will become more difficult. Accordingly, the Census Bureau is investigating means to revise existing practices to keep pace with the increasing demand for the collection and dissemination of data products.

One of the most complex and more cumbersome of the procedures undertaken by the Geography Division of the U.S. Bureau of the Census is the mapping of the urban fringe prior to conducting each census. A variety of data must be collected and integrated to obtain maps of fringe areas. Conventional data collection and integration practices have been found to be less than adequate for the derivation of urban fringe maps in a timely manner. Consequently, new technologies are being developed to avoid a potential backlog in obtaining map products.

In response to the needs of the Geography Division, the Census-Urbanized Area Project was initiated. The purpose of this Project has been to test the utility of Landsat data for the urban fringe mapping applications of the U.S. Bureau of the Census. Specifically, the problems addressed in this ASVT are two: First, can Landsat data and image processing technology be used to obtain accurate renditions of urban fringe areas? Second, if such information is derived, can it be interfaced with other materials available to the Census Bureau for decision making purposes? Other factors such as the cost of data processing, the speed of information retrieval, the quality of output products, and the accuracy of those products are being reviewed as well.

1. Data Processing Needs of the Bureau of the Census

Beginning with the 1980 decennial census, the Geography Division of the Bureau of the Census must revise the urbanized area (UA) boundaries of all Standard Metropolitan Statistical Areas (SMSA) in the U.S. every five years. While in 1970 there were 270 SMSAs, after the 1980 census it is expected that there may be as many as 300 SMSAs. Since these UA boundaries will be revised every five years, at least 600 UA maps will be constructed during the decade 1980-1989. To meet the needs of many Federal agencies that require knowledge of urbanized areas for decision making purposes, the Census Bureau will not be able to enjoy the luxury of processing UA maps on a weekly basis. If the mapping project is extended to cover the entire ten-year period, a minimum of 60 maps must be updated each year. Based on that average, more than one map must be processed each week.

a. Current Mapping Practices. Currently, urbanized area maps are compiled by integrating data obtained from a variety of sources. The updating process begins with a revised estimate of the extent of each urbanized area prior to conducting the census. The urbanized area boundary delimited as a result of the last census is integrated with information obtained from local and regional governments, aerial photographs, and population estimates and projections by the Census Bureau to define an updated UA boundary estimate. The region between the previous urbanized area boundary (inner line) and the current estimate boundary (outer line) is commonly referred to as the urban fringe zone (Figure 1-1). Prior to conducting each census, the urban fringe zone is subdivided into small geographic units or enumeration districts. After the census is conducted, statistics gathered for each enumeration district are analyzed, and decisions are made to determine if each enumeration district is urbanized. The decision is primarily based on population density. Finally, a new UA map is compiled by constructing a perimeter around the previous urbanized area and all newly-urbanized enumeration districts.

The most time-consuming part of UA revision is the demarcation of the urban fringe zone. Although the inner line is given, little is known about the position of the outer line. The process of combining the various data obtained from several sources is quite complex, and decisions are often subjectively based. Care must be taken not to omit any possible area from consideration. Consequently, the outer line of the urban fringe zone usually includes much rural land. If the outer line could be estimated more accurately, the subsequent census enumeration

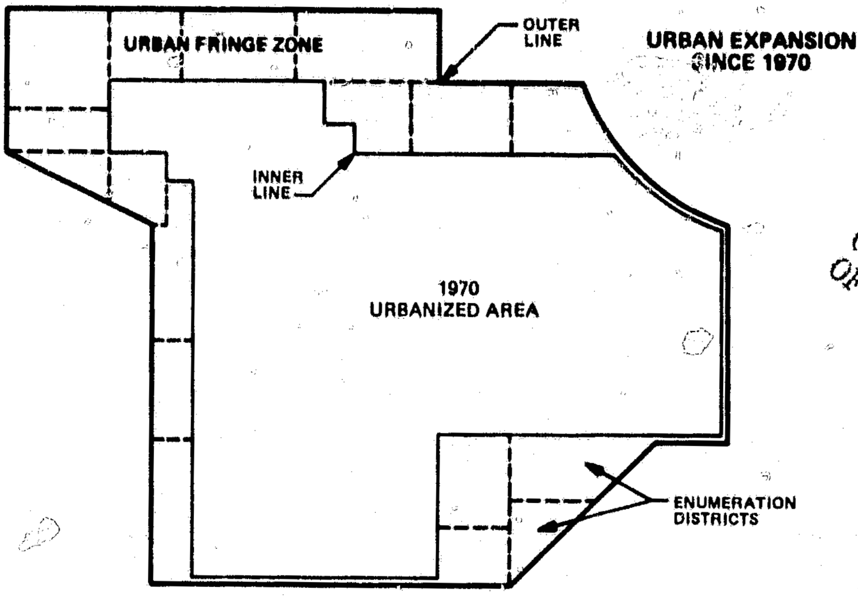

Figure 1-1. Dividing the Urban Fringe Into Enumeration Districts

process could be streamlined, and, as a result, the entire UA mapping project would become more manageable.

b. Automated Mapping Procedures. One purpose of the Census-Urbanized Area Project was to test the utility of Landsat imagery and image processing technology in obtaining more accurate renditions of the urban fringe zone. Not only was it envisioned that the fringe area could be delimited more accurately, it was believed that the entire process of estimating the urban fringe zone could be shortened with the implementation of computer technology. The use of an information system for interfacing remotely sensed data with other data available to the Geography Division of the Bureau of the Census was to be investigated.

In subsequent phases of the Project, remote sensing technology needed to derive urban fringe maps from Landsat data will be transferred to the Geography Division. An information system used to integrate the remotely sensed data and the conventional data also will be provided.

2. Principal Investigators

Three principal investigating teams were selected to conduct research in support of the Census-Urbanized Area Project: (1) the Earth Resources Branch of the Goddard Space Flight Center (NASA/GSFC) (References 1-3 and 1-4), (2) the Earth Resources Applications group at the Jet Propulsion Laboratory (NASA/JPL) (References 1-5, 1-6, and 1-7), and (3) the Image Processing and Analysis Center of the General Electric Company (GE) (References 1-8, 1-9, and 1-10). The primary responsibility of NASA/GSFC was coordination of the research efforts of the other two agencies. NASA/JPL was delegated the responsibility of developing a fully-automated information system capable of providing the products needed to update urbanized area maps for the Geography Division. GE developed procedures required to transfer technology to the Bureau of the Census. GE also created a base-line mapping approach to the problem.

The body of this report is divided into four sections. A description of IBIS is covered in Section II. The urban fringe mapping techniques developed at JPL are covered in Section III. Description of three mapping applications are included in Section IV. Finally significant conclusions drawn from the JPL effort will be summarized in Section V. A series of appendices that include a technical description of IBIS, output products, and program timings are also included in this report.

SECTION II

THE IMAGE-BASED INFORMATION SYSTEM: AN OVERVIEW

The Image-Based Information System[1] (IBIS) is a computer-based approach to the analysis of geographical situations. By grouping selected IBIS programs into processing operations, a variety of spatial phenomena can be investigated. The basic concepts of data management and data processing within the Image-Based Information System are covered in this section.

IBIS is considered to be a raster-based information system (References 2-1, 2-2, 2-3). Most data entered into IBIS are in raster (image-based) format. However, the system is configured in such a manner that other data types, such as graphical and tabular data, may be used in analysis as well.

Logical and mathematical interfaces have been provided to link all data files in an IBIS data-base superstructure (Figure 2-1). By utilizing these interfaces, information may be derived from simple associations of, or comparisons between, two or more data files stored in an IBIS data base. More complex procedures including polygon overlay and cross-tabulation can also be investigated through IBIS technology.

A. DATA MANAGEMENT CONSIDERATIONS

The image-formatted data plane is the primary data type utilized in IBIS processing. IBIS data planes may be obtained directly in image form, as in Landsat imagery, or they may be derived from data compiled by sources such as the U.S. Geological Survey, the U.S. Bureau of the Census, and the Defense Mapping Agency.

Regardless of data type and origin, all data planes are incorporated into a data set that is referred to as the IBIS data base (Figure 2-2). When investigating a specific problem, a data plane may be included in, excluded from, or modified before any IBIS processing step. New data planes may be constructed with the system and may be used in subsequent processing steps.

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[1]The Image-Based Information System was designed by N. A. Bryant and A. L. Zobrist of the Image Processing Laboratory at JPL. The description of IBIS included in this section is quite general. A technical description of the system is included in Appendix A.

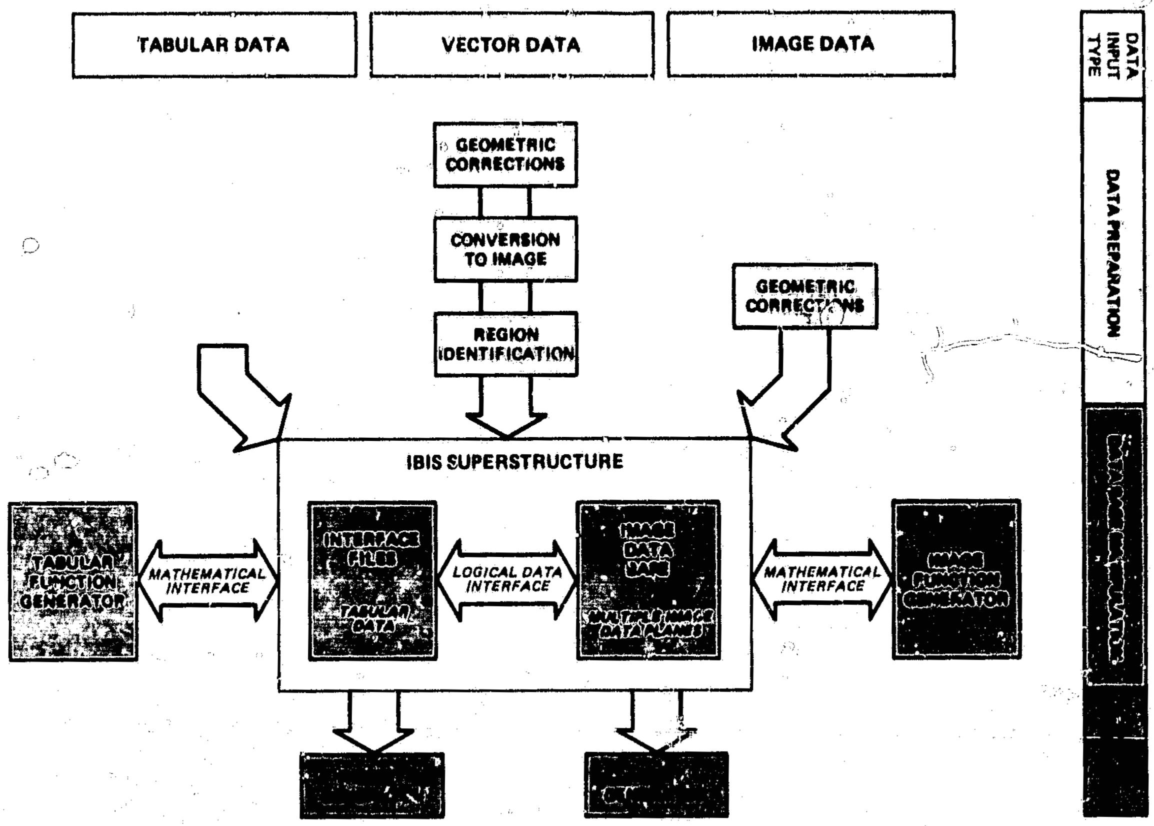


Figure 2-1. A Configuration Diagram of the Image-Based Information System

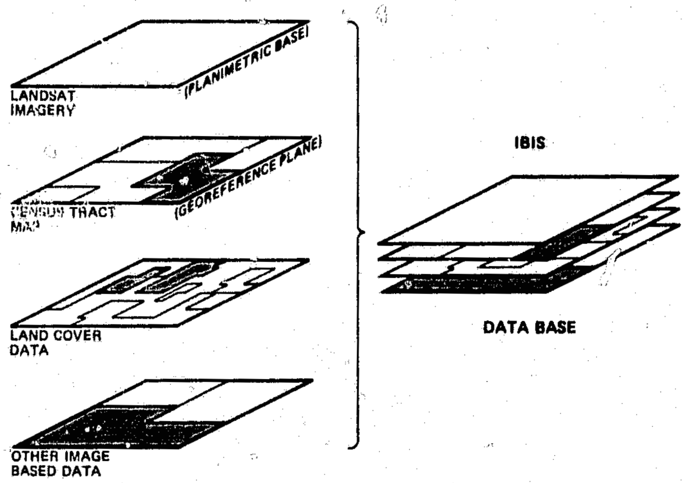


Figure 2-2. Formation of an IBIS Data Base

To maintain geometric consistency between all data planes included in the data base, an image plane exhibiting good radiometric or planimetric qualities is designated the planimetric base. Digitized topographic maps are excellent for this purpose, having been constructed from precise point datum and calibration. All other data planes are geometrically corrected to register with the planimetric base.

1. Modes of Data Input

The user of IBIS can integrate various data types to form an IBIS data base. Since the primary data structure is a raster format, image data planes are directly entered into the system. Graphical forms of data, usually obtained in Cartesian reference form, must be transformed into image space prior to inclusion as a data plane. Tabular data are not transformed into image space, but are linked to the image data base through a logical interface. Data processing requirements for each data type are unique and will be covered individually.

a. Image Data. Most image data sets entered into the data base are usually derived from Landsat imagery or other multispectral scanner sources. Other data are digitally encoded or scanned from aerial photographic products. Since image data planes are obtained from many sources, the spatial alignment of features contained in those images are often inconsistent from image to image. Consequently, provisions have been made to obtain a unified spatial surface through the implementation of resampling and spatial rectification procedures.

Geometric correction procedures and spatial rectification routines for modifying image data are features of the VICAR image processing system. Although not specifically considered to be IBIS programs, these and other VICAR programs are necessary parts of the IBIS process. VICAR software is often used to obtain special information from image data sources. Multispectral classification of Landsat imagery is one example of a VICAR procedure that produces a data set used in IBIS procedures.

b. Graphical Data. Graphical or vector data may also be entered into the IBIS data base. Graphical data are either produced locally on a coordinate digitizer, or are obtained from data tape. The Bureau of Census Urban Atlas file and DIME file are examples of data obtained on computer tapes. Regardless of data origin, graphical data are transformed into image space prior to inclusion in the IBIS data base.

As with image data, graphical data files must be in registry with the primary data base. Provisions have been made within IBIS to achieve the proper spatial alignment. (These corrections are made before the data are transformed into image space.) The registration technique utilized is a two-step process. Initially, a general surface fit is achieved through the use of a least-squares affine transformation, then an exact geometric correspondence is obtained by implementing a spatial rectification procedure. The deformation of the original surface is controlled by the selection of tie points linking geographical features that are identifiable on both the graphical data file and the primary data base.

Point and vector data are transformed into image space after geometric modifications are completed. Three-dimensional or z-value data (x, y, z) are processed in a similar manner. The Cartesian reference components of the data (x, y) are transformed into image space coordinate values, while the z-value remains unchanged.

c. <u>Tabular Data.</u> Tabular data may be entered into IBIS via computer cards or digital tape. These data are stored in a tabular file that is linked to the data base through a logical interface. As a result of this link, such data files are termed <u>interface files</u>.

2. The Georeference Plane

One of the more important graphical data files entered onto the IBIS data base is the <u>georeference plane</u>. The georeference plane is a polygon file used in data aggregation and map generation procedures. In one case (the Census-Urbanized Area Project), the georeference plane has been constructed from census tract data obtained from the Urban Atlas files of the U.S. Bureau of the Census.

Once the georeference plane is transformed into image space, each polygon, or region, must be identified. The region identification process involves the assignment of a unique value (or gray tone) to each individual region. After region identification, the georeference plane may be used in several higher-order IBIS procedures. For example, a polygon overlay of the georeference plane with some other image data plane can be initiated (Figure 2-3), or the gray values of each polygon in the georeference base may be modified to produce a map depicting the results of a modeling application with data stored in an interface file.

Several georeference planes may be included in an IBIS data base. For example, a data base may contain a census tract georeference plane and a congressional district georeference plane. The maximum number of regions that can be included in one georeference plane is virtually unlimited. Currently, up to 20,000 regions can be identified by gray value for an individual georeference plane.

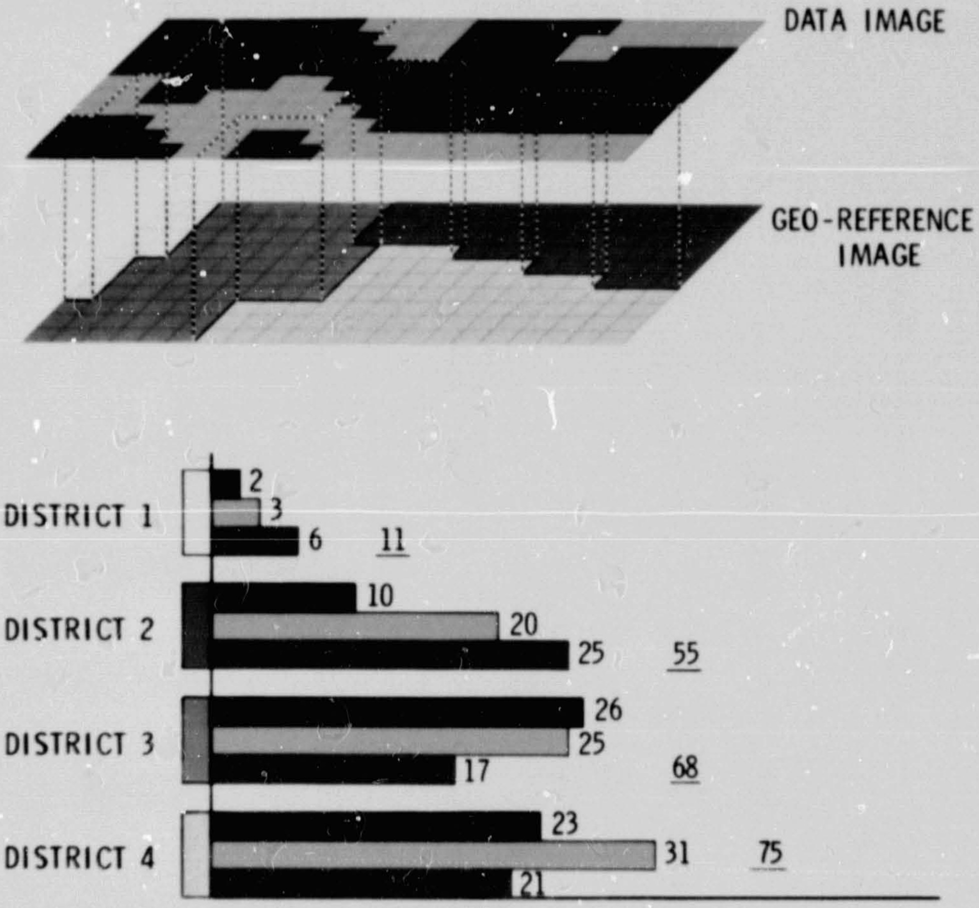
3. The Data Interface and Tabular Files

All tabular files (interface files) are linked to at least one of the georeference planes included in the IBIS data base. The specific link is obtained by storing the numerical value (gray tone) representing each region of the georeference plane with tabular data describing attributes of that region (Figure 2-4). Attribute data may be statistical in origin, an identification code, or may be the result of an image plane comparison routine such as polygon overlay or cross-tabulation.

B. MANIPULATING DATA AND OUTPUT PRODUCTS

If IBIS, or any other information system, were only a device to collect and store geographic data, the utility of the system would be quite limited. Most users of an information system require far more powerful features. Several means of data output, both pictorial and tabular, are needed. Also, the researcher may want to undertake complex modeling applications with the data files stored in the information system superstructure.

CONCEPTUAL FRAMEWORK OF IBIS INTERFACE FILE GENERATION



	TOTAL AREA	BLUE AREA	YELLOW AREA	RED AREA
DISTRICT 1	11	2	3	6
DISTRICT 2	55	10	20	25
DISTRICT 3	68	26	25	17
DISTRICT 4	75	23	31	21

Figure 2-3. The IBIS Polygon Overlay Procedure

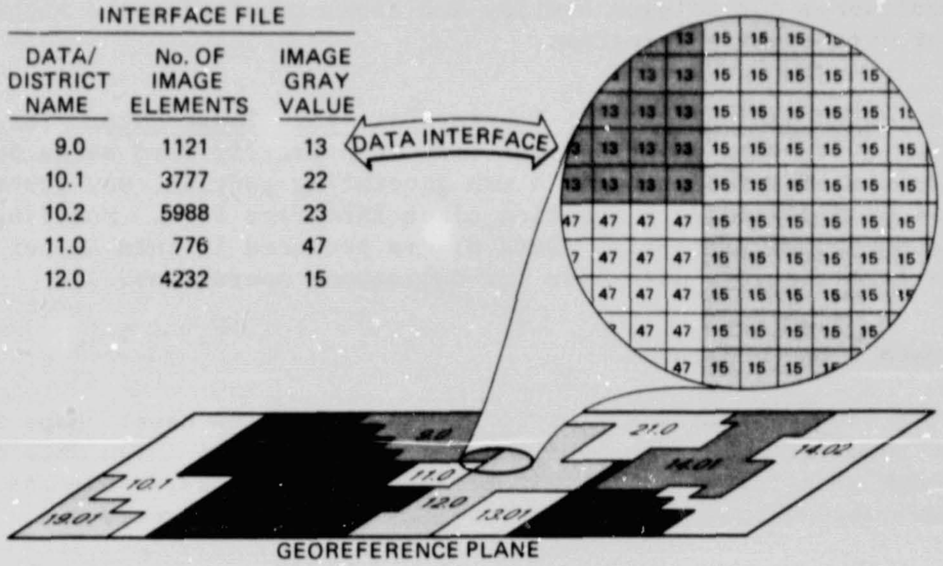


Figure 2-4. The Date Interface

Procedures for data output and data manipulation have been derived as part of the Image-Based Information System. Maps may be generated and tabular reports can be obtained.

1. Data Manipulation Procedures

Data stored in either the data base or an interface file can be modified or manipulated with IBIS software. New data planes and interface files are easily generated. Four basic data-manipulation procedures are currently available.

a. Data Manipulation Between Image Planes. New image data planes are generated as a function of two or more image data planes. Chiefly, the procedures implemented to derive such data planes are VICAR routines, although some IBIS routines are also used.

Simple transformations such as image addition, subtraction, multiplication, and division are easily obtained. Complex functions are handled nearly as easily, and precise mathematical formulas may be specified. Image enhancement routines are available, as are several data classification and stratification routines.

b. Data Manipulation Within the Interface File. Most functions available in the image domain are also available for analysis of tabular data. Resultant from such operations, new tabular data entries are generated. Complex mathematical functions may be used to derive higher-order properties of data stored in an interface file.

c. Data Manipulation of Image Data into Tabular Data. By implementing certain IBIS routines, data originally stored in image format may be summarized and copied into a tabular file. The majority of these routines are aggregation functions, an example of which is histogramming.

IBIS procedures for polygon overlay and cross-tabulation are within this realm of data transfer programs.

d. Data Manipulation of Tabular Data into Image Data. The representation of tabular data in image form is primarily used as an output aid. By the implementation of a map generating routine, any georeference base can be modified as a function of an interface file. Modeling of data is performed similarly. Data planes produced in this manner can be entered into the IBIS data base for subsequent operations.

2. Data Output Features

Two output formats are available to the system user: maps and tabular reports. Maps are produced directly from any image data plane or through modification of a georeference plane. Tabular reports are made available through the operation of a report generator.

C. SUMMARY

With a knowledge of image processing, an analyst can learn to operate the IBIS system. A researcher can utilize the system to store several data planes and much tabular data. With all of the information at the data user's disposal, many complex modeling problems may be solved relatively effortlessly.

The various modes of data entry, data manipulation, and data output provide the researcher with complete flexibility to structure a unique data base specifically designed for a particular problem or investigation. IBIS is merely a framework for analysis of spatial data. The actual information system is constructed with the selection of specific image and tabular data.

SECTION III

URBANIZED AREA MAPPING TECHNIQUES

The Geography Division of the U.S. Bureau of the Census must frequently update urbanized area maps of all SMSAs in the United States. In response to a demand for more-current versions of these maps, the utility of new data sources and new technologies are being considered as a means to expedite the mapping process. One avenue of experimentation being investigated is the mapping of urbanized areas from Landsat imagery.

A. A BASE FOR AUTOMATED MAPPING

Landsat is an ideal data source for the production and revision of small-scale maps depicting large urban regions. The areal coverage afforded by a single satellite image is quite extensive, and most urban regions are contained in a single frame. New imagery is made available on a regular basis. Consequently, map revision may be undertaken more frequently. Since imagery is available in series, maps depicting higher-order features of the urban environment, such as urban expansion, can be derived as well.

1. Data Analysis

To obtain urbanized area maps, a Landsat image must be analyzed and pertinent information must be extracted from the abundance of data contained in the satellite base. Analysis can be undertaken by visual techniques (much like visual interpretation of aerial photographs), or with the aid of digital image processing. Visual analysis of Landsat imagery is an involved and time-consuming process that often requires the making of subjective decisions. For those reasons, visual analysis may at best provide an interim option for the Bureau of the Census. Conversely, digital image processing of Landsat imagery can provide similar information in a timely and objective manner. Once a specific technique has been developed, any SMSA can be mapped if satellite coverage is available. Since a standardized sequence of processing steps is being utilized, the analyst can be certain that the mapping of any SMSA will be a completely controlled process.

2. A Methodology for Mapping the Urban Environment

The Jet Propulsion Laboratory is investigating methods for the detection and mapping of urban land cover from Landsat multispectral scanner (MSS) imagery. Through digital processing of Landsat data with the VICAR system, several land cover maps have been produced. Many of these maps are eventually used as image data planes in an IBIS data base, such as the IBIS modeling applications developed for this Project.

Covered in this section is a description of a technique that has been developed to transform Landsat data into urban land cover maps. The mapping technique is referred to as a <u>binary processor</u>. A simplified exp[illegible] of the binary processor is included in this section. More de[illegible] descriptions can be found in another report (Reference 3-1).

3. The Study Area

As a means to further an understanding of the basic steps in the implementation of the binary processor, a mapping example has been included in this section: Landsat imagery covering the Orlando SMSA has been selected, and land cover maps have been produced. The Bureau of the Census indicated that the Orlando region experienced a marked increase in population since 1970. It was hoped that the expansion of the urbanized area could be detected by this mapping technique.

Two Landsat frames covering the Orlando SMSA were selected for analysis: (1) April 28, 1973 (1279-15285), and (2) April 18, 1975 (1999-15091). Anniversary dates were selected to minimize any spectral variances that could be attributed to seasonal factors.

B. PREPARATION OF LANDSAT DATA

Several processing steps must be completed before urban land cover information is extracted from Landsat imagery. Initially, the imagery is obtained in the standard EROS data format (References 3-2 and 3-3). The imagery is reformatted to be compatible with VICAR system guidelines. The Landsat frame is modified to correspond to either a sinusoidal projection or a "space oblique" Mercator projection (Reference 3-4).

Following reformatting, the region containing the study area is extracted (Figure 3-1). At the analyst's discretion, cosmetic procedures such as destriping and bad-line removal are performed.

1. Planimetric Modifications

Several Landsat images are processed to obtain maps depicting changes in land cover or other dynamic aspects of the urban environment. To facilitate comparisons between maps or images, a planimetric data base is selected for the purpose of registering these data planes. A planimetric base may be a topographic map, a UTM grid, or any other geographic expression of the Earth's surface. Often, a Landsat image can be selected as the planimetric base when the study area is of a limited size, and precise radiometric accuracies are not critical.

The Landsat images are registered with the planimetric base through the implementation of a surface-fitting algorithm. Tie points selected to define the deformational characteristics of the surface are found with the aid of an interactive duoimage pattern recognition and comparison routine. An equation of transformation is derived, and the image is spatially rectified to coincide with the planimetric base.

Figure 3-1. A Landsat Image Covering the Orlando SMSA

2. Information Enhancements

After all needed imagery is registered to the planimetric base, the next phase of data preparation is begun. The raw satellite data is transformed into a more usable data plane (Figure 3-2) through the implementation of an information-enhancement routine. Simply, the process of information enhancement yields an image that contains more usable information for the analyst. Ratio (Reference 3-5) and eigenvector (principal components) (Reference 3-6) transformations are routines commonly used for information enhancement.

In the case of the Census-Urbanized Area Project, information-enhancement routines were implemented to enable easier distinction between urban and nonurban land cover. In another research project, it was found that ratio-transformed images were especially useful in the mapping of land cover from Landsat imagery for areas of Los Angeles, California, and Madison, Wisconsin (Reference 3-1). A similar technique (Reference 3-7) was used to investigate land-use change around Atlanta, Georgia. Later investigations into eigenvector processing have also proven quite promising for improving data quality.

One consequence of the utilization of information-enhancement routines was the reduction in the number of data planes needed for mapping the urban landscape. When as many as four raw-data planes were required for classification of land cover with conventional operations, only one data plane was required to achieve the same classification after an information-enhancement routine had been implemented. With a

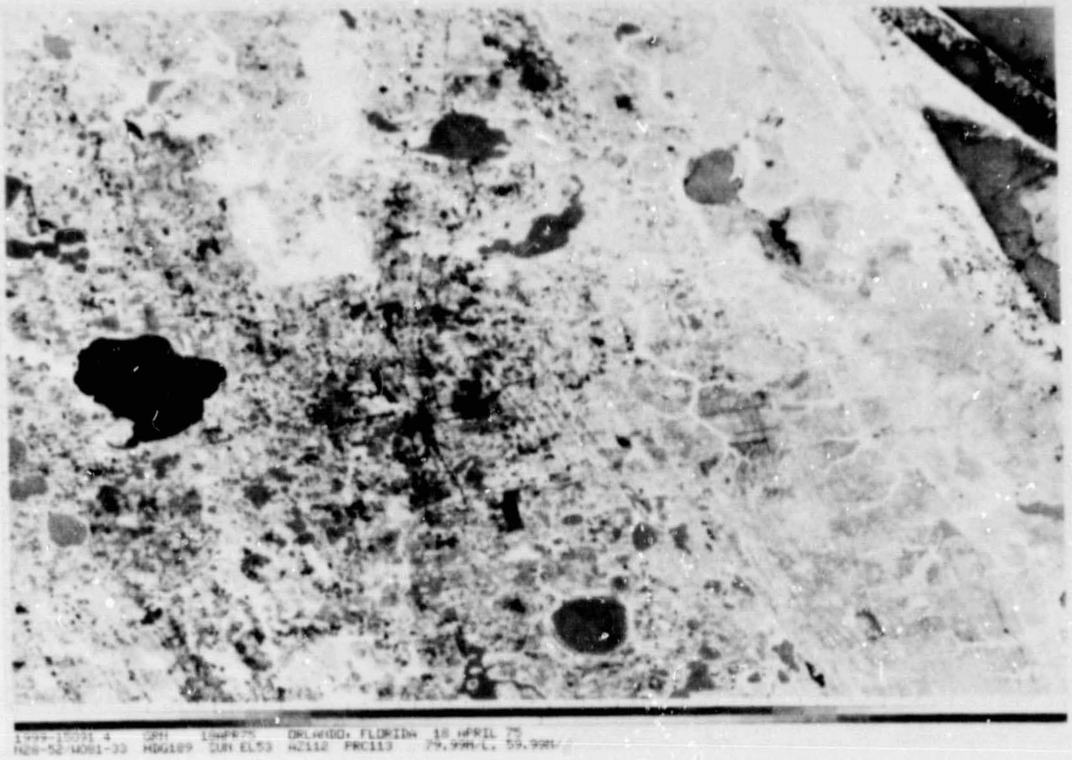


Figure 3-2. The Second Data Vector of an Eigenvector Transformation Implemented to Enhance Information Content

reduction in the number of data planes needed for classification, a complex Bayesian or maximum-likelihood classifier was no longer needed. A simpler and much faster classifier could be utilized to derive similar results.

C. THE BINARY PROCESSOR

The Geography Division of the U.S. Bureau of the Census is primarily concerned with distinguishing urban from nonurban land cover. To obtain such information, the classification of Landsat imagery was based on a binary decision: Is the land urban or nonurban? A simple binary decision processor was implemented to obtain the desired maps.

1. Theoretical Considerations

Binary classification of land cover is based on analysis of a histogram sampled from a Landsat image covering a study area. Simply, a histogram is considered to be a spectral signature characterizing the spectral attributes of all features contained in the satellite image. Given that the implementation of an information processing algorithm has actually facilitated the distinction between urban and nonurban land cover, a histogram sampled from that image should also indicate the distinction. More specifically, the histogram consists of two predominant spectral signatures representing urban and nonurban land cover. Furthermore, the histogram should tend to be a bimodal distribution (Figure 3-3).

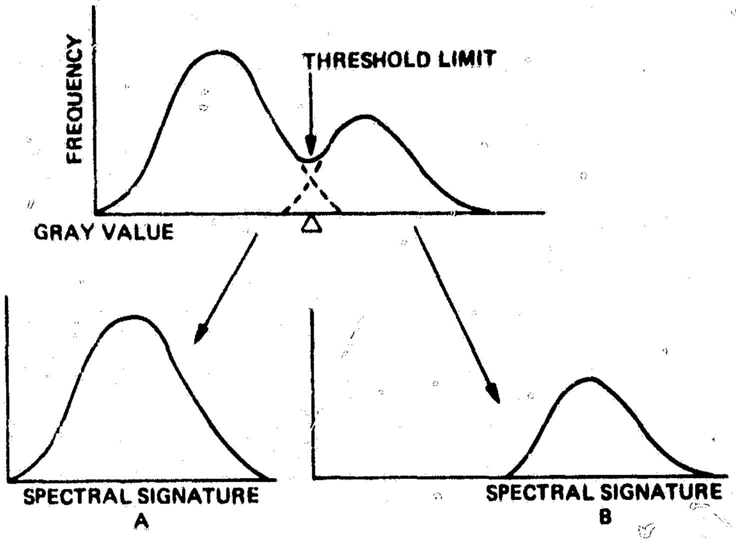


Figure 3-3. Two Spectral Signatures Derived From a Bimodal Distribution Sampled From a Landsat Image

a. Threshold Analysis. Through closer inspection of the histogram, an intersection between the two spectral signatures can be found. The point of intersection is referred to as the threshold limit of the distribution. The threshold limit separates the distribution into two distinct ranges of data. Each range corresponds to the unique spectral signature of urban or nonurban land cover.

b. Classification. After determining the threshold limit, the Landsat image that has been the source of data sampling can be classified. As with the histogram, the data contained in the Landsat image are divided into two ranges. Data in one range correspond to urban land cover. When each range of data is symbolized, a two-class land cover map (Figure 3-4) is produced.

2. Application of the Binary Processor

Two mapping exercises were completed by processing imagery covering the Orlando area. Each exercise was based on the implementation of the binary processor. The primary difference between the two exercises was that a different information enhancement routine was utilized in the course of completing each map.

a. An Application Based on a Ratio Transformation, Application 1. Previous research indicated that effective land cover maps could be derived from ratio-transformed data. Consequently, such imagery was utilized in the first mapping application. Usually, the ratio transformation used in analysis is formed when the red data band (MSS 5) is divided by the first infrared data band (MSS 6) of the Landsat MSS. However, in the Orlando case study, the data were useless due to severe striping of MSS band 6. Instead, MSS band 7, the other infrared data band, was utilized in the ratio transformation.

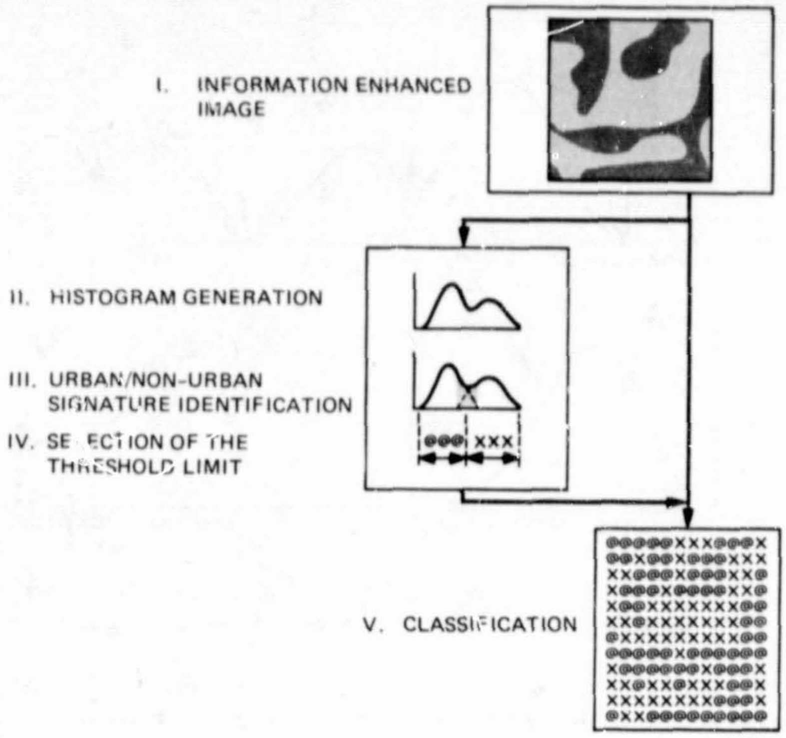


Figure 3-4. Diagrammatic Depiction of the Binary Processor

A histogram (Figure 3-5) was generated by sampling a portion of the transformed image. Through visual analysis of the histogram, two distinct spectral signatures representing nonurban and urban land cover were identified. A threshold limit was determined, dividing the distribution into two data ranges. In previous research (Reference 3-1) it had been determined that the urban spectral signature (characterized by light materials such as concrete) was confined to the upper spectral range, and nonurban to the lower range (where dark-colored materials were predominant).

Based on the analysis of the histogram, the ratio-transformed image was divided into two ranges of data. Each range was symbolized to derive an urban land cover distribution map (Figure 3-6).

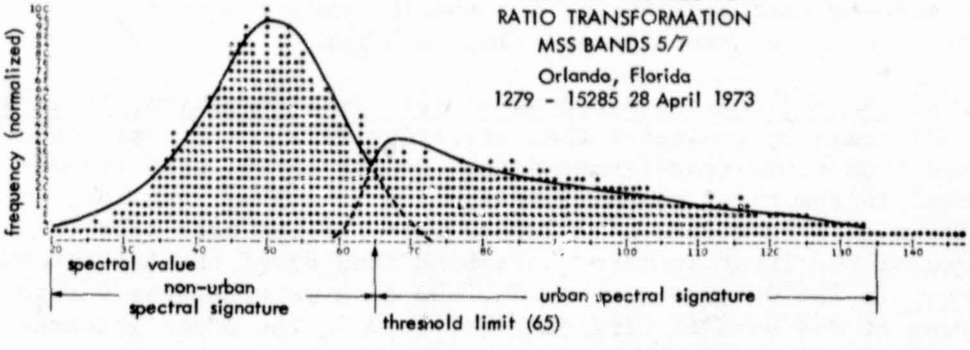


Figure 3-5. A Histogram Used in the Analysis of the Ratio Transformation: MSS Bands 5/7

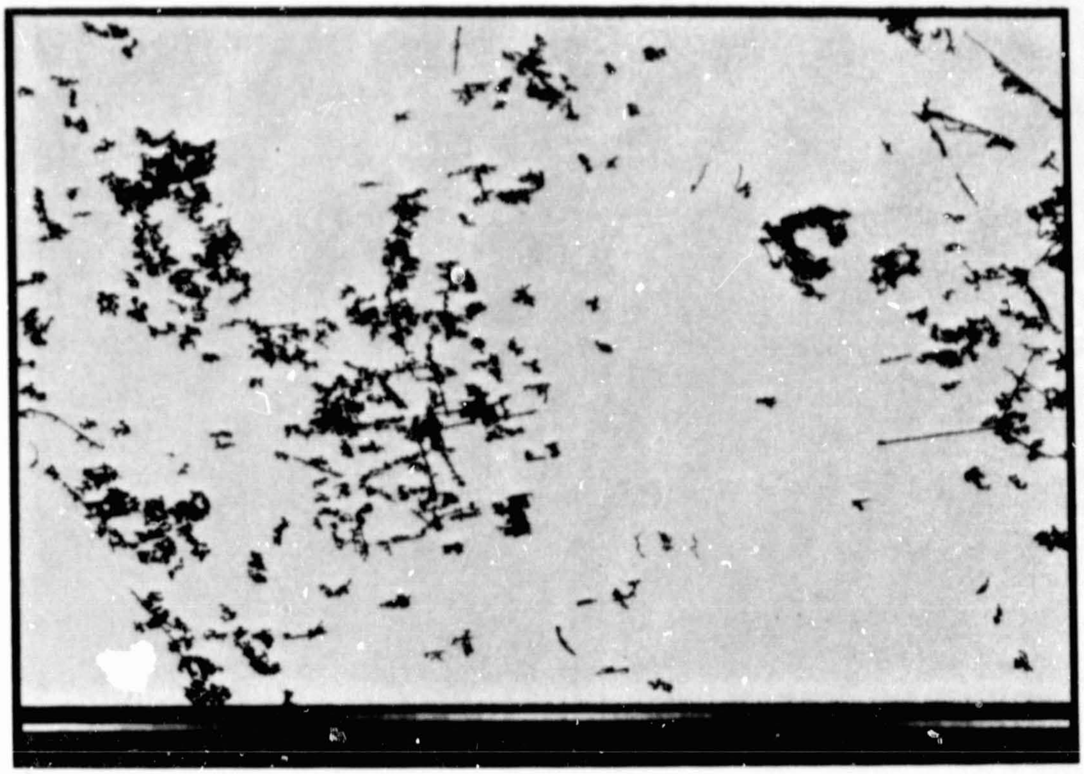


Figure 3-6. The Binary Classification of the Ratio Transformation. Features Depicted in Black are Urban

The distinction between urban and nonurban land cover was not particularly effective[2]. Although major urban regions were identified, a significant amount of nonurban land was also erroneously included in the urban class. Consequently, classification based on the ratio transformation was not useful in this application.

b. <u>An Application Based on Eigenvector Data, Application 2</u>. A second attempt to map the distribution of urban land cover around Orlando was initiated. In the second application, the raw data were transformed by the implementation of an eigenvector algorithm. Of the four data vectors derived, data vectors 1 and 2 (Figure 3-7) were used in the classification of land cover.

In the previous mapping exercise, one iteration of the binary processor was utilized to obtain a land cover map. However, two iterations were required when eigenvector data were utilized. One iteration of the binary processor was implemented to remove any conflicts between the spectral signatures of urban land and water.

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[2] A major cause of the misclassification has been attributed to signal attenuation caused by water saturated soils. The signal attenuated tends to modify the nonurban spectral signature in such a manner as to resemble urban spectral signatures.

Figure 3-7. The Second Data Vector of an Eigenvector Transformation

Histograms (Figure 3-8) were sampled from eigenvectors 1 and 2. The distribution of eigenvector 1 was used to separate land from water, and a map depicting those features was produced. The water features mapped from vector 1 were subtracted from the second eigenvector image, removing any conflicts between the spectral signatures of water and urban land. Then a histogram was sampled from the second data vector, and a map depicting the distribution of urban land cover was produced in the usual manner.

Since the Geography Division was interested in sequential mapping for updating purposes, two Landsat images (1973 and 1975) were classified (Figures 3-9 and 3-10). Because the raw-data images were registered to the planimetric base, all resultant maps were registered to the base as well. Consequently, maps depicting changes in the distribution of urban land cover could be easily obtained. Urban expansion between 1973 and 1975 has been documented in this manner (Figure 3-11).

D. SUMMARY

The procedures utilized for the preparation and classification of Landsat imagery to obtain land cover maps have been covered in this section. As a result of the analysis, a map depicting the distribution of urban land in 1975 (see Figure 3-10) has been produced. That image has been utilized as an image data plane in the IBIS mapping application covered in the next section of the report.

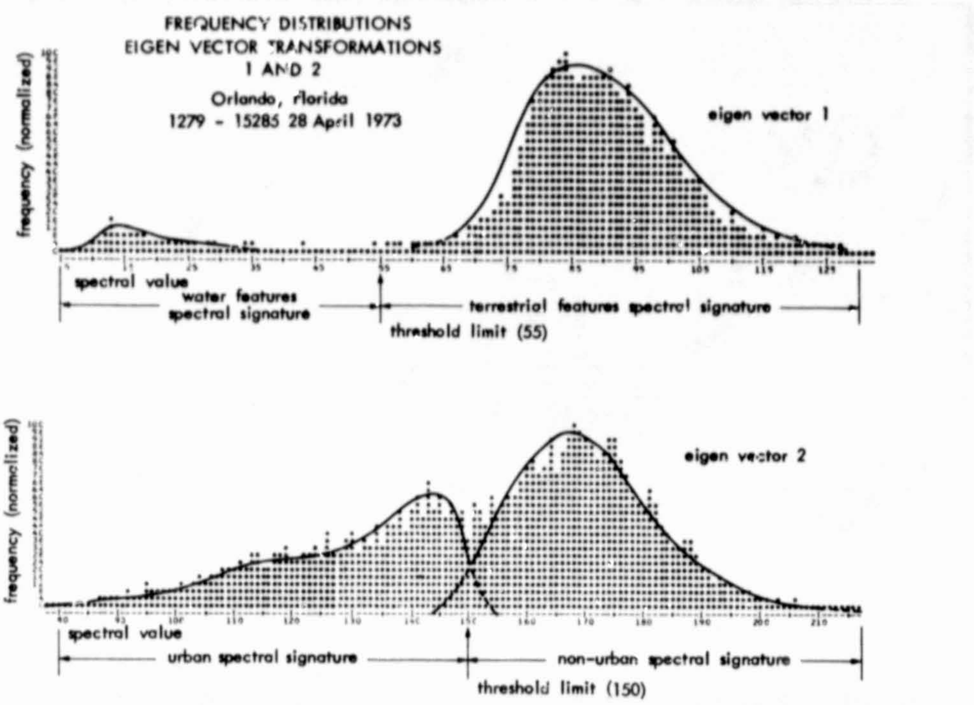

Figure 3-8. Two Histograms Used in the Analysis of Eigenvector Images

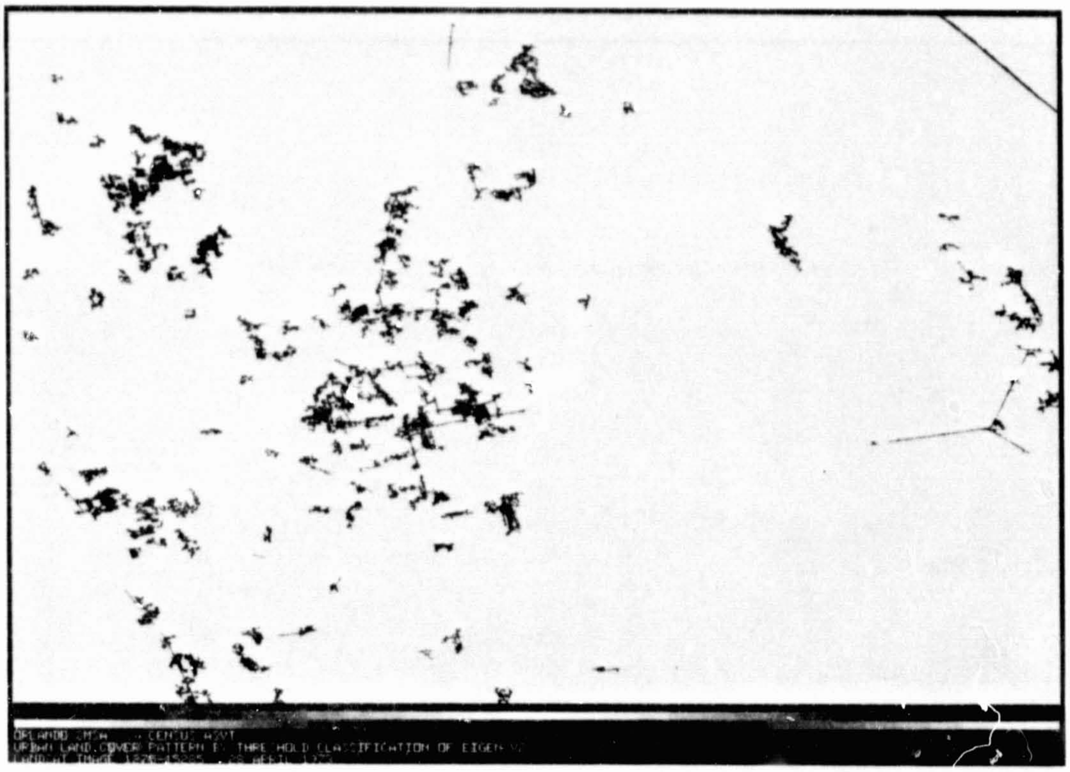

Figure 3-9. The Binary Classification of the Second Data Vector of the Eigenvector Transformation, 1973

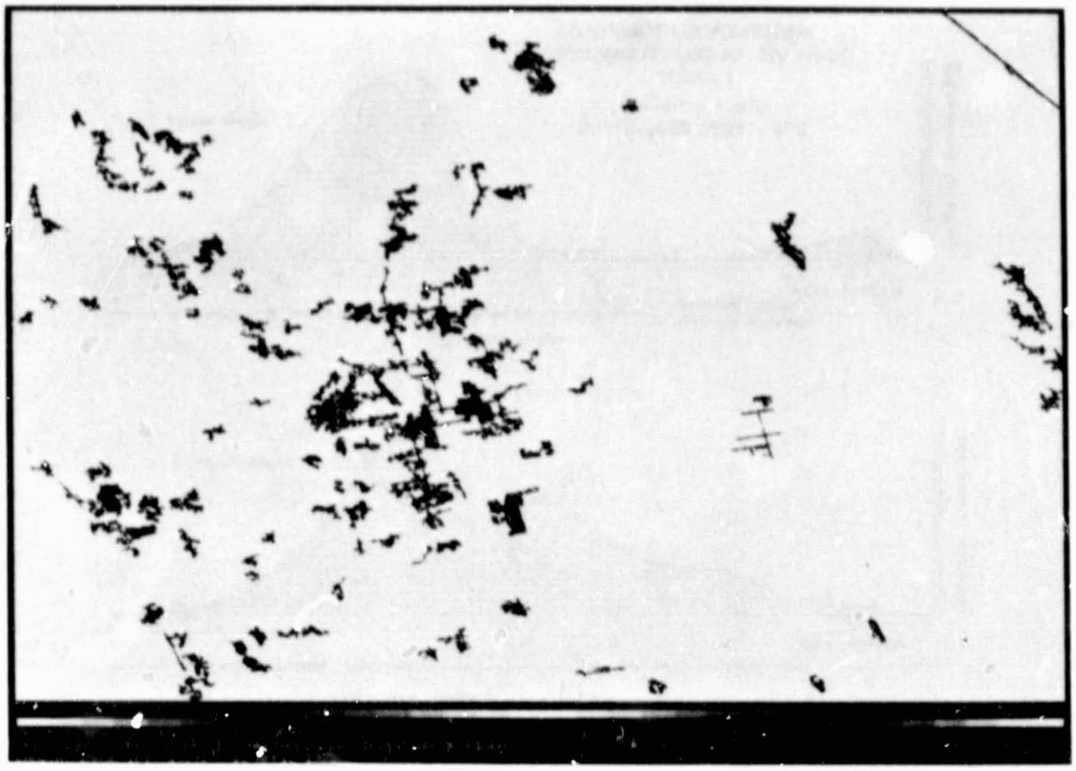

Figure 3-10. The Binary Classification of the Second Data Vector of the Eigenvector Transformation, 1975

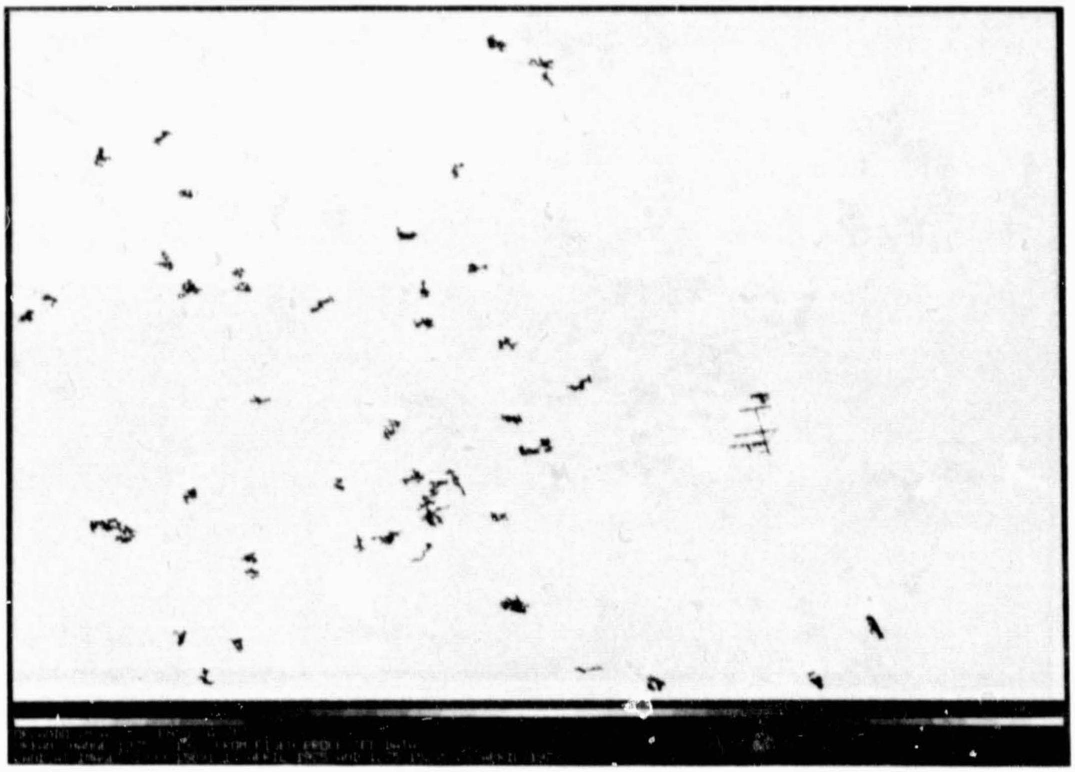

Figure 3-11. Urban Land Cover Change Between 1973 and 1975

SECTION IV

TECHNOLOGY APPLICATIONS

The Jet Propulsion Laboratory has developed a complete mapping system designed to meet the needs of the Geography Division of the U.S. Bureau of the Census. The mapping system has been designed for the purpose of updating urbanized area boundaries on maps covering major urban regions in the United States. To achieve that purpose, procedures needed for data-base management, urban land cover mapping, and thematic map generation have been designed as basic components in the system.

The mapping system is based entirely on routines contained in either the VICAR image processing system or the Image-Based Information System (IBIS). The basic features of both VICAR and IBIS used in the mapping system have been described in previous sections of this report. In this section, application tests using the mapping system will be described.

Three applications of the VICAR/IBIS-based mapping system were undertaken. These applications were specifically devised for the purpose of testing the system design and verifying the utility of the system for mapping urbanized areas. To fully demonstrate the complete features of the JPL approach, the utilization of different processing schemes was emphasized in each application.

In the first mapping exercise, urbanized areas within the Orlando SMSA were mapped. As the initial test of the system, basic data-base management procedures and mapping techniques were developed. The next test was implemented on data covering a portion of the Seattle-Everett SMSA. Emphasis was placed on the ability to utilize land cover data compiled by other researchers. The final mapping application covering portions of seven SMSAs around Boston, Massachusetts, was the most complex test of the mapping system. In that application, data planes were completed only when several smaller data planes were combined.

A. MAPPING URBAN EXPANSION WITHIN THE ORLANDO SMSA

The population of the Orlando SMSA has substantially increased since the 1970 census. It is highly probable that urbanized regions within the SMSA have also expanded during that period, and, as a result, the urbanized area map compiled from 1970 census data required revision. Through the implementation of VICAR and IBIS programs, information pertaining to urban expansion was gathered for map revision.

1. Preparing the Data Base

Derivation of the Orlando urban expansion map required the creation of a data base. The data planes comprising the data base were obtained from many different sources, since complete information was not available from any one source. Two primary data planes directly entered into the data base were a census tract outline and a Landsat image.

a. <u>Selection of the Planimetric Base</u>. The first decision required during the formation of the data base was the selection of a planimetric base. The planimetric base must be relatively distortion free, or many problems will be encountered when attempts are made to register other data planes to it. Because of this consideration, a portion of a Landsat image[3] (1279-15285, April 1973) covering the Orlando SMSA was selected to be the planimetric base for this application (Figure 4-1). All other

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[3]The Orlando SMSA covers about 4,900 square kilometers (3,000 square miles) and is contained in a region measuring 80 x 120 kilometers (50 x 75 miles). Since Landsat imagery can be considered to be radiometrically accurate for areas of that size, no significant spatial distortions should be detected in any of the data planes included in the data base. Landsat imagery has been selected as the planimetric base for all three Project applications. Other data planes such as a topographic map could be used as a planimetric base if they are more desirable.

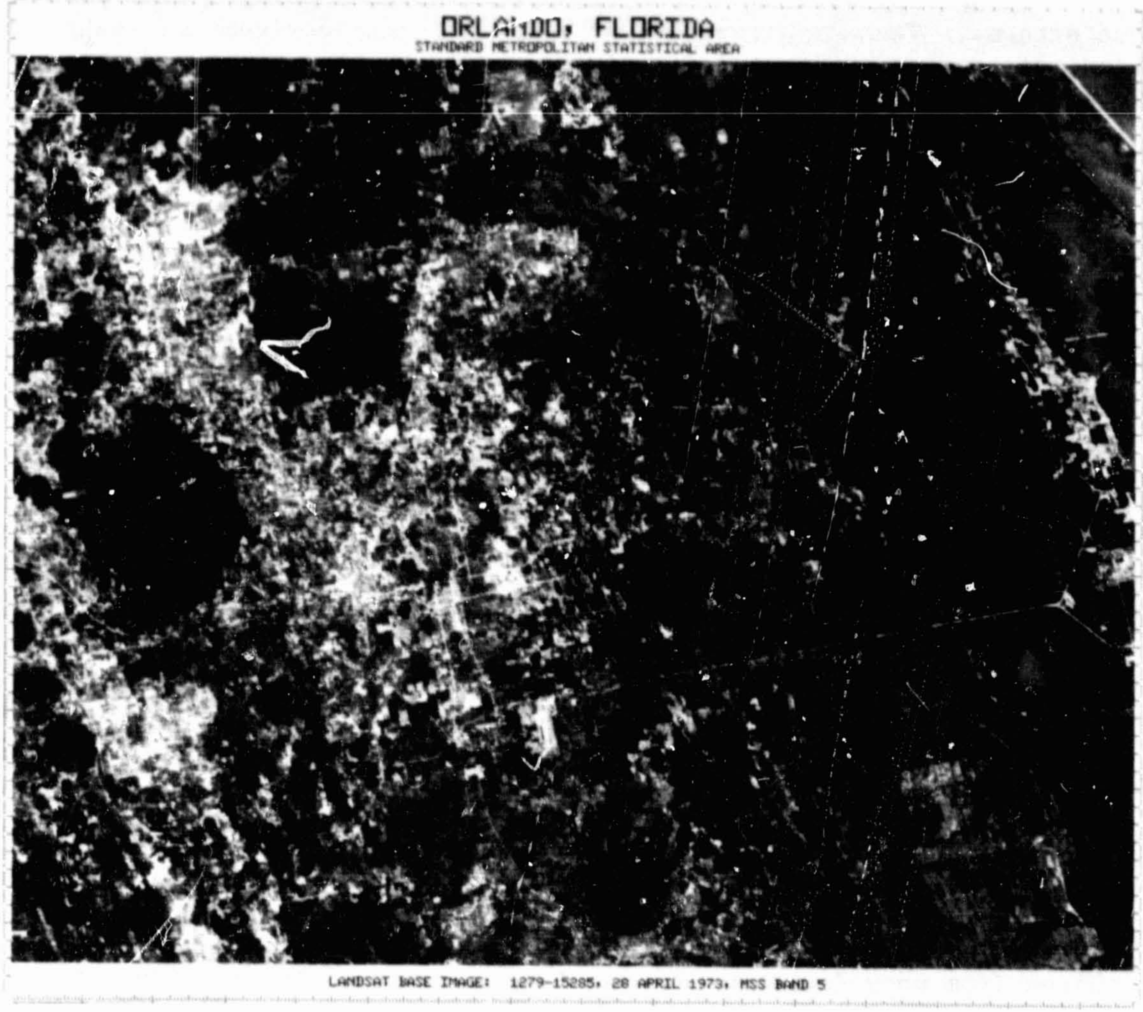

Figure 4-1. The Planimetric Base for the Orlando SMSA

data planes including another Landsat image, a census tract outline image, and all other data planes derived through IBIS processing, were registered to the planimetric base.

b. Forming the Georeference Plane. Another important data plane in the data base was the georeference plane. Because of the Geography Division's familiarity with census tract data, a logical choice for the georeference image was a census tract map. The georeference plane, based on census outline data, was not directly entered into the data base. Rather, it had to be generated through IBIS processing steps.

Initially, the census tract data[4] were obtained in Cartesian reference form and had to be translated into image-based coordinates. Then the coordinate data were modified to correspond to the surface characteristics of the planimetric base. First, a least-squares surface fitting algorithm was implemented to obtain a general fit, after which a spatial rectification algorithm was invoked to remove any local distortions. Once the desired surface correspondence was achieved, the image-based coordinates were transformed into image space, resulting in the generation of another data plane (Figure 4-2). To verify the accuracy of the surface fit, the census tract image and the planimetric base could be combined (Figure 4-3).

Once the census tract data was transformed into image space, the actual georeference plane was created by assigning each census tract a unique value (gray tone). In the Orlando SMSA, 101 census tracts were identified in this manner (Figure 4-4). It should be noted that because the georeference plane had been derived directly from the census tract outline data plane, the georeference plane was already registered to the planimetric base.

To establish a link between a georeference plane and other forms of data, an interface file was produced. The interface file is a tabular type of data file designed to contain pertinent information about each region in the georeference plane. Besides containing the linking information (gray value codes) for each census tract, the interface file commonly contains other types of data such as population counts, area calculations, and land cover aggregations.

2. Preparing the Thematic Data Planes

In the Orlando research application, a decision was made to map urban expansion for the period 1970-1975. Two data planes were integrated to produce a map depicting that theme. One data plane, derived

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[4] Census tract data used in the Orlando application was digitized by the Geography Division of the U.S. Bureau of the Census. The data, stored with data for other SMSAs, was accessed from a digital tape referred to as the Urban Atlas File tape. The data files, including the Orlando data file, contain a record of census tract identification codes and digitized coordinates outlining each census tract in the SMSA.

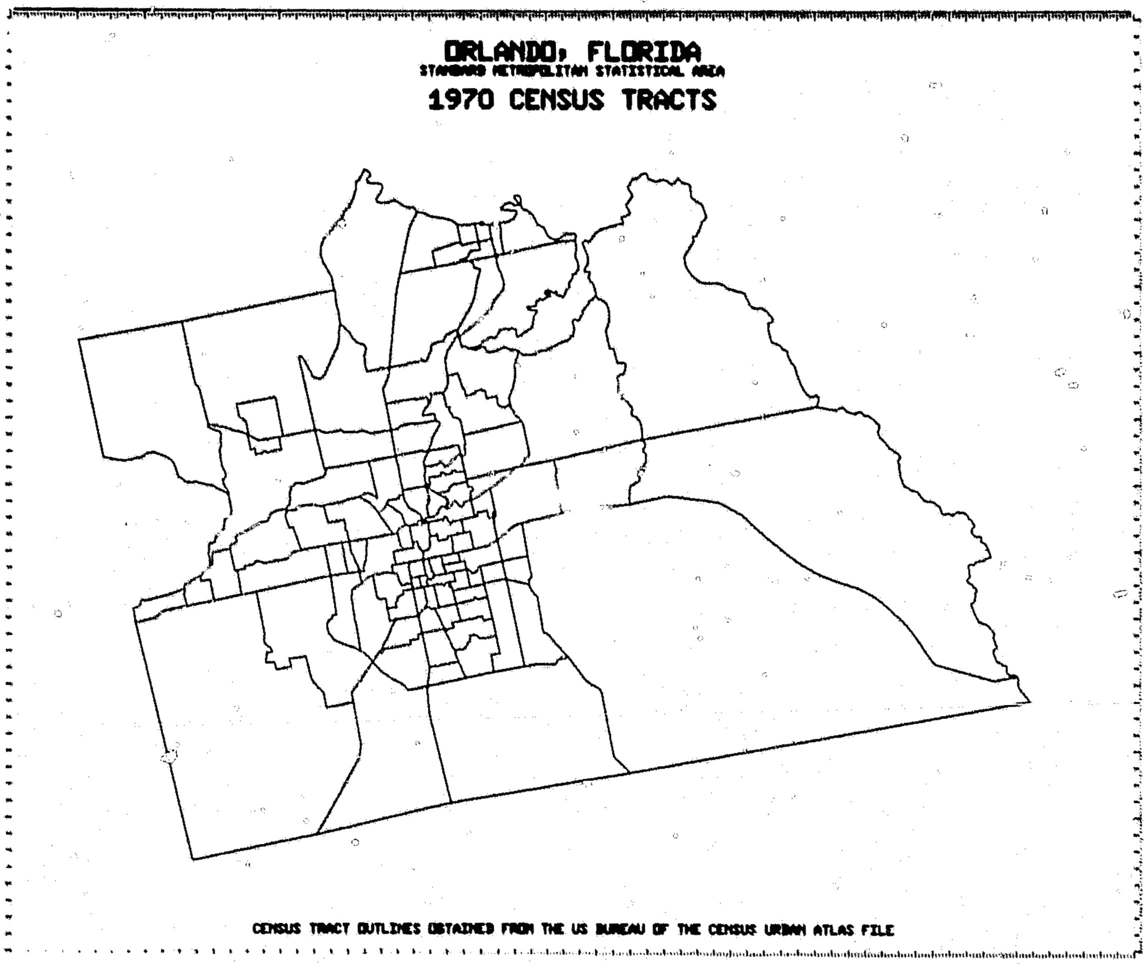

Figure 4-2. The Census Tract Data Plane for the Orlando SMSA

from census data, represented urbanized areas in 1970. Another data plane, obtained through analysis of Landsat imagery, portrayed urbanized lands for the later date.

a. Forming the 1970 Urbanized Area Map. Population density is the primary factor considered by the Geography Division when determining if an area is urbanized. Generally, if an area has a population density of at least 1000 people per square mile, the area is considered to be urbanized. While other factors are also considered, they are not of major concern for this specific application. A map of urbanized areas is produced by delineating all areas that have been designated as urban, based on that criterion. Usually, the urbanized area map is established from data gathered at the block level.

At the time the Orlando research project was undertaken, the 1970 urbanized area map produced by the Bureau of the Census was not available. Consequently, an urbanized area map (Figure 4-5) was computed through IBIS processing. Simply, population density values were computed with population and areal data previously stored in an interface file. Then, based on the 1,000-people-per-square-mile criterion for urbanized land, two classes of data were derived. Finally, a map-generating routine

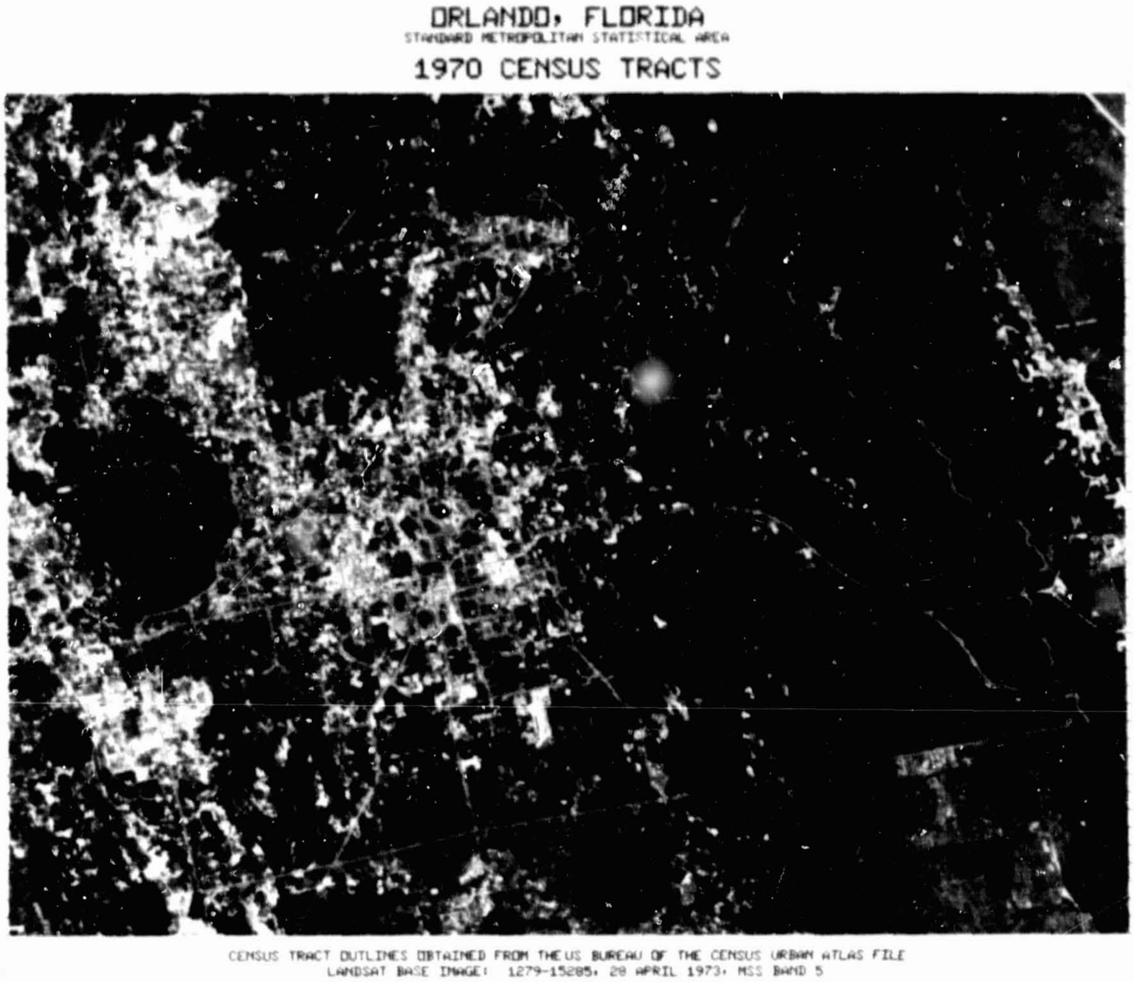

Figure 4-3. The Integration of the Two Data Planes to Check Registration Accuracy: the Orlando SMSA

was implemented to modify gray values of each region in the census tract georeference plane by a function of that data division. The resulting map depicted urbanized regions for the Orlando SMSA in 1970. That urbanized area map, established from data gathered at the census tract level, was not finely detailed when compared to the typical urbanized area maps compiled by the Bureau of the Census. However, the map did present a useful reference point for delineating urban growth.

b. Forming the 1975 Urbanized Area Map. A map typifying the distribution of urbanized land in the Orlando SMSA during 1975 was derived from Landsat imagery (1999-15091, May 1975). The Landsat imagery were also data planes in the Orlando data base. Before an urbanized area map (Figure 4-6) could be generated, the imagery had to be transformed to increase information content, and then a binary processor was implemented to classify the data. Those procedures required for information enhancement and classification have been detailed in Section 3.

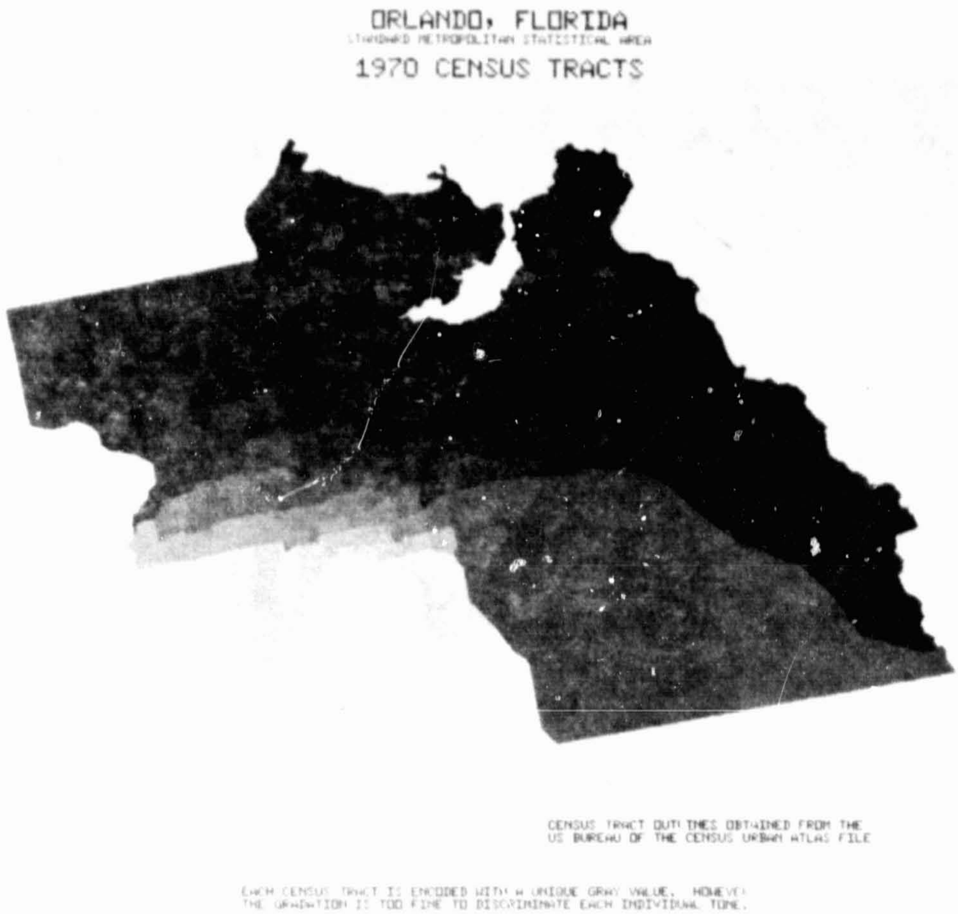

Figure 4-4. The Georeference Plane for the Orlando SMSA

3. Synthesis of the Data Planes

Once the two thematic data planes representing urbanized lands in 1970 and 1975 were generated, a new thematic data plane (Figure 4-7) portraying urban expansion between 1970 and 1975 could be produced. The new thematic data plane was derived through the synthesis of the two initial urbanized data planes.

a. Visual Acuity. One consequence of integrating data obtained from two different sources into a single map form is that differing spatial characteristics of the data become evident. The 1970 data, being a result of areal generalization, were delineated along census tract boundaries and appeared as a highly simplified feature. The 1975 data, obtained from Landsat imagery, were of a much finer resolution and appeared as a highly complex feature.

The nature of data representation is chiefly a function of differing modes of data collection and symbolization. Population statistics and areal measurements used in the derivation of the 1970 urbanized area map were accumulated by census tract. Because calculated population density values used to define the urban/nonurban nature of a tract do

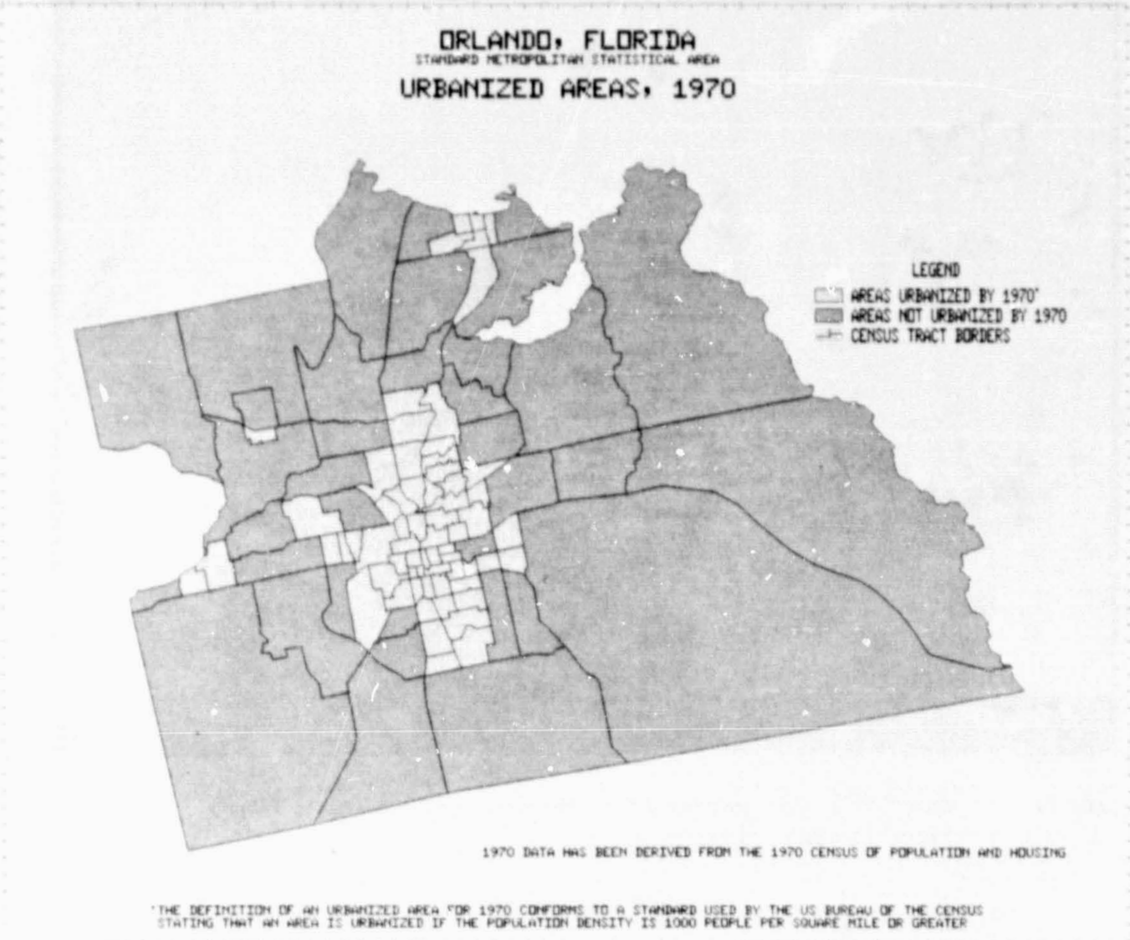

Figure 4-5. The 1970 Urbanized Area Map of the Orlando SMSA Derived From Population Density Statistics

not indicate where the urbanized areas are distributed within a tract, the only meaningful representation of urban land in 1970 was at the tract level. Conversely, the map depicting urbanized areas in 1975 was based on the analysis of Landsat imagery. Landsat data are collected at the much finer resolution of an 80 x 60 meter grid. The daca are not aggregated before analysis, and can be depicted at that fine resolution in the output product.

b. Statistical Reports. In addition to the 1970-1975 urban expansion map, a statistical report[5] of urban expansion was obtained as well. The report was derived through the implementation of various IBIS procedures. First, the land cover counts for each type of land cover (nonurban, urban in 1970, and urban by 1975) were tabulated by census tract. The tabulation was obtained through polygon overlay of the thematic map and the georeference plane (of the census tracts), then percentage coverages for each type of land cover were computed by census tract, and finally a report was produced via a report generator.

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[5]All statistical reports are included in Appendix B.

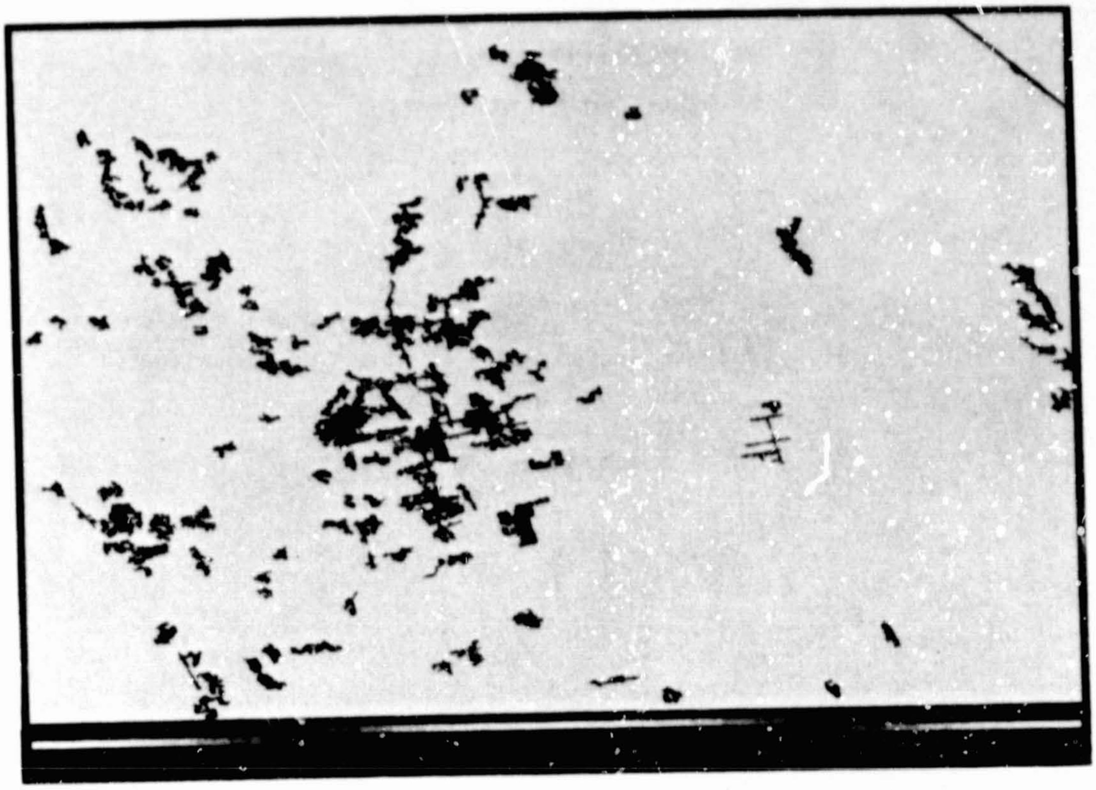

Figure 4-6. The 1975 Urbanized Area Map of the Orlando SMSA Derived from Landsat Imagery

B. MAPPING URBAN EXPANSION WITHIN THE SEATTLE-EVERETT SMSA

During the Orlando application of the mapping system, all thematic data planes were constructed with techniques developed at JPL. The census tract data plane was created through the implementation of IBIS software, and the Landsat image was classified with the binary processor.

In application to the Seattle-Everett SMSA, thematic Landsat data planes were obtained from another source. All other procedures utilized in the mapping of urban expansion were completed exactly as in the Orlando experiment.

Other governmental agencies are investigating the utility of Landsat imagery for mapping purposes. One of the primary investigators exploring the use of Landsat for urban area mapping is the U.S. Geological Survey (USGS). At the Western Regional Applications Center of the USGS (NASA/AMES), a high-quality land cover map has been produced for most of the Seattle-Everett SMSA from 1975 Landsat imagery. To demonstrate the capability of utilizing data planes developed by other research teams, the USGS land cover classification was utilized as one of the urbanized area data planes in the Seattle-Everett application. The data plane was used exactly as it was in the Orlando experiment.

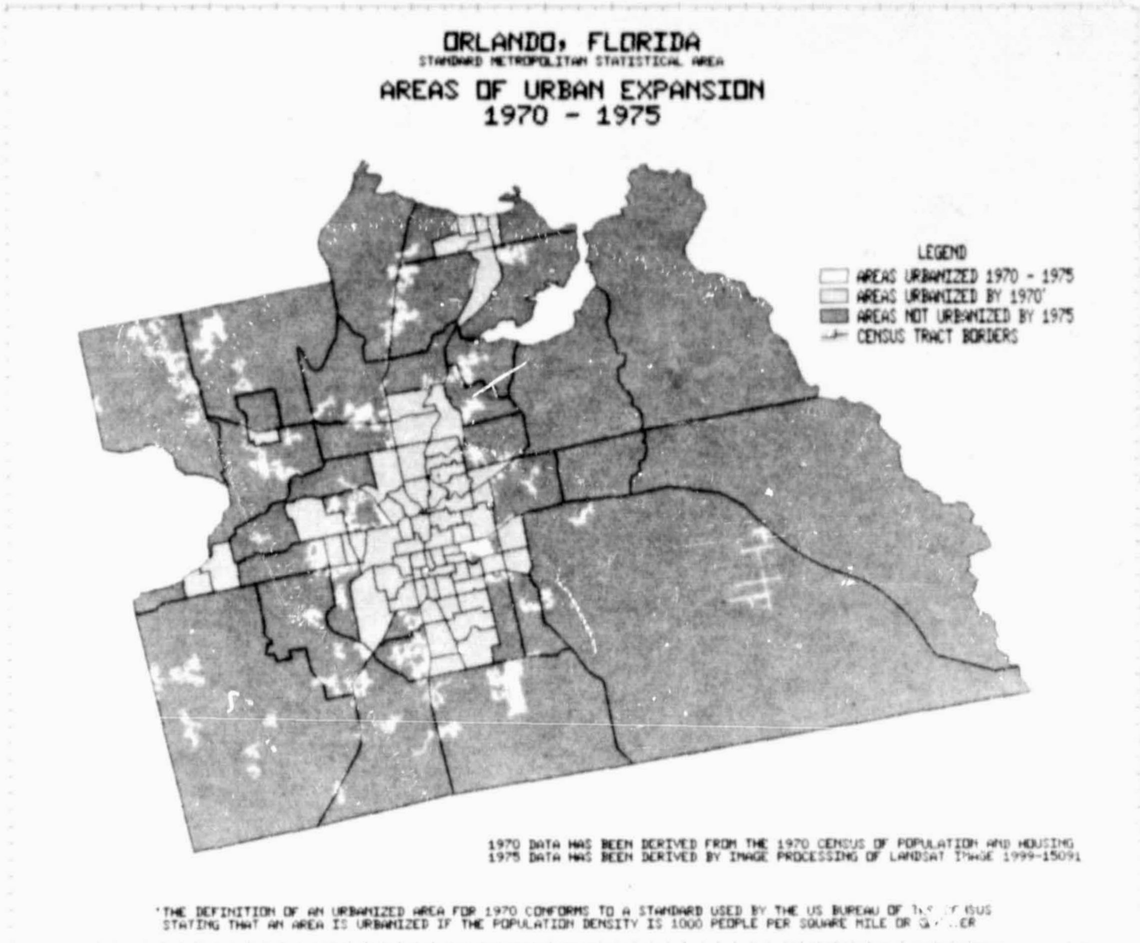

Figure 4-7. Urban Expansion in the Orlando SMSA for the Period 1970 - 1975

1. Preparing the Data Base

a. Selection of the Planimetric Base. Because a thematic land cover classification of Landsat imagery was available, the Landsat image from which the classification was created was a logical choice for the planimetric base (Figure 4-8). A Landsat image (1690-18245, June 1974) and the classified scene derived from a 1975 Landsat image (2182-18201, July 1975) were precisely registered to a map base where true north was directly vertical. Rotation due to satellite trajectory was removed and local surface distortions were minimized. As in VICAR and IBIS processing, the imagery was precisely registered to a map base with the implementation of a surface fitting routine.

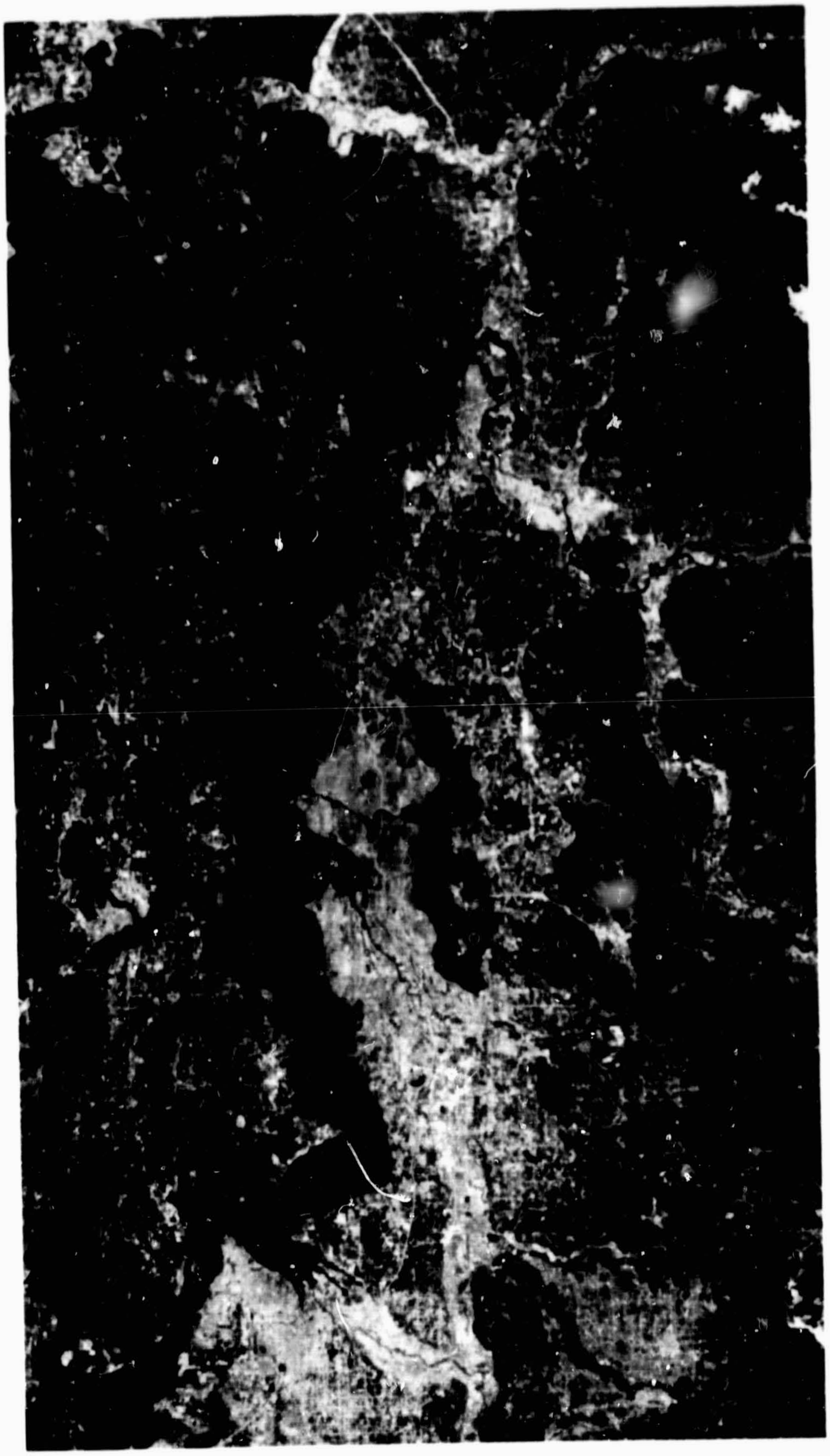

Figure 4-8. The Planimetric Base for the Seattle-Everett SMSA

b. Forming the Georeference Plane. The georeference plane was prepared in the usual manner. Census tract data, obtained from an Urban Atlas file, were registered to the planimetric base, and a census tract data plane[6] (Figure 4-9) was created. The census tracts were then assigned unique values (gray tones) to form the georeference plane. Finally, an interface file was generated.

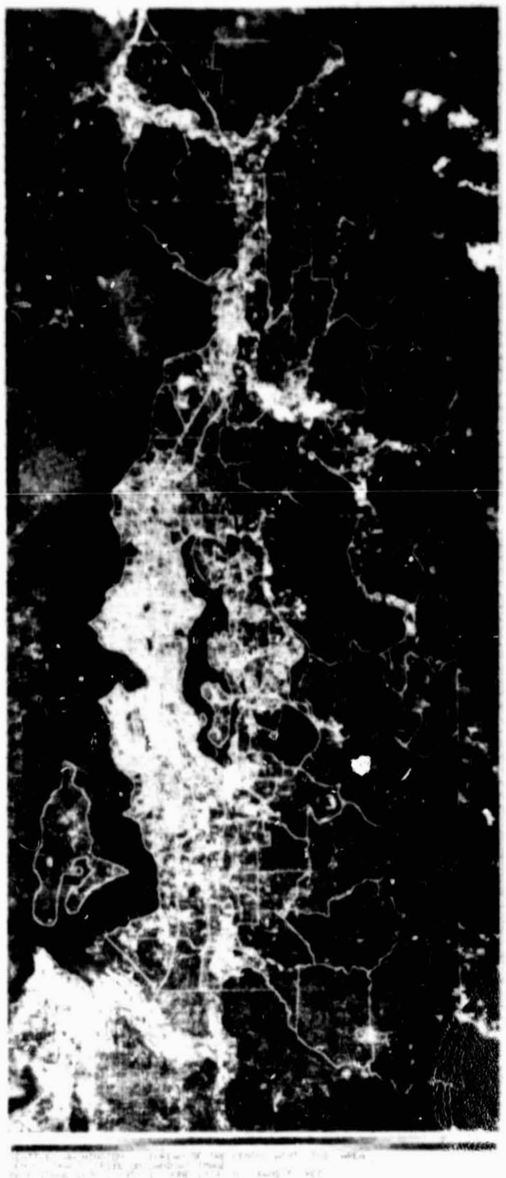

Figure 4-9. The Census Tract Data Plane Overlayed on the Planimetric Base of the Seattle-Everett SMSA

[6] It should be noted that some census tracts in the eastern portion of the SMSA were deleted from the georeference base. They were not included because satellite imagery is not available for those areas.

2. Preparing the Thematic Data Planes

a. Forming the 1970 Urbanized Area Map. As in the Orlando experiment, the 1970 urbanized area map (Figure 4-10) was derived through a calculation of population density. The population statistics, obtained from the 1970 census, were divided by IBIS-calculated area measurements for each census tract.

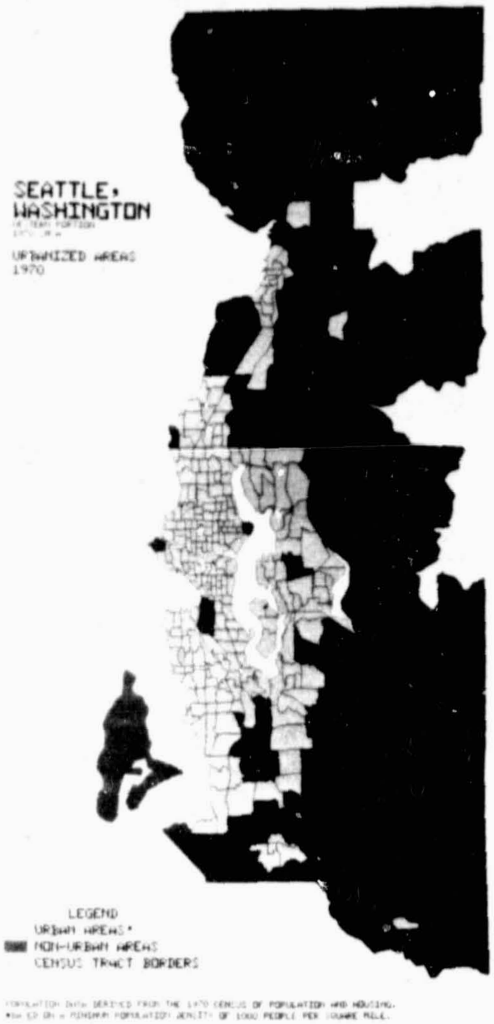

Figure 4-10. The 1970 Urbanized Area Map of the Seattle-Everett SMSA Derived From Population Density Statistics

b. Forming the 1975 Urbanized Area Map. Instead of a JPL classification of the land cover, the land cover classification of a Landsat image recently completed by the USGS was utilized. Originally, twenty-one classes were included in the map. However, that level of detail was not needed for the Seattle-Everett application. The number of classes were reduced to three (urban, nonurban, and water) before the data plane was finalized (Figure 4-11). The pattern of urban land cover, the darkest tone, is clearly visible.

Figure 4-11. The 1975 Urbanized Area Map of the Seattle-Everett SMSA Derived From Landsat Imagery

3. Synthesis of the Data Planes

Once the 1970 and 1975 urbanized area maps were completed, they were combined as in the previous experiment. The result of the synthesis was a map depicting urban expansion between 1970 and 1975 (Figure 4-12).

The visual appearance of the map is quite similar to that for the Orlando SMSA. The 1970 distribution, based on areal measurements, is very generalized. The 1975 urbanized area additions are point-specific data derived from the more-finely resolvable Landsat data source.

The USGS is still in a research mode for the generation of these Landsat-based land cover maps. However, when they are made available, the utilization of these maps as a data plane will greatly reduce the processing time required to generate urban expansion maps. Other data collecting and mapping agencies may also be able to supplement the Bureau of the Census with land cover maps for major urban regions.

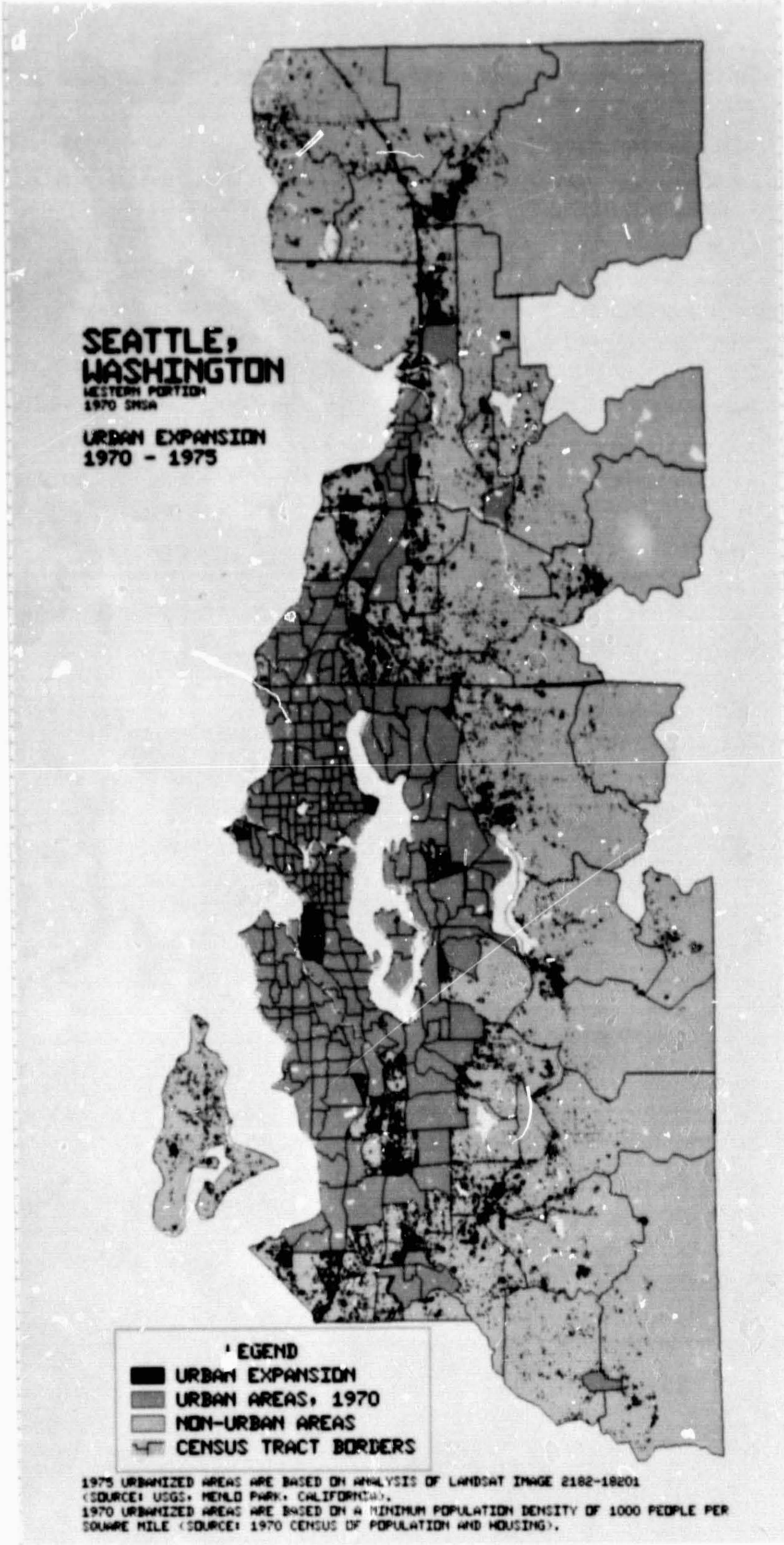

Figure 4-12. Urban Expansion in the Seattle-Everett SMSA for the Period 1970-1975

C. MAPPING URBAN EXPANSION WITHIN THE BOSTON REGION

For urban area analysis, the Bureau of the Census often requires precise delineation of the urban fringe. Since the utilization of population density values measured by census tract can only be at best a rough approximation of the urbanized area boundary, the Geography Division must consider other, more detailed, geographic parameters for determining the urban fringe. For the application covering the Boston region, the actual 1970 urbanized area boundary was digitized and processed. The Boston application represented the most complex of situations, as seven SMSAs were included in the study region.

Instead of providing maps of urban expansion for final products as in the previous experiments, several new products were produced for the Boston application. The products provided the Bureau of the Census with a variety of ancillary photoproducts with increased spatial acuity. The products might be included with the digitally-processed urban expansion data to enhance the locational factors of those maps. The products could also be used within the more traditional framework of photointerpretation practiced by the Geography Division to provide a regional base for their mapping applications.

1. Preparing the Data Base

a. Selection of the Planimetric Base. As in previous experiments, Landsat imagery was selected for the planimetric base. However, two Landsat scenes (20829-14311 and 20829-14317, both imaged on April 30, 1977) were combined to form this planimetric base. The Boston study region, covering an extremely large area, was contained in two sequential images. The images were intersected to obtain the desired study region (Figure 4-13).

In an attempt to assess the effect of new data formats with the upcoming Landsat 3 imagery, the scale of resolution for the planimetric base was modified. Instead of the normal 60 x 80 meter resolution, the imagery was resampled to an effective resolution of 57 x 57 meters. No major degradations were initially apparent as a result of the resampling.

b. Forming the Georeference Plane. Portions of the seven SMSA regions were included in the Boston study region. These SMSAs were individually processed to form the complete georeference plane. Each SMSA was registered to the planimetric base individually, since distortions were a localized problem. Six complete SMSAs were included in the data base: (1) Boston, (2) Brocton, (3) Fitchburg-Leominster, (4) Lawrence-Haverhill, (5) Lowell, and (6) Worcester. A portion of the Providence SMSA was also included.

At the time of the 1970 census, some portions of the Boston region were not included in the network of SMSAs along the eastern seaboard. Census tracts and municipal boundaries were added in those areas to complete the georeference plane. This ancillary data was digitized from maps prepared by the Geography Division. Clearly, the census tract data plane (Figure 4-14) for the Boston area is very complex.

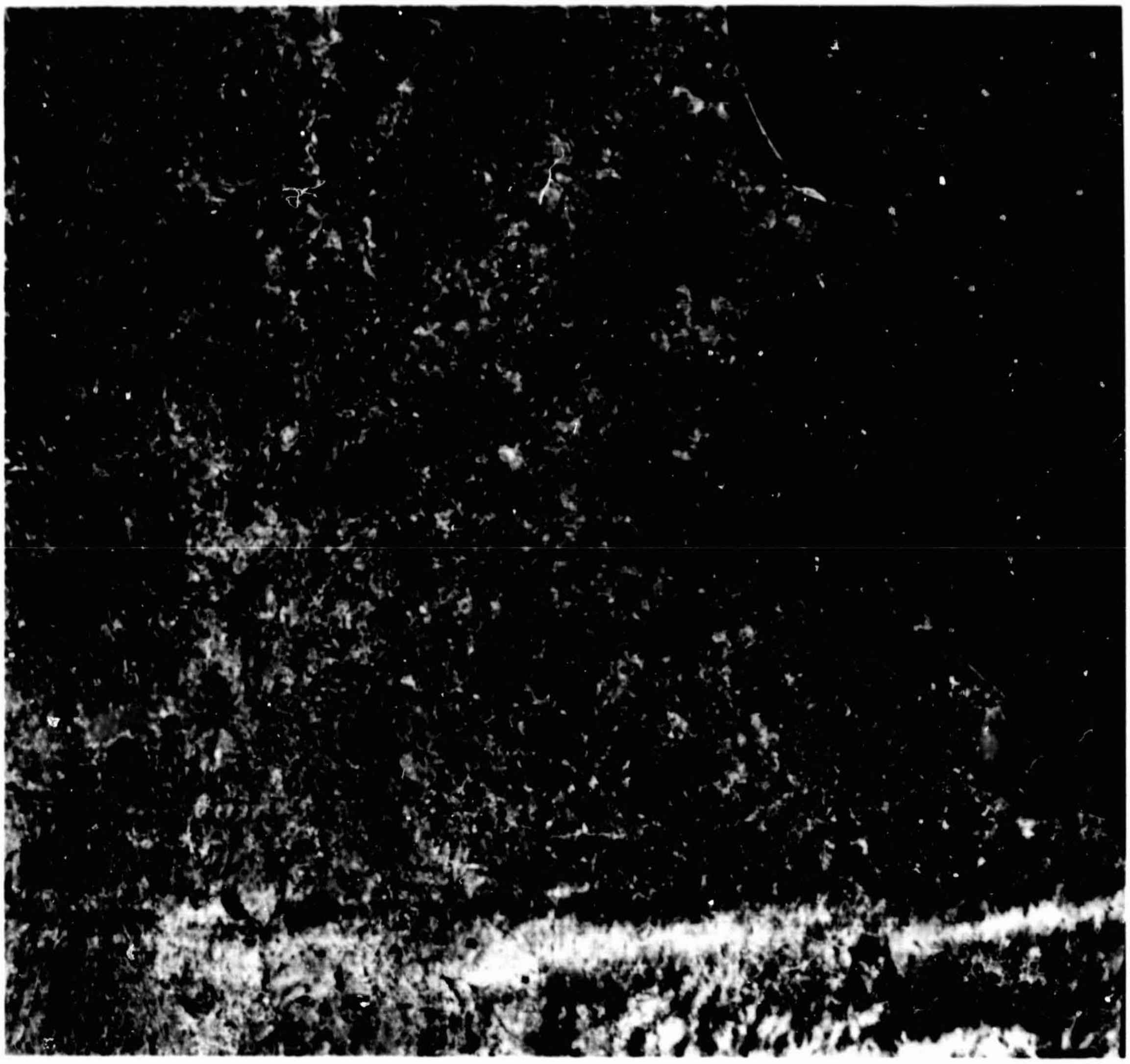

Figure 4-13. The Boston Area Planimetric Base

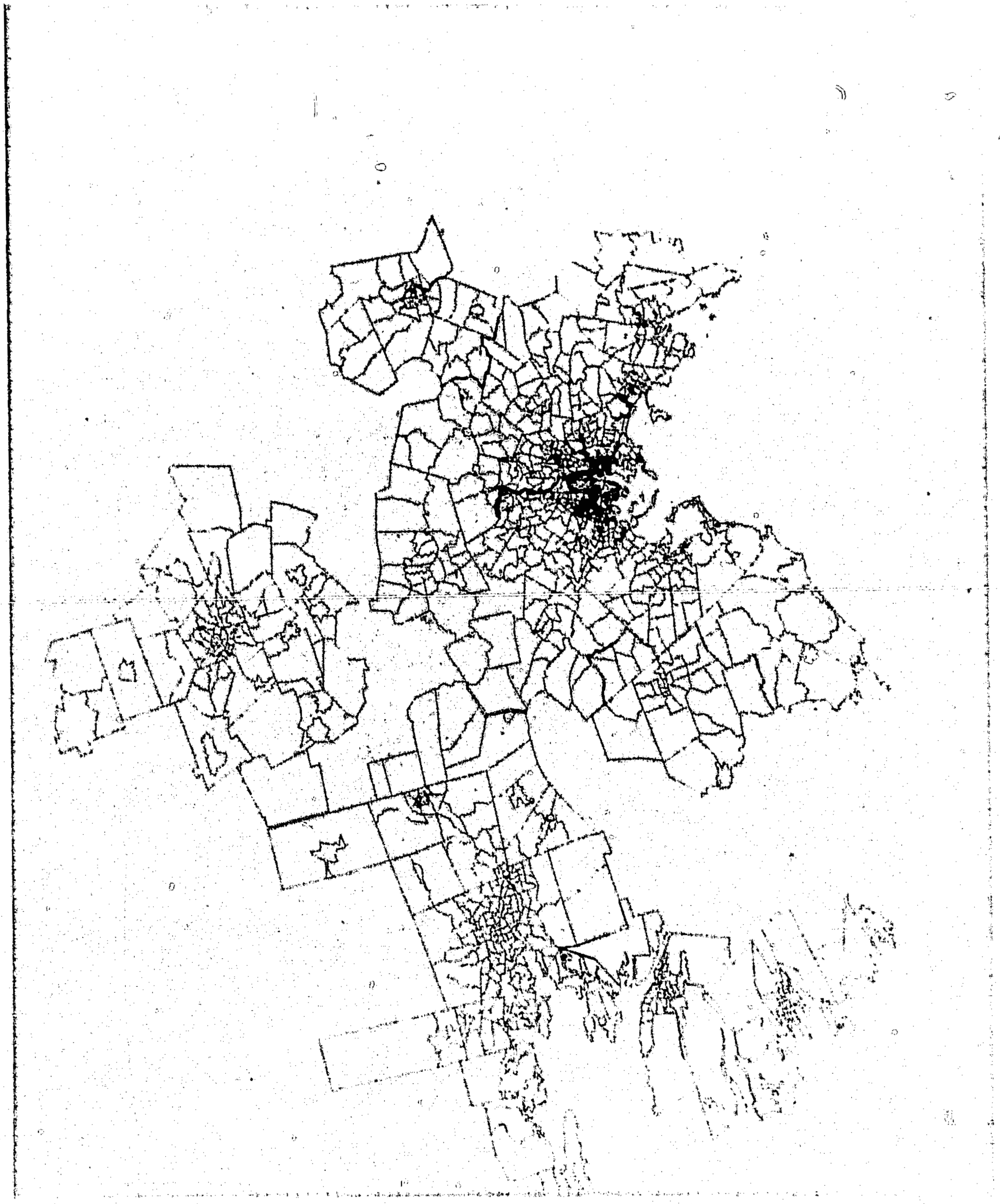

Figure 4-14. The Census Tract Data Plane for the Boston Region

c. Forming the 1970 Urbanized Area Map. Instead of utilizing population density values to determine urbanized areas within the Boston region in 1970, a new data plane was included in the data base. The 1970 urbanized area data plane was based on the inner line map developed by the Bureau of the Census after the 1970 census. All regions within the inner line were considered to be urbanized in 1970. Through analysis of the 1970 urbanized area data plane (Figure 4-15) it was noted that urbanized area boundaries did not always conform to specific census tract boundaries.

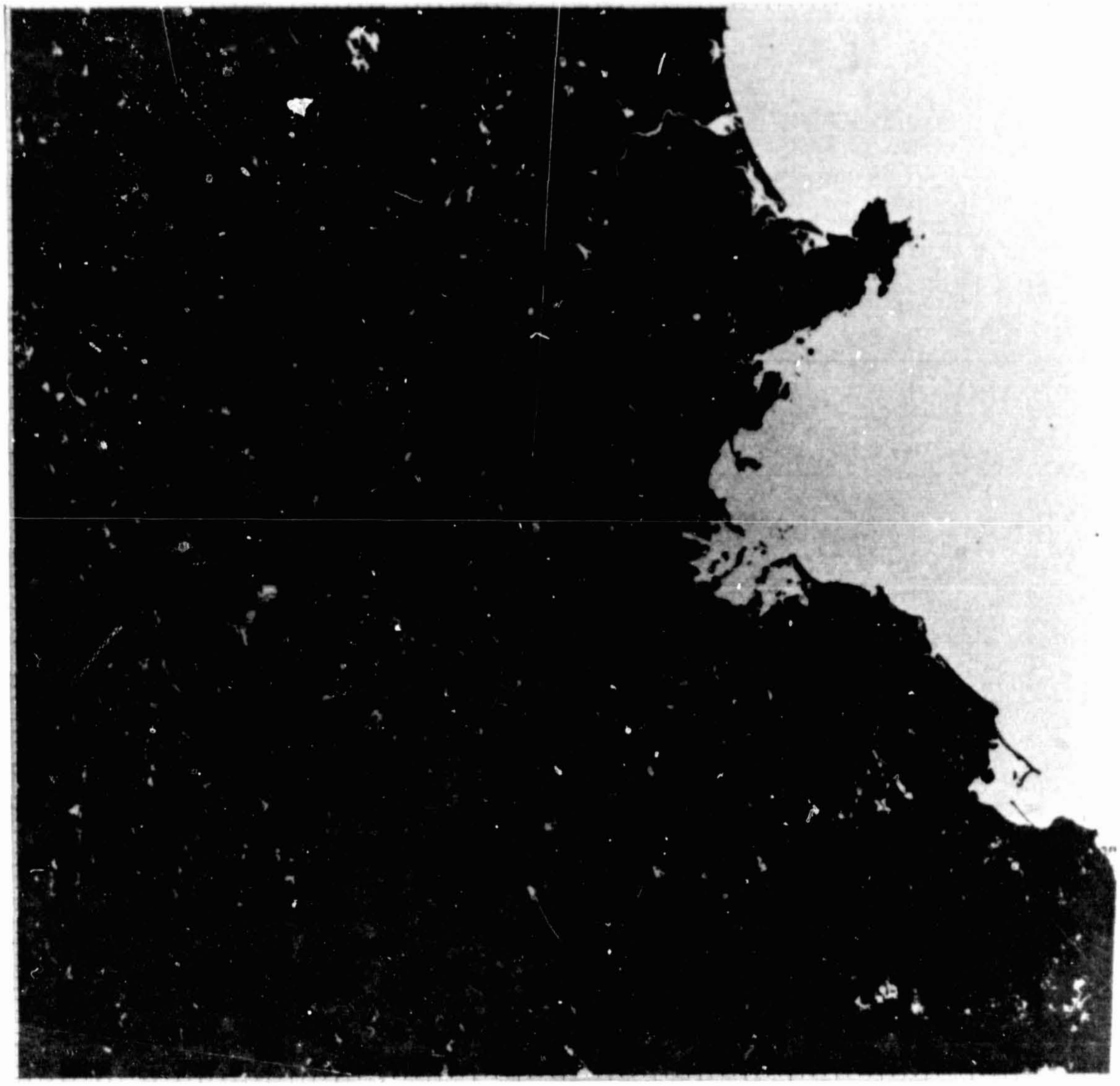

Figure 4-15. The 1970 Urbanized Area Map of the Boston Region

2. Synthesis of the Data Planes

The final product from the Boston application was intended for manual photointerpretation of urban expansion between 1970-1977. The 1977 Landsat image used to form the planimetric base was modified to highlight the areas urbanized by 1970 with an orange tint (Figure 4-16). With a typical color reconstruction of a Landsat image, urban regions are characteristically represented by deep blue tones. With the

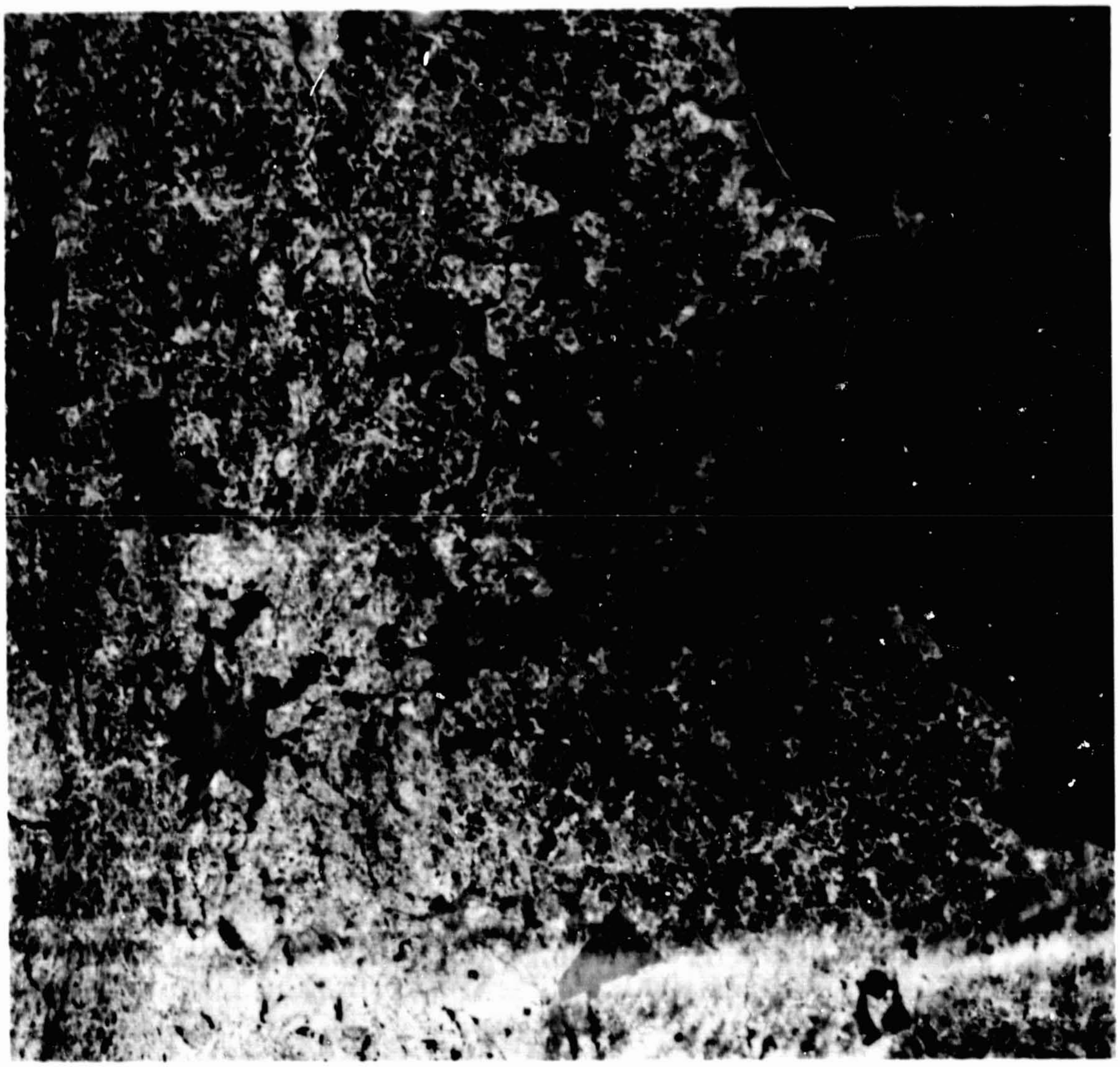

Figure 4-16. A Color Reconstruction of a Landsat Image of the Boston Region Where the Urbanized Area in 1970 has been Modified

integration of the 1970 urbanized area information, only those urban areas that were not considered urbanized in 1970 retained a true color representation, allowing immediate recognition of urban expansion since 1970.

D. SUMMARY

The research covered in this section represents the culmination of JPL's research in support of the Census-Urbanized Area Project. Through the utilization of the mapping system developed at JPL, the needs of the Geography Division of the Census Bureau can be satisfied.

Landsat imagery may be quickly classified into urban and nonurban classes. Data for 1970 can be derived as well. The various data planes can be combined to form the map depicting urban area expansion, and statistical reports summarizing urban land cover changes can also be obtained. These maps may be displayed at any desired map scale, because the photorecorded image is easily enlarged. Consequently, the Bureau of the Census geographer can assess the need for revision of enumeration district boundaries for the upcoming census.

SECTION V

CONCLUSIONS

A mapping system has been developed by the Jet Propulsion Laboratory to serve the needs of the Geography Division of the U.S. Bureau of the Census. Through implementation of VICAR and IBIS programs, the basic components of the system, the Geography Division can obtain maps depicting many characteristics of the urban environment. By integrating Landsat imagery with more traditional data types, elements of urban expansion are easily identified. The information depicted on such maps could be useful for identification of urbanized area boundaries and revision or addition of enumeration districts prior to the 1985 census.

A. SYSTEM FLEXIBILITY

Depending on guidelines formulated by the Geography Division for the Census-Urbanized Area Project, a sequence of image processing steps can be designed to produce specific maps or products requested. A variety of such products have been presented in this report.

1. Levels of Technology

In the body of the report, many maps and map-like products have been utilized to represent intermediate steps in mapping processes. Consequently, the attributes of these maps have not been emphasized. However, in some instances there may be sufficient mapped information to be useful in updating urbanized area boundaries. IBIS processes can be categorized within a hierarchical structure based on technology formulated for a previous level or levels. While each higher level is based on more sophisticated data processing procedures, the time required for map analysis after data processing is shortened with each technological advancement.

a. Level 1: Image Enhancement. The most basic approach to the problem of revising urbanized area maps is through visual analysis of color-enhanced Landsat imagery. As exemplified in the Boston application, sufficient information can be obtained from such imagery (see Figure 4-13) to provide a trained geographer with the data needed to identify urban regions. When the 1970 urbanized area mask is integrated with the satellite scene (see Figure 4-16), assessments of urban expansion can also be made.

b. Level 2: Addition of a Georeference Plane. The addition of a georeference plane such as a census tract boundary image (see Figures 4-9 and 4-15) can simplify the task of urban area analysis. Since the visual stimulus of the census tract data is easily assimilated by the geographer, the spatial aspects of the satellite-image phenomena can be more clearly identified.

c. Level 3: Thematic Maps. A more sophisticated approach to urbanized area mapping is based on the utilization of land cover maps (see Figure 4-11) produced through multispectral classification of

Landsat imagery. This analytic approach to data collection provides an objective basis for future map revision applications.

d. <u>Level 4: Data Integration</u>. The most elaborate means to revise urbanized area maps is based on the integration of conventional data types (such as population statistics) with Landsat imagery. Information that can not be derived from individual data sources can be obtained after the two data planes are integrated. Urban expansion between 1970 and 1975 has been mapped by this process for the Orlando SMSA (see Figure 4-7) and the Seattle-Everett SMSA (see Figure 4-12).

2. Other Thematic Maps

A statistical map generation program has been developed for the construction of thematic maps from data stored in IBIS data files. Through implementation of this program, a choroplethic map (Figure 5-1) depicting levels of population density in 1970 has been produced for the Orlando SMSA. All data required for the production of this map were included in the interface file and georeference plane used on the Orlando application.

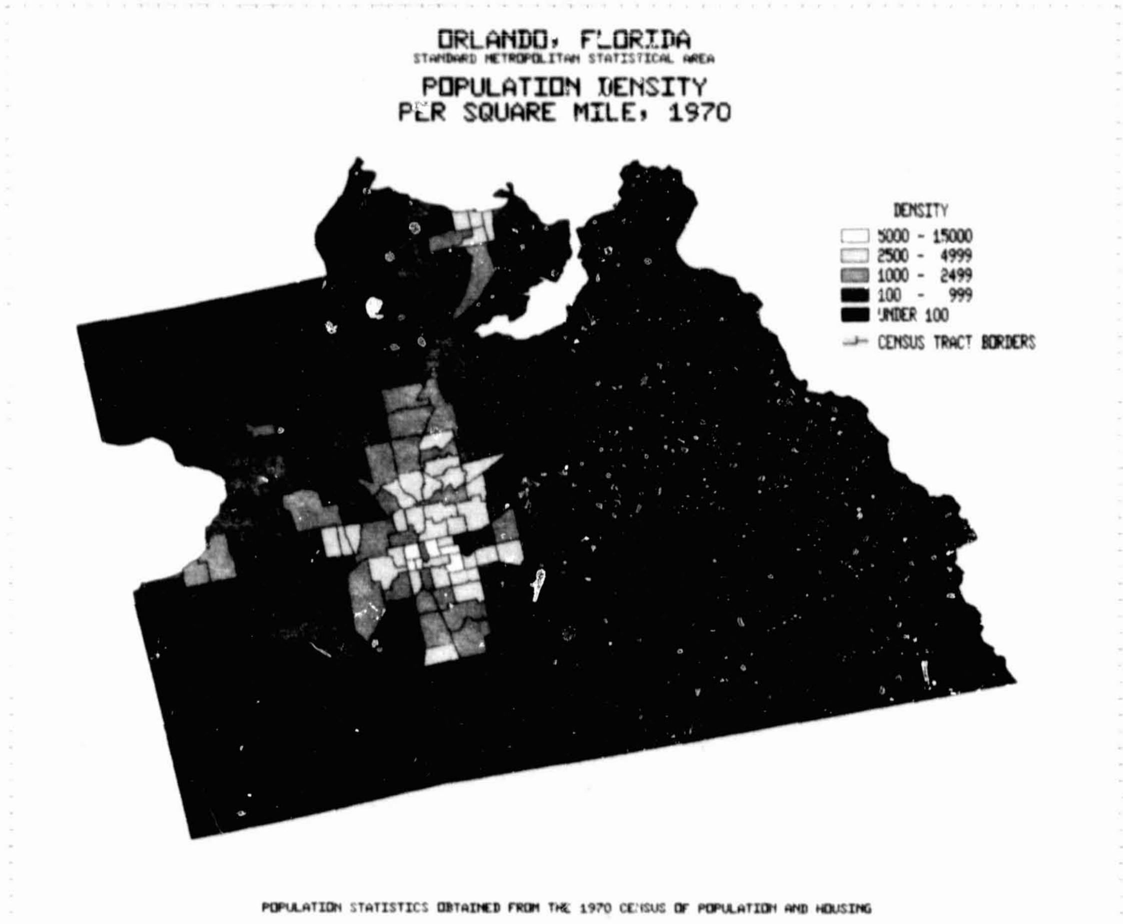

Figure 5-1. Choroplethic Map of Population Density of the Orlando SMSA

The mapping system is easily adaptable to atlas generation. Statistical distributions can be calculated with data stored in an interface file, and the georeference plane can be modified to depict the data distribution. Gray tones and patterns are easily selected for symbolization of spatial data.

B. COST OF OPERATION

1. Main-Frame System

The Geography Division is naturally concerned with the expected costs of operating any mapping system where Landsat data is analyzed in a digital mode. Selected program timings for the three mapping applications completed during phase I of the Program are included in Appendix C. It is made evident in the Orlando case, where IBIS and non-IBIS processing times are itemized, that IBIS data processing does not significantly increase the computer time expended in the mapping process. The added benefits of the products derived through IBIS software should outweigh any increased costs.

2. Minicomputer Systems

All data processing described was performed on an IBM 360-65 computer located in the Image Processing Laboratory (IPL) at the Jet Propulsion Laboratory. Since the Geography Division may have difficulty in accessing a large, main-frame computer under normal operating conditions, the options that utilize a minicomputer system may be preferable. During 1979, JPL completed mimicomputer versions of VICAR and IBIS. These versions of "mini-VICAR" and "mini-IBIS" can be made available to the Bureau of the Census or other potential system users upon a request made to NASA-COSMIC.

Although testing of the mapping system with the minicomputer system has not begun, three limiting factors about system characteristics are known. First, since minicomputers do not have large direct-access memories, many data sets will reside on peripheral storage units. Consequently, input/output timings will be increased as these files are transferred to and from memory. Second, certain programs that are 'compute-bound' will require more time for completion because the central processing units of most minicomputers are slower than main-frame devices. The spatial rectification and region-identification routines will be most affected. Third, there will be certain limitations to data set sizes. Some large regions may need to be segmented for processing in a minicomputer environment.

The minicomputer approach offers several processing advantages. The hands-on capabilities of minicomputer systems will enable faster processing of data. Routines that require several iterations to achieve desired results will be completed more quickly, as errors are identified and corrections are made during data processing sessions. All intermediate steps in a mapping procedure can be monitored. Consequently, back tracking usually caused by the unavailability of intermediate products can be eliminated in the minicomputer mode.

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APPENDIX A

A TECHNICAL DESCRIPTION OF THE

IMAGE-BASED INFORMATION SYSTEM

In Section II the Image-Based Information System (IBIS) was described on a conceptual level. A more concise and technical description of IBIS is included in this appendix. Most computer programs comprising the system are described in summary form. The following article is a facsimile of a paper presented at the 30th Annual Conference of the Society of Photographic Scientists and Engineers, Los Angeles, May 1977.

AN IMAGE BASED INFORMATION SYSTEM:
ARCHITECTURE FOR CORRELATING SATELLITE AND TOPOLOGICAL
DATA BASES

N.A. Bryant and A.L. Zobrist

INTRODUCTION

Geographic information systems should satisfy four basic criteria if they are to be useful: 1) They should provide specific point locations, as well as area locations of data; 2) They should provide for variable aggregation (sub-setting) of data; 3) They should provide a method for representing spatial arrangements; and 4) They should be able to interface with mathematical and statistical programs which can be called as needed to aid in the analysis of spatially-oriented data.[1] Practitioners of the art of geocoded systems design have progressed with varying degrees of success towards the goals outlined. As a rule, generalized systems have only rudimentary data manipulation capability (i.e., status updating and interrogation by area), while highly specific and specialized systems have progressed further with modelling applications.[2]

In response to the desire to access data for selected areas, polygon and grid cell geocoded information systems have been developed. Such systems rely on the tabular formatting of the input data, a costly and time consuming process. Often the system falls into disuse because the updating of major segments of the data base becomes prohibitively expensive. In response to the desire to provide up-to-date resource information, investigators have studied the feasibility of applying Landsat and high altitude photo imagery to natural resource mapping. The consensus which appears to be evolving is that, while remotely sensed imagery can provide timely coverage and sufficiently accurate maps using ADP techniques, the end product is still a map that cannot interface directly with an existing geocoded information storage and retrieval system.[3]

FUNCTIONAL REQUIREMENTS

Data Management Considerations

The ease with which an agency can establish a geographic information system is constrained by the level of detail and the computer technology available. With geocoded data, there is a dramatic increase in file size with every added variable and increased resolution. Thus, a parcel level system for the City of Los Angeles consists of over 800,000 records, while a census tract level system has less than 1,000. The use of newer generation computers has only moderately improved the overall operation, as the major efforts are involved in both file generation and editing and computer software architecture. Frequently, urban information systems have become underutilized because of high manpower requirements for the initial encoding of data and the heavy expense involved in updating. Land use characteristics have consistently been the most expensive data to incorporate in information systems, primarily because there has been no subsidy available to the user in recording and preparing resource inventory data, such as occurs with demographic, economic, health, and assessor data sets.[4]

There are a number of ways to encode spatial data.[5] It is possible, however, for illustration purposes, to dichotomize referencing systems into nominal and ordinal, and data types into tabular, graphical, and image. Ordinal systems reference data by the actual geographical coordinate values. Thus, natural resources such as forests, rivers, crop lands, and geologic formations are mapped with selected identifiers (total area, boundary, centroid) referenced to latitude and longitude or other selected geographic coordinate system. Nominal systems are "name referencing", i.e., data or information is referenced to a name-designating system. Any district-based referencing convention, such as census tract, sewer district, township, or transportation zone, assumes the operator knows where each administrative area is located and leaves the analysis of contiguity-effects, etc., up to the individual.[6] Problems invariable arise during the computational processing involved in conversions between ordinally and nominally referenced data and have, with the exception of the Census DIME (Dual Independent Map Encoding) File system, forced the conversion of all data to one reference system or the other.[7]

Of equal concern to the designer of a geographic information system is an incorporation of the various geocoded data types to assure adequate "data capture". It is only through the integration of tabular, graphical, and image data types that geographic information systems achieve the synergistic impact required to offset their initial cost. For instance, tabular tabular files may keep records of individual weather stations, while graphical files record elevation contours, and image data sets the distribution of land use. The combination of all three data types would provide analysts with the variety of spatial data needed to model alternative sources of non-point source air pollution. The need to deliver a uniformly encoded result to the user has been a key element to changes that have occurred in both geocoding approaches and computer system architecture applied to geographic information systems.[8]

Approaches to Geocoding

There exist three principal goecoding architectures, which have evolved from simple grid cell systems to the complex polygon methodologies, and most recently include the image raster data type (see Figure 1).

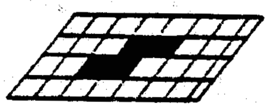
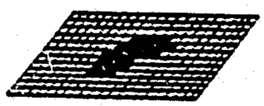
METHOD	COST CONSIDERATION	OVERALL FLEXIBILITY
GRID CELL: 	MANUALLY OPERATED	SPATIAL RESOLUTION POOR, UPDATING DIFFICULT
POLYGON: 	EXPENSIVE FOR LARGE DATA SETS	CERTAIN OPERATIONS PROHIBITED
IMAGE RASTER: 	REQUIRES IMAGE PROCESSING TECHNOLOGY	NEITHER SCALE NOR DATA FORMAT DEPENDENT

FIGURE 1. Approaches to Geocoding

From several recent reviews, it is evident that the goals of geographic information systems have become more ambitious as faster computer systems evolved and peripherals become more sophisticated.[9] Grid cell methods serve the need to retrieve geo-located data and generate maps through the cross tabulation of variables encoded within a particular cell. Several important drawbacks reduce the overall flexibility of grid cell systems: a) Their spatial resolution is only as accurate as the grid cell size (usually ranging from one acre to ten square miles); b) The systems permit the referencing of data in either a nominal or ordinal manner, never both; c) The need for manual encoding of the input data files has made updating difficult and even prohibitively expensive and effectively limited the spatial resolution of grid cells to satisfy the need to achieve regional coverage.

In response to the failings of grid cell geocoding, polygon systems grew as electronic coordinate digitizers became generally available. Polygon geocoding formats effectively solved the spatial resolution dilemma inherent with grid cell formats, while coordinate digitizing hardware has permitted rapid encoding of data. The most important achievement, however, was the integration of nominal and ordinal referencing in the Census DIME file methodology.[10] Despite these significant achievements, polygon geocoding systems have left the problem of ordinal data updating unresolved and created new challenges inherent in their graphical data structure. These problems include: a) considerable computational expense associated with file editing; b) complex topological architectures to achieve efficient data extraction from any given area;[11] and c) large investments in computer systems to achieve polygon overlay of separate files for encoding ordinal data into nominal encoding formats (e.g., acreage of land use for each census tract). Many of these constraints can be mitigated by the use of an image raster encoding procedure and application of digital image processing algorithms to implement geographic information system analyses.

IBIS Data Management

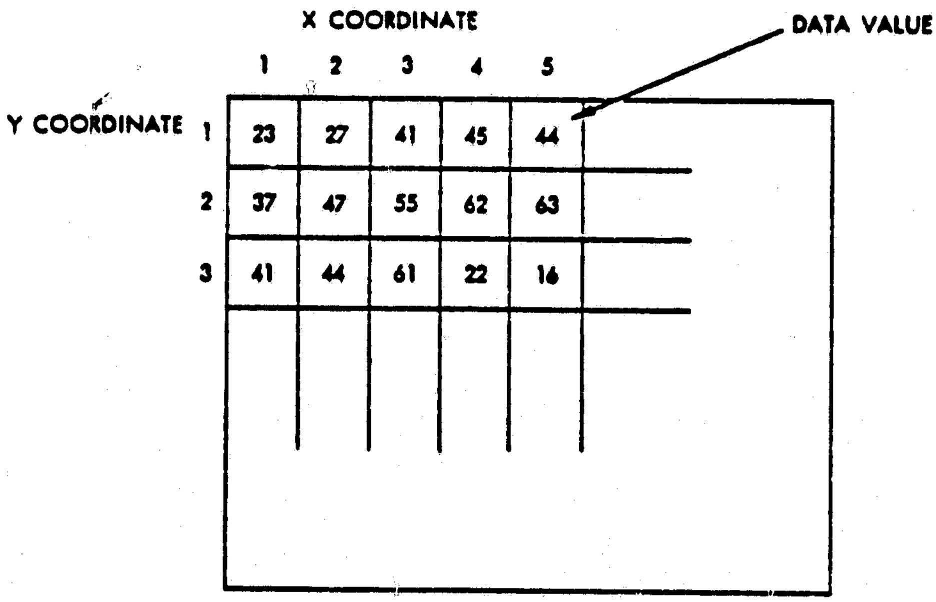
Digital image processing techniques can be applied to interface existing geocoded data sets and information management systems with thematic maps and remotely sensed imagery. The basic premise is that geocoded data sets can be referenced to a raster scan that is equivalent to an ultra-fine mesh grid cell data set, and that images taken of thematic maps or from remote sensing platforms can be converted to a raster scan. Until recently, the image format has been used primarily as a computer processable equivalent of a photograph, with the value stored in each cell of the image representing a shade of grey or a color. But if the image is of a geographical point can be accessed immediately by position in the image matrix. Figure 2 illustrates the calculation of memory address of the data value from a latitude-longitude pair.

The image datatype seems to be a powerful and general representation for spatially distributed data, and the range of uses can be divided into several broad categories:[12]

Physical Analog: The pixel value represents a physical variable such as elevation, rainfall, smog density, etc.

District Identification: The pixel value is a numerical identifier for the district which includes that pixel area.

Class Identification: The pixel value is a numerical identifier for the land use or land cover, or for any other area classification scheme.



LOCATION FORMULAS:

X = [A × LAT + B × LONG + C] NEAREST INTEGER

Y = [D × LAT + E × LONG + F] NEAREST INTEGER

MEMORY ADDRESS = BASE + KX + Y

FIGURE 2 Image Matrix As A Data Representation

<u>Tabular Pointer</u>: The pixel value is a record pointer to a tabular record which applies to the pixel geographical area.

<u>Point Identification</u>: The pixel value identifies a point, or the nearest of a set of points, or the distance to the nearest set of points.

<u>Line Identification</u>: The pixel value identifies a line, or the nearest of a set of lines, or the distance to the nearest of a set of lines.

This range of uses required that the system be able to handle images composed of words of varying length. For example, to identify census tracts in Los Angeles County requires 1500 different pixel values and elevation maps can require 15,000. This is more than the usual 256 grey levels handled by photographic image processing systems.

For each data type, the overriding consideration is usually getting the data into the system for it is in this area where greatest costs and difficulties are usually incurred. Figure 3 depicts data input as a three stage process. The first stage, called data capture, includes all operations up to the point where a data file is computer readable. Data capture costs are enormous for many basic kinds of data, for example, demographic and economic data gathered by the U.S. Bureau of the Census. These data are then made available on computer tape at nominal cost to any user. Another common method of data capture is coordinate digitization of boundaries or linear features from a map. The map is not computer compatible but the digitizer output is. Manual photointerpretation (for example, manual determination of land use boundaries) is a common step prior to coordinate digitizing. Landsat imagery is a particularly attractive data source because it is already computer compatible and gives up-to-date coverage of large areas at nominal cost. Editing costs vary widely depending upon the nature of the data source. Reformatting can also be a major operation where large data files are involved. A good example is community analysis where data are gathered by various districtings (police, fire, sewer, census tract, etc.) but must be reformatted to a common districting so that analysis can be performed (for example, to obtain police calls per capita). The final stage of data input is to obtain a temporal baseline. For example, police calls in 1976 cannot be divided by 1970 population to obtain a per capita figure because of a temporal difference. Establishing a temporal baseline involves projection and modelling of the initial data to one or more common points of time.

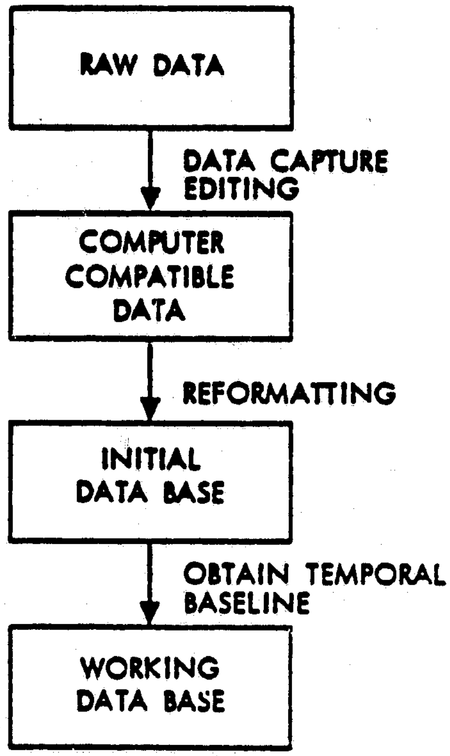


FIGURE 3 Data Input Stages

IBIS Data Analysis

Once a working data base is set up, provisions must be made for information retrieval, information analysis, and report generation. Operations here are usually of a much smaller scale than data capture in terms of time and cost, but there is instead a question of flexibility and ease of use, and a question of system cost. All data analyses can be laid out as a sequence of primitive steps, thus, a functional requirement is that an adequate set of primitive operations can be implemented. Mathematical and statistical analyses of tabular files are well-understood, and packaged systems can easily be interfaced. The open question is whether geo-based file computational steps can be implemented. Some examples of these are: 1) Given a point and a district, does the point lie within the district. 2) Given a point and a district file, which district contains the point. 3) Given a particular district in a district file, what are its neighbors. 4) Given a district file and an area classification file, what are the acreages of each area classification in each district. 5) Given two district files, one major and one minor, what are the proportions of each minor district in each major district. 6) Given a district file and a line segment, what are the mileages of the line segment in each district. 7) Given a point p and a point file, what is the point in the point file nearest to p. 8) Given a point p and a point file, what is the distance from p to the nearest point in the point file. 9) Given a point and a line segment file, which line segment passes closest to the point. 10) Given a density map and a district file, what are the volumes in each district (spatial integral of density). 11) Given a district, what is the centermost point (an inside point which is farthest from the boundary). And for the connoisseur: 12) Given a district file, assign four colors to the districts so that a map can be produced with adjacent regions always a different color.

The preceding list is just a sample of the sorts of spatial or geometric calculations which need to be performed by a comprehensive geo-base information system. More complex operations will usually be implemented as a sequence of these primitive operations, but because of the magnitude of the data files and because of iteration due to modelling, compute time can be a serious problem. A method which solves one of the primitive problems in 0.1 second may seem usable, but not if it has to be performed ten million times for a particular application.

It is worth noting here that many of these operations are difficult and time consuming if the working data base is in polygon or graphical format (i.e., lines are specified by their end points and a district is given by a sequence of line segments). In particular, the operation called polygon overlay which solves primitive problems four and five is extremely difficult to perform on large files in graphical format. If the files are in image format, then polygon overlay becomes a simple counting operation (Figure 4).

A different area of concern is the interfacing of nominal and ordinal geo-referenced files. Given that part of the working data base has been obtained (or reformatted) into an ordinal format, the major part of the data base will probably still be in tabular form. As an example, an air pollution density image might be interfaced with a population table to obtain a measure of health effect. Speaking more generally, the system must be able to perform operations on mixed data types, thus allowing the working data base to be built from raw data in its most natural form.

An operation of special importance is crosstabulation, mentioned previously in connection with data management. It converts data aggregated by one district convention to an aggregation by another district convention. The operation itself is trivial since it involves multiplying by a set of factors which measure the percentage subareas of one districting in the other. The crosstabulation factors are derived by polygon overlay and may also be modified by a density estimate of the variable being crosstabulated. A comprehensive system should be able to represent district data sets in such a way that they can easily be updated and the factors rederived. This means that the tabular data can be kept in its natural unit of aggregation in the working data base and quickly crosstabulated to whatever districting is needed as analysis proceeds.

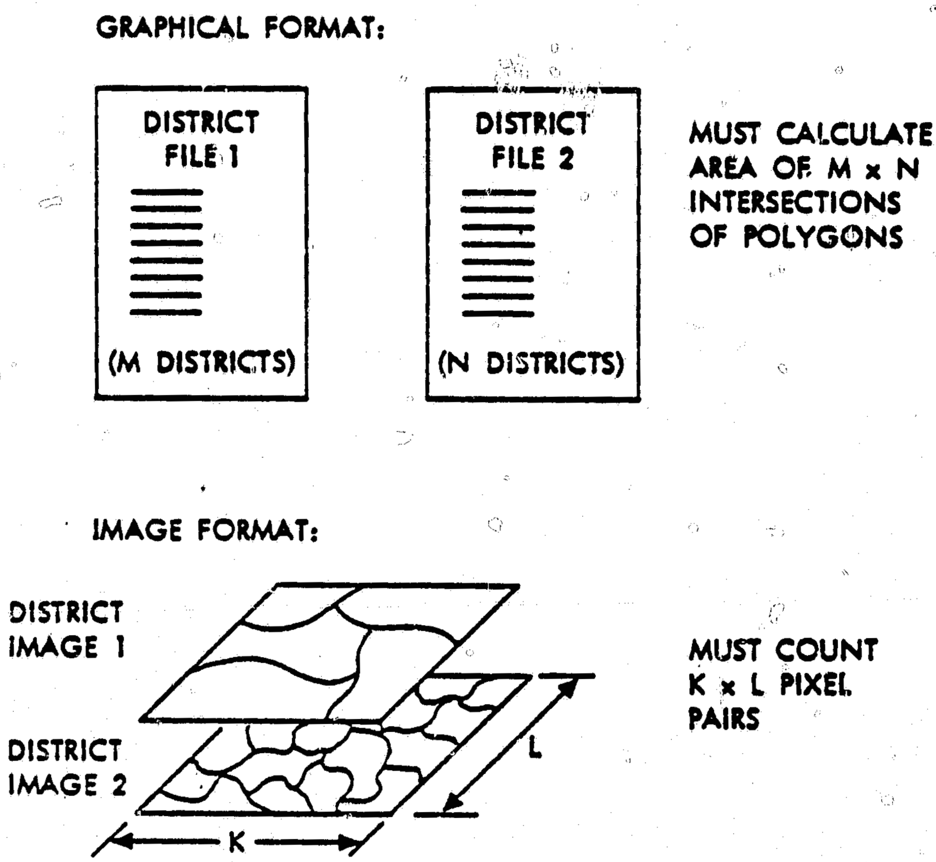


FIGURE 4 Comparison of Polygon Overlay Techniques

Because the image datatype is used, capabilities for digital image file handling, image manipulation, and image processing are required. Thus, the IBIS system has been built upon an existing image processing system, VICAR (Video Image Communication and Retrieval), developed at JPL.[13] Certain basic image processing operations are absolutely essential. One must accomplish image-to-image registration, whereby images of different scale, rotation, or map projection are superimposed precisely enough so that corresponding pixels represent the same geographic location. Rubber-sheet registration is almost always necessary to achieve the needed degree of accuracy. On other hand, it is anticipated that even esoteric image processing operations, such as convolution smoothing will be useful for certain types of applications. The conclusion here is that any image-based information system must contain a powerful image processing subsystem.

Finally, the system must be capable of computations which will allow it to run a variety of models. The key here is the introduction of the image raster as a spatial data representation. Contiguity effects can then be handled because adjacent areas are contiguous in the image raster (in terms of their computer address) whereas, with other file representations, adjacent areas are accessed by file searching. Basic operations, such as spatial integration with reporting by district are greatly simplified with an image representation. More esoteric models, say, involving cellular transformations or diffusion processes may already use a matrix on raster representation but will be helped by the synergism of placing their specialized capabilities into a general and comprehensive data management system.

SYSTEM DESCRIPTION

IBIS is presently resident on an IBM 360/65 system with one megabyte of core with interfaces to a large number of disks and tape drives to accommodate the large files associated with image processing technology. The operating system is OS 360/MVT and all IBIS routines are designed to run in a 150 kilobyte region. Present applications use less than one twentieth of the total machine time, so this hardware configuration would be suitable for a large scale data processing operation at the national level. A mini-computer version is partially complete. Although the total cost of an IBIS system is high, the unit cost of operation is low, expecially when compared to existing methods of performing the types of tasks the system is intended for.

The user request is given to the IBIS system by means of a language which is translated into the host machine job control language. The translated code can then invoke system functions or processing modules. This organization makes the system flexible and easily extendable. The system software consists of a number of FORTRAN modules and a relatively small nucleus. All of the factors mentioned here (modular design, use of FORTRAN, good interfaces to user and hardware) made technology transfer more feasible.

The processing modules constitute a primitive set of functions operating on the various datatypes to achieve the functional requirements set out in the previous section. Figure 5 is a schematic layout of the central part of the IBIS system, emphasizing the interfaces between image, tabular, and graphical datatypes.

The first set of routines convert graphical (polygon) data files to digital image descriptions of regions or areas.

VTRACTI, SCRBGEN, VSCRBGEN - All three programs basically have the same function, convert polygon files described by x,y coordinates to a VICAR record format, but each uses a different input type:

VTRACTI - Census Tracts

SCRBGEN - Cards

VSCRBGEN - Tape

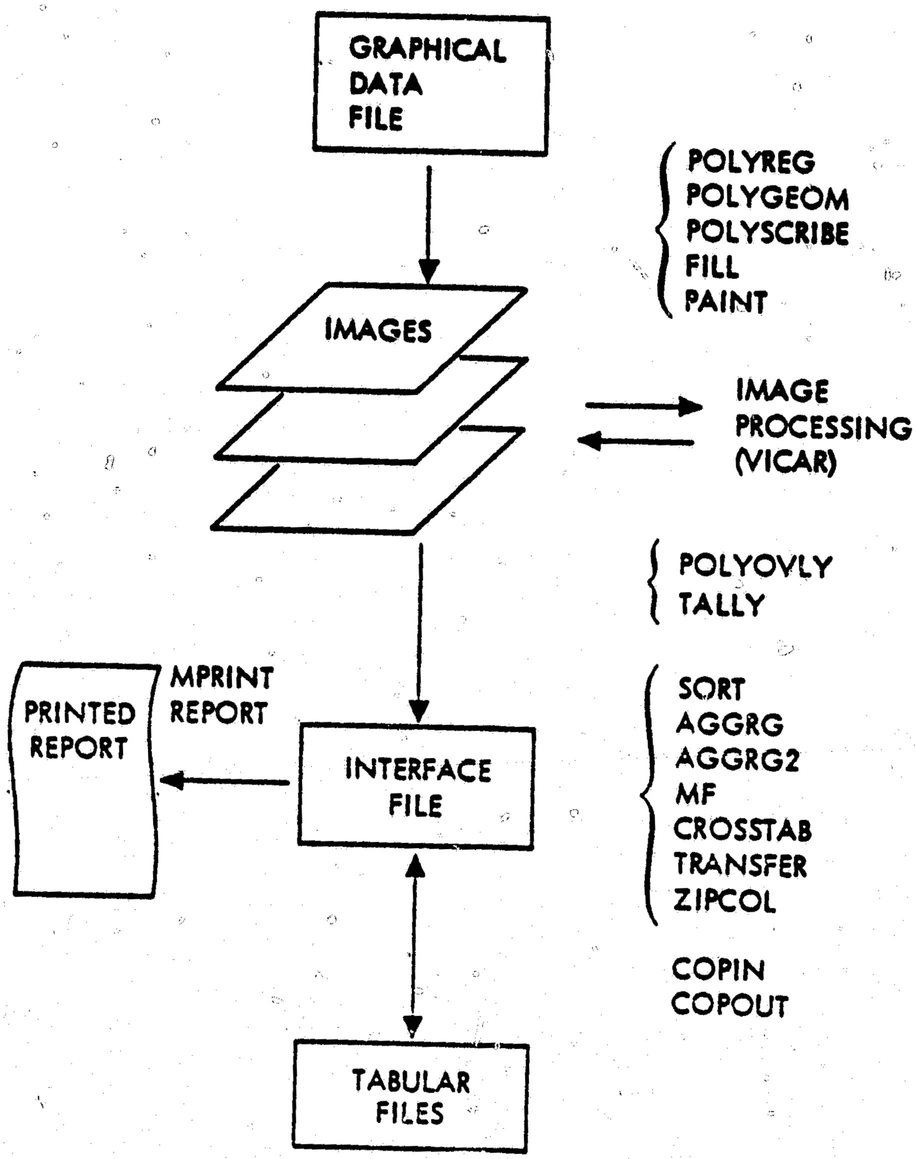


FIGURE 5 IBIS Schematic

POLYREG - Performs rigid rotation and scaling of polygons prior to input into POLYSCRB.

POLYGEOM - Performs rubber sheet mapping on polygons prior to input into POLYSCRB.

POLYSCRB - Scribes lines into an image file, by setting the boundaries of polygons to a particular DN (grey scale) value. The routine was especially designed for the conversion of thousands of lines and has parameters for chaining lines and closure of polygons.

FILL - Fills holes, thickens lines and/or removes noise with variable thresholds and window sized for enhancement of scribed polygons prior to PAINT.

PAINT - Converts an image with scribed polygons into a multi-color map where the DN corresponds to a map color. The routine will handle up to 30,000 polygons or regions.

Moving from top to bottom in Figure 5, the VICAR image processing routines are next. The VICAR system presently has over 100 routines for the manipulation of images of varying work length. Of special interest to modellers is the following routine.

F2 - Performs array arithmetic on a pair of images in byte or halfword format. The function to be applied is specified by a FORTRAN-like expression.

Polygon information extraction routines perform the overlay operation on two sets of polygons, the reference polygon created in paint and digital image data. Each pixel on the image file is matched with the corresponding pixel on the reference file and stored by pixel pairs. The following programs are used in the overlay process.

POLYOVLY - Produce a histogram (or pixel count) or registered images by DN values for single pixels or a joint histogram by DN pairs as generated in the overlay procedure. Since the problem of storage is critical to this process, the user has three optional storage methods specified in the parameters.

TALLY- Produces a histogram similar to POLYOVLY except that the DN values in one of the two images are summed.

The results of POLYOVLY and TALLY generate data files stored by column. The column organized file is called the interface file. This file serves as an interface between image and tabular data sets. The interface file is manipulated to produce a report by the following routines:

SORT - Sorts the interface file into ascending or descending order according to one or more columns.

AGGRG - Aggregates columns of numbers using a designated column as an index for summation in other columns.

AGGRG2 - Summarizes and collates columns of numbers to produce a single row for each control value in the column which is used as an index.

MF - Performs column arithmetic given an arithmetic expression in the parameter field which denotes columns such as:

"C5=C2/C3+100+SQRT(C2)".

CROSSTAB - Tabulates information referenced to one polygon districting to another polygon districting through the polygon overlay technique.

TRANSFER - Change vertically aligned columns of data as produced in POLYOVLY and used in previous routines to smaller vertical columns based upon data values (e.g., land use).

ZIPCOL - Substitutes column index values with user district names or numbers.

After processing by the above routines, the interface file is ready for report generation.

MPRINT - Prints out the interface file according to a relatively simple format.

REPORT - Prints out the interface file with user specified titles, column titles, paging, spacing, etc. Subtotaling on a given control column can be requested. There are numerous features for formatting and for printing alphabetic data.

To interface tabular files and also to give tape output as an alternative to report generation, the following routines are used.

COPIN - Copies columns of a tape file into columns of the interface file according to an index column in the interface file. The index must be present in the tape file. The files must be sorted according to the index and a merge is performed.

COPOUT - The reverse of COPIN. Columns are written from the interface file to the tape.

CONCLUSION:

An image-based information system is necessary for the full utilization of satellite imagery data and anticipated development of regional land capability analysis centers.[14] The future availability of frequent updates of land resource inventory statistics, with a known and acceptable sampling accuracy, should permit the incorporation of this data with the annual up-dates published by other governmental bureaus. An image based information system does more than introduce remotely sensed imagery to the mainstream of data processing application; it provides a new approach to the management and analysis of spatially-referenced data.

The projected demands to be placed upon geographic information systems will place a strong emphasis upon the capability to store and retrieve large amounts of data and manipulate data sets for portions of the files efficiently. A major drawback facing most geocoding procedures is that they rely on sequential computations applied to tabular data strings, and as such require a large investment in formatting or processing data that is inherently two-dimensional. Raster scan data bases will avoid many of these problems and possess additional advantages. The video communications field has been and is continuing to address both the problems of mass storage and applications of rapid interactive processing that places a minimal reliance upon computer software routines. The specialized requirements of geographic information systems should derive considerable benefit from the image processing field in the future.

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APPENDIX B

SELECTED STATISTICAL REPORTS

The tabular report summarizing information stored in an IBIS data base is a major feature of the Image-Based Information System. These reports may be useful to the Census Bureau geographer in determining areas of urban expansion.

Two reports are included in this appendix. The first report is a complete summary of urban land cover in 1970 and 1975 for the Orlando SMSA. The second report is a limited summary of land cover in 1970 and 1975 for the Seattle-Everett SMSA. Only those tracts that were found to be nonurban in 1970 have been listed.

Table B-1.

URBANIZED LAND COVER STATISTICS FOR THE ORLANDO SMSA
ORLANDO, FLORIDA
1970 AND 1975

1970 STATISTICS BASED ON THE 1970 CENSUS OF POPULATION AND HOUSING
1975 STATISTICS BASED ON URBAN CHANGE DETECTION FROM LANDSAT IMAGERY

---	CENSUS TRACT NUMBER	TOTAL ACRES PER TRACT	1970 POPULATION STATISTICS: NUMBERS OF PEOPLE	1970 POPULATION STATISTICS: DENSITY PER MILE SQUARED	1970 URBANIZED LAND COVER STATISTICS: ACRES	1970 URBANIZED LAND COVER STATISTICS: PCT	1975 URBANIZED LAND COVER STATISTICS: ACRES	1975 URBANIZED LAND COVER STATISTICS: PCT	URBANIZED LAND COVER CHANGE BETWEEN 1970 AND 1975: ACRES	URBANIZED LAND COVER CHANGE BETWEEN 1970 AND 1975: PCT	URBANIZED LAND COVER CHANGE BETWEEN 1970 AND 1975: MAJOR
1	101.00	268	789	1884.4	268	100.0	268	100.0	0	0.0	
2	102.00	451	4370	6207.2	451	100.0	451	100.0	0	0.0	
3	103.00	472	3402	4613.7	472	100.0	472	100.0	0	0.0	
4	104.00	160	3285	13134.0	160	100.0	160	100.0	0	0.0	
5	105.00	194	3988	13125.3	194	100.0	194	100.0	0	0.0	
6	106.00	487	3937	5170.4	487	100.0	487	100.0	0	0.0	
7	107.00	831	2852	2196.0	831	100.0	831	100.0	0	0.0	
8	108.00	934	5484	3756.4	934	100.0	934	100.0	0	0.0	
9	109.00	328	1777	3462.6	328	100.0	328	100.0	0	0.0	
10	110.00	372	3379	5808.4	372	100.0	372	100.0	0	0.0	
11	111.00	434	2800	4129.3	434	100.0	434	100.0	0	0.0	
12	112.00	569	4897	5506.7	569	100.0	569	100.0	0	0.0	
13	113.00	754	5476	4647.4	754	100.0	754	100.0	0	0.0	
14	114.00	490	1257	1642.8	490	100.0	490	100.0	0	0.0	
15	115.00	509	3222	4053.8	509	100.0	509	100.0	0	0.0	
16	116.00	1227	4772	2488.6	1227	100.0	1227	100.0	0	0.0	
17	117.00	1633	11539	4523.1	1633	100.0	1633	100.0	0	0.0	
18	118.00	605	2763	2924.2	605	100.0	605	100.0	0	0.0	
19	119.00	2521	4904	1245.1	2521	100.0	2521	100.0	0	0.0	
20	120.00	765	4857	4064.5	765	100.0	765	100.0	0	0.0	
21	121.00	577	4213	4669.4	577	100.0	577	100.0	0	0.0	
22	122.00	1084	6499	3838.0	1084	100.0	1084	100.0	0	0.0	
23	123.00	3629	6468	1140.5	3629	100.0	3629	100.0	0	0.0	
24	124.00	3575	2610	467.3	0	0.0	1260	35.3	1260	100.0	YES
25	125.00	895	2657	1899.5	895	100.0	895	100.0	0	0.0	
26	126.00	582	3910	4298.3	582	100.0	582	100.0	0	0.0	
27	127.00	874	6118	4480.7	874	100.0	874	100.0	0	0.0	
28	128.00	1066	4327	2597.9	1066	100.0	1066	100.0	0	0.0	
29	129.00	703	3231	2940.9	703	100.0	703	100.0	0	0.0	
30	130.00	1717	7023	2617.9	1717	100.0	1717	100.0	0	0.0	
31	131.00	1503	1259	535.9	0	0.0	1048	69.7	1048	100.0	YES
32	132.00	1539	4820	2004.3	1539	100.0	1539	100.0	0	0.0	
33	133.00	792	5042	4074.0	792	100.0	792	100.0	0	0.0	
34	134.00	1246	6535	3356.2	1246	100.0	1246	100.0	0	0.0	
35	135.00	5125	1717	214.4	0	0.0	442	8.6	442	100.0	
36	136.00	4247	5801	874.1	0	0.0	301	7.1	301	100.0	
37	137.00	817	4826	3780.7	817	100.0	817	100.0	0	0.0	
38	138.00	1176	7344	3996.0	1176	100.0	1176	100.0	0	0.0	
39	139.00	806	2793	2217.0	806	100.0	806	100.0	0	0.0	

Table B-1 (continuation 1)

---	CENSUS TRACT NUMBER	TOTAL ACRES PER TRACT	1970 POPULATION STATISTICS: NUMBERS OF PEOPLE	1970 POPULATION STATISTICS: DENSITY PER MILE SQUARED	1970 URBANIZED LAND COVER STATISTICS: ACRES	1970 URBANIZED LAND COVER STATISTICS: PCT	1975 URBANIZED LAND COVER STATISTICS: ACRES	1975 URBANIZED LAND COVER STATISTICS: PCT	URBANIZED LAND COVER CHANGE BETWEEN 1970 AND 1975: ACRES	URBANIZED LAND COVER CHANGE BETWEEN 1970 AND 1975: PCT	URBANIZED LAND COVER CHANGE BETWEEN 1970 AND 1975: MAJOR
40	140.00	1942	5020	1654.2	1942	100.0	1942	100.0	0	0.0	
41	141.00	2484	4045	1042.2	2484	100.0	2484	100.0	0	0.0	
42	142.00	1195	4902	2624.9	1195	100.0	1195	100.0	0	0.0	
43	143.00	1830	6168	2157.6	1830	100.0	1830	100.0	0	0.0	
44	144.00	895	2864	2047.5	895	100.0	895	100.0	0	0.0	
45	145.00	1702	2127	800.0	0	0.0	403	23.7	403	100.0	YES
46	146.00	4390	10129	1476.8	4390	100.0	4390	100.0	0	0.0	
47	147.00	3437	3031	564.3	0	0.0	662	19.2	662	100.0	YES
48	148.00	15705	3373	137.5	0	0.0	1278	8.1	1278	100.0	
49	149.00	5100	2908	364.9	0	0.0	739	14.5	739	100.0	YES
50	150.00	5014	4558	581.8	0	0.0	146	2.9	146	100.0	
51	151.00	5075	6331	798.4	0	0.0	130	2.6	130	100.0	
52	152.00	2762	6479	1501.5	2762	100.0	2762	100.0	0	0.0	
53	153.00	950	4285	2887.5	950	100.0	950	100.0	0	0.0	
54	154.00	1187	4936	2661.6	1187	100.0	1187	100.0	0	0.0	
55	155.00	1897	3468	1169.9	1897	100.0	1897	100.0	0	0.0	
56	156.00	1000	4908	3142.5	1000	100.0	1000	100.0	0	0.0	
57	157.00	952	3181	2138.2	952	100.0	952	100.0	0	0.0	
58	158.00	1032	4286	2659.1	1032	100.0	1032	100.0	0	0.0	
59	159.00	717	4361	3590.7	717	100.0	717	100.0	0	0.0	
60	160.00	964	4216	2799.0	964	100.0	964	100.0	0	0.0	
61	161.00	1142	4355	2441.0	1142	100.0	1142	100.0	0	0.0	
62	162.00	804	6235	4963.7	804	100.0	804	100.0	0	0.0	
63	163.00	1157	6162	3407.8	1157	100.0	1157	100.0	0	0.0	
64	164.00	7420	3959	341.5	0	0.0	687	9.3	687	100.0	
65	165.00	9319	4067	279.3	0	0.0	0	0.0	0	0.0	
66	166.00	88141	2224	16.1	0	0.0	6	0.0	6	100.0	
67	167.00	157858	7379	29.9	0	0.0	1483	0.9	1483	100.0	
68	168.00	41116	6369	99.1	0	0.0	2864	7.0	2864	100.0	
69	169.00	3943	5371	871.9	0	0.0	1374	34.9	1374	100.0	YES
70	170.00	24780	3345	86.4	0	0.0	1351	5.5	1351	100.0	
71	171.00	76679	3817	31.9	0	0.0	2406	3.1	2406	100.0	
72	172.00	1749	1007	368.5	0	0.0	0	0.0	0	0.0	
73	173.00	1240	2911	1502.1	1240	100.0	1240	100.0	0	0.0	
74	174.00	2554	4811	1205.6	2554	100.0	2554	100.0	0	0.0	
75	175.00	14725	5823	253.1	0	0.0	1327	9.0	1327	100.0	
76	176.00	787	2633	2140.3	787	100.0	787	100.0	0	0.0	
77	177.00	2795	3197	732.1	0	0.0	72	2.6	72	100.0	
78	178.00	30054	4600	98.0	0	0.0	1694	5.6	1694	100.0	

Table B-1. (continuation 2)

---	CENSUS TRACT NUMBER	TOTAL ACRES PER TRACT	1970 POPULATION STATISTICS: NUMBERS OF PEOPLE	1970 POPULATION STATISTICS: DENSITY PER MILE SQUARED	1970 URBANIZED LAND COVER STATISTICS: ACRES	1970 URBANIZED LAND COVER STATISTICS: PCT	1975 URBANIZED LAND COVER STATISTICS: ACRES	1975 URBANIZED LAND COVER STATISTICS: PCT	URBANIZED LAND COVER CHANGE BETWEEN 1970 AND 1975: ACRES	URBANIZED LAND COVER CHANGE BETWEEN 1970 AND 1975: PCT	URBANIZED LAND COVER CHANGE BETWEEN 1970 AND 1975: MAJOR
79	179.00	30379	3533	74.4	0	0.0	2026	6.7	2026	100.0	
80	201.00	445	2842	4090.6	445	100.0	445	100.0	0	0.0	
81	202.00	596	3244	3481.1	596	100.0	596	100.0	0	0.0	
82	203.00	732	3253	2845.8	732	100.0	732	100.0	0	0.0	
83	204.00	1359	4750	2237.2	1359	100.0	1359	100.0	0	0.0	
84	205.00	647	3223	3186.2	647	100.0	647	100.0	0	0.0	
85	206.00	4349	1461	215.0	0	0.0	294	6.8	294	100.0	
86	207.00	21553	1637	48.6	0	0.0	471	3.1	671	100.0	
87	208.00	12496	3889	199.2	0	0.0	1383	11.1	1383	100.0	YES
88	209.00	3130	5876	1201.4	3130	100.0	3130	100.0	0	0.0	
89	210.00	11803	943	51.1	0	0.0	684	5.8	684	100.0	
90	211.00	3545	2845	513.6	0	0.0	0	0.0	0	0.0	
91	212.00	64934	2131	21.0	0	0.0	0	0.0	0	0.0	
92	213.00	26394	3620	87.8	0	0.0	0	0.0	0	0.0	
93	214.00	6035	1650	175.0	0	0.0	636	10.5	636	100.0	YES
94	215.00	5227	4940	604.9	0	0.0	285	5.4	285	100.0	
95	216.00	11830	3519	190.4	0	0.0	1253	10.6	1253	100.0	YES
96	217.00	4705	5620	764.5	0	0.0	489	10.4	489	100.0	YES
97	218.00	2356	7034	1910.8	2356	100.0	2356	100.0	0	0.0	
98	219.00	2077	3744	1153.5	2077	100.0	2077	100.0	0	0.0	
99	220.00	2633	7913	1923.1	2633	100.0	2633	100.0	C	0.0	
100	221.00	4526	3865	546.5	0	0.0	726	16.0	726	100.0	YES
101	222.00	5517	5693	660.4	0	0.0	480	8.7	480	100.0	
102	NO TRACT	1161155	0	0.0	0	0.0	0	0.0	0	0.0	
		1960873	428009		77365		105964		28599		

Table B-2.

URBANIZED LAND COVER STATISTICS FOR THE SEATTLE SMSA
SEATTLE, WASHINGTON   1970 AND 1975
BUREAU OF CENSUS ASVT
JET PROPULSION LABORATORY - IMAGE PROCESSING LABORATORY

1970 STATISTICS BASED ON THE 1970 CENSUS OF POPULATION AND HOUSING
US BUREAU OF THE CENSUS

1975 STATISTICS BASED ON LAND COVER CLASSIFICATION OF LANDSAT IMAGERY
LEN GAYTUS   USGS   MENLO PARK, CALIFORNIA

			1970 POPULATION STATISTICS		1970 URBANIZED LAND COVER STATISTICS		1975 URBANIZED LAND COVER STATISTICS		URBANIZED LAND COVER CHANGE BETWEEN 1970 AND 1975		
SEQ	CENSUS TRACT NUMBER	SQUARE MILES PER TRACT	NUMBERS OF PEOPLE	DENSITY PER SQ MI	SQ MI	PCT	SQ MI	PCT	SQ MI	PCT	GT 10 PCT
23	23.00	0.70	200	284.9	0.0	0.0	0.58	82.5	0.58	82.5	YES
55	55.00	1.09	466	427.1	0.0	0.0	0.63	58.0	0.63	58.0	YES
93	93.00	3.66	1541	420.8	0.0	0.0	3.44	94.0	3.44	94.0	YES
158	237.00	3.08	2074	674.0	0.0	0.0	2.06	66.8	2.06	66.8	YES
171	250.00	15.98	5101	319.3	0.0	0.0	1.44	9.0	1.44	9.0	
180	259.00	3.39	306	90.3	0.0	0.0	1.61	47.4	1.61	47.4	YES
198	277.00	37.14	6516	175.5	0.0	0.0	5.33	14.4	5.33	14.4	YES
204	283.00	3.47	3450	994.1	0.0	0.0	1.58	45.5	1.58	45.5	YES
213	292.00	10.23	6950	679.2	0.0	0.0	5.30	51.8	5.30	51.8	YES
217	296.00	4.11	3271	796.5	0.0	0.0	0.92	22.4	0.92	22.4	YES
220	299.00	4.36	2957	677.8	0.0	0.0	1.43	32.9	1.43	32.9	YES
224	303.00	12.46	9447	758.4	0.0	0.0	4.58	36.8	4.58	36.8	YES
225	304.00	9.12	5262	577.3	0.0	0.0	2.49	27.3	2.49	27.3	YES
226	305.00	6.24	5276	845.5	0.0	0.0	2.53	40.5	2.53	40.5	YES
230	309.00	3.01	2921	969.1	0.0	0.0	0.92	30.6	0.92	30.6	YES
231	310.00	4.83	169	35.0	0.0	0.0	0.53	11.0	0.53	11.0	YES
233	312.00	23.42	4489	191.7	0.0	0.0	3.61	15.4	3.61	15.4	YES
234	313.00	37.30	4474	119.9	0.0	0.0	2.04	5.5	2.04	5.5	
236	315.00	100.68	3165	31.4	0.0	0.0	1.90	1.9	1.90	1.9	
237	316.00	38.20	4315	112.9	0.0	0.0	2.54	6.7	2.54	6.7	
238	317.00	9.23	5829	631.7	0.0	0.0	3.07	33.2	3.07	33.2	YES
239	318.00	11.37	2606	229.1	0.0	0.0	1.11	9.8	1.11	9.8	
240	319.00	19.73	11117	563.6	0.0	0.0	3.72	18.8	3.72	18.8	YES
241	320.00	63.76	8856	138.9	0.0	0.0	4.03	6.3	4.03	6.3	
24[illegible]	321.00	55.08	7145	129.7	0.0	0.0	2.02	3.7	2.02	3.7	
24[illegible]	322.00	42.21	5337	126.4	0.0	0.0	2.82	6.7	2.82	6.7	
244	323.00	81.39	13246	162.7	0.0	0.0	8.83	10.8	8.83	10.8	YES
245	324.00	32.69	1767	54.1	0.0	0.0	0.63	1.9	0.63	1.9	
246	326.00	24.02	2453	102.1	0.0	0.0	1.34	5.6	1.34	5.6	
259	413.00	7.54	3819	506.5	0.0	0.0	2.51	33.3	2.51	33.3	YES
261	415.00	2.67	1255	470.7	0.0	0.0	0.84	31.5	0.84	31.5	YES
262	416.00	9.98	7079	709.3	0.0	0.0	2.20	22.1	2.20	22.1	YES
265	419.00	6.12	4983	814.0	0.0	0.0	2.57	42.0	2.57	42.0	YES
266	420.00	7.50	2832	377.8	0.0	0.0	1.16	15.4	1.16	15.4	YES
272	506.00	1.25	[illegible]79	702.2	0.0	0.0	0.34	27.0	0.34	27.0	YES
284	518.00	3.61	3564	987.1	0.0	0.0	1.36	37.7	1.36	37.7	YES
285	519.00	28.03	21558	769.0	0.0	0.0	8.46	30.2	8.46	30.2	YES
286	520.00	6.54	1313	200.6	0.0	0.0	1.42	21.6	1.42	21.6	YES
287	521.00	52.68	5116	97.1	0.0	0.0	3.82	7.3	3.82	7.3	
288	522.00	59.75	7127	119.3	0.0	0.0	2.64	4.4	2.64	4.4	
289	523.00	55.74	2853	51.2	0.0	0.0	0.97	1.7	0.97	1.7	
291	525.00	28.55	5223	183.0	0.0	0.0	3.89	13.6	3.89	13.6	YES
292	526.00	17.13	6568	383.3	0.0	0.0	1.73	10.1	1.73	10.1	YES
293	527.00	26.56	3927	147.8	0.0	0.0	1.07	4.0	1.07	4.0	
294	528.00	11.99	7252	604.7	0.0	0.0	3.83	31.9	3.83	31.9	YES
296	530.00	35.75	3028	84.7	0.0	0.0	2.57	7.2	2.57	7.2	
297	531.00	20.39	1943	95.3	0.0	0.0	1.33	6.5	1.33	6.5	
298	532.00	29.18	1707	58.5	0.0	0.0	2.84	9.7	2.84	9.7	
299	533.00	43.80	4154	94.8	0.0	0.0	2.97	6.8	2.97	6.8	
300	534.00	49.25	1439	29.2	0.0	0.0	1.30	2.6	1.30	2.6	
301	535.00	165.19	6714	40.6	0.0	0.0	4.93	3.0	4.93	3.0	
		1331.15	235039		0.0		127.79		127.79		

APPENDIX C

COMPUTER PROCESSING TIMINGS

Three tables containing timings of major computer processing steps for the three Census-Urbanized Area ASVT applications have been compiled. Timings refer to data processing on an IBM 360-65 located at JPL. Both the elapsed time (wall-clock time) and the compute time (central processing unit time) have been tallied in minutes of execution.

The table summarizing the Orlando application is most detailed, and has been divided into two segments, IBIS and VICAR processing steps. Processing summaries for the Seattle-Everett and Boston applications have been listed in the sequence of execution.

Table C-1. COMPUTER PROCESSING TIMINGS ORLANDO SMSA APPLICATION

IBIS Processing Steps	Timing in Minutes: Elapsed Time	Timing in Minutes: Compute Time
1. General surface fit of census tract file to planimetric base	15.39	2.87
2. Final adjustments to complete fit (rubber-sheeting)	11.40	4.48
3. Region identification (formation of the geo-reference plane)	32.99	11.22
4. Process census tract centroid data	11.17	2.05
5. Polygon overlay of geo-reference plane (to obtain 1970 area calculations)	6.71	1.17
6. Generate 1970 population statistics	1.58	0.25
7. Generate 1970 urbanized area map	39.41	16.55
8. Generate 1970-1975 urban expansion map (data plane integration)	23.31	3.13
9. Polygon overlay of expansion map and geo-reference plane (for statistics)	15.05	2.38
10. Derive statistics and report (urban expansion 1970-1975)	5.32	1.05
TOTAL IBIS PROCESSING TIME	162.33 (2:42.33)	45.17 (0:45.17)

VICAR Processing Steps	Timing in Minutes: Elapsed Time	Timing in Minutes: Compute Time
1. Logging of 1973 Landsat imagery (planimetric base)	131.28	52.35
2. Logging of 1975 Landsat imagery (for 1975 urbanized land cover)	79.10	56.50
3. Extraction of test area from 1973 imagery	11.80	1.97
4. Registration of 1975 imagery to 1973 imagery (rubber-sheeting)	40.04	7.98
5. Eigenvector transformations of 1973 and 1975 imagery	126.35	30.57
6. Mask water bodies from eigenvector 2 of both 1973 and 1975 imagery	16.80	4.62
7. Mapping of urban/non-urban land cover for both 1973 and 1975 imagery	24.73	4.75
TOTAL VICAR PROCESSING TIME	430.10 (7:10.10)	158.74 (2:38.74)
TOTAL PROCESSING TIME	592.43 (9:52.43)	203.89 (3:23.89)

Table C-2. COMPUTER PROCESSING TIMINGS SEATTLE-EVERETT SMSA APPLICATION

	TIMING IN MINUTES	
	ELAPSED TIME	COMPUTE TIME
1. General surface fit of census tract file to planimetric base	18.21	3.88
2. Final adjustments to complete fit (rubber-sheeting)	146.85	56.77
3. Region identification (formation of the geo-reference plane)	79.59	31.28
4. Process census tract centroid data	57.71	29.64
5. Polygon overlay of geo-reference plane (to obtain 1970 area calculations)	3.34	2.12
6. Generate 1970 population statistics	1.48	0.31
7. Generate 1970 urbanized area map	41.83	12.56
8. Extract 1975 land cover data from larger classification image	5.96	1.40
9. Generate 1970-1975 urban expansion map (data plane integration)	62.00	22.09
10. Polygon overlay of expansion map and geo-reference plane (for statistics)	28.05	6.35
11. Derive statistics and report urban expansion 1970-1975	5.58	1.62
TOTAL PROCESSING TIME	450.60 (7:30.60)	166.62 (2:46.62)

Table C-3. COMPUTER PROCESSING TIMINGS BOSTON REGION APPLICATION

	Timing in Minutes: Elapsed Time	Timing in Minutes: Compute Time
1. Logging of 1977 imagery (2 images required)	225.66	89.68
2. Extraction of test region (including modification of resolution to 57 meters)	274.23	26.00
3. General surface fit of inner line to planimetric base	5.49	0.68
4. Final adjustments to complete fit (rubber-sheeting)	57.31	10.00
5. Region identification and masking (1970 urbanized areas)	87.48	21.56
6. Preparation of color composite Landsat imagery	31.74	8.28
7. Data integration of Landsat and 1970 urbanized area data planes (black & white)	75.44	22.78
8. Data integration of Landsat and 1970 urbanized area data planes (color)	61.37	12.18
TOTAL PROCESSING TIME	818.72 (7:30.60)	191.16 (2:46.62)

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