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CENTRAL ATLANTIC REGIONAL ECOLOGICAL TEST SITE: A PROTOTYPE REGIONAL ENVIRONMENTAL INFORMATION SYSTEM

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By

Robert H. Alexander

U.S. Geological Survey

FINAL REPORT—VOLUME 1

CENTRAL ATLANTIC REGIONAL ECOLOGICAL TEST SITE (CARETS) PROJECT

SPONSORED BY
National Aeronautics and Space Administration
Goddard Space Flight Center
Greenbelt, Maryland 20771
and
U.S. Geological Survey
Reston, Virginia 22092

1979

CENTRAL ATLANTIC REGIONAL ECOLOGICAL TEST SITE: A PROTOTYPE REGIONAL ENVIRONMENTAL INFORMATION SYSTEM

by Robert H. Alexander

U.S. Geological Survey
Reston, Virginia 22092

Recommendations contained in this report are the responsibility of the author and are not necessarily endorsed by the U.S. Geological Survey

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(continued on attached sheet)

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16. Abstracts (continued)

photographs rather than satellite multispectral scanner data. Among project recommendations are establishment of a network of regional land resource information centers, working toward improved compatibility of Federal, State and local information programs supportive of land use decisions.

LANDSAT FALSE-COLOR IMAGE MOSAIC OF NORTHEASTERN UNITED STATES

Approximate scale: 1:7,500,000

Mosaic compiled by General Electric Space Systems, Photographic Engineering Laboratory. EDC-010136

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PREFACE

The Central Atlantic Regional Ecological Test Site (CARETS) demonstration project, in its lifetime of five years, attempted to examine the conditions under which elements of space technology might assist in the solving of environmental problems. The method chosen was to analyze patterns and processes of land use, the dynamics of which can be observed with orbiting remote sensors.

We thank the sponsoring agencies, the National Aeronautics and Space Administration (NASA) and the U.S. Geological Survey (USGS), for funds, administrative support, and patience. We also thank the many cooperating organizations, especially the Metropolitan Washington Council of Governments, the Southeast Virginia Planning District Commission, the Maryland State Planning Office, the International Geographical Union Commission on Geographical Data Sensing and Processing, and the Canada Geographic Information System, an agency of the Department of Environment, Government of Canada.

Attempting to respond to the different requirements of the sponsors, and at the same time to a larger need for environmental information not yet fully articulated by the region's land management institutions, we strove to cut across traditional organizational boundaries and tap the reservoir of knowledge and talent that resides in many dedicated individuals who live and work in the central Atlantic region. We also attempted to cut across traditional scientific discipline boundaries, though incorporating the contributions of specialists. Our hope was that the interactions among researchers with different specialties would somehow help us better understand the complex processes governing how people and their works interact with the land, water, and air resources. Decisionmakers and creators of institutions that deal with various aspects of the environment are also incorporated into the investigation.

We wanted to integrate the results into a cohesive analysis that would permit viewing the test region in a holistic sense, as a set of interrelated phenomena and processes, as a component of the worldwide terrestrial ecosystem--views which are indeed suggested by examining a small-scale image of the region obtained from satellite sensors orbiting 900 kilometers above the Earth's surface (frontispiece).

While the results fell short of our goals and expectations, we feel that the documentation of our successes and failures will be useful to those who follow. In addition to the formal reports, maps and data summaries that are the tangible products of the effort, many indirect benefits from CARETS have been realized through contacts with other investigators and through direct program developments that have grown out of the CARETS experience, for example, certain components of the USGS Land Use and Land Cover Mapping Program. The flow of benefits goes both ways, however, and it is appropriate here to acknowledge the contributions of the following individuals who coordinated, advised, approved, reviewed, or otherwise participated in the CARETS Project.

Edward A. Ackerman
Paul Alfonsi
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Robert Anderson
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Roger F. Tomlinson
Willem Van Veldheusen
Richard S. Williams, Jr.
Charles F. Withington
Richard E. Witmer
Priscilla Woll
James R. Wray

While the above-mentioned individuals provided valuable assistance in many ways, the absolutely essential component of the CARETS project was supplied by the core team of USGS geographers who did the full-time work: examining and interpreting thousands of aerial photographs and Landsat images, drafting the land use maps and the other maps which constitute the CARETS data base, checking land use interpretations in the field, assisting users at workshops and in the CARETS information center, answering crisis calls for presentations to sponsors, and doing

the bulk of the report writing in the project's final phases. These key individuals in the CARETS core team are: Peter J. Buzzanell, Peter W. DeForth, Katherine A. Fitzpatrick-Lins, Ivan L. Hardin, Harry F. Lins, Jr., and Herbert K. McGinty, III.

Katherine Cook managed the typing and manuscript preparation for all the CARETS final reports, assisted by Cynthia Cunningham, Darleen Anderson, and Marilyn Sullivan. Sheryl Kipnis, Jacqueline Myers, Cynthia Cunningham, and Edna Burkett typed this final report summary volume. Maps and graphics were handled by Patricia Kewer and Karen Letke.

While all of the above-named individuals deserve credit for their contribution to the CARETS project and to the present final summary report, errors and omissions remain the responsibility of the author.

*The use of brand names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

LIST OF FINAL REPORT VOLUMES

(CARETS)/Landsat Investigation SR-125 (IN-002)

Robert H. Alexander, Principal Investigator

Volume 1. CENTRAL ATLANTIC REGIONAL ECOLOGICAL TEST SITE: A PROTOTYPE REGIONAL ENVIRONMENTAL INFORMATION SYSTEM by Robert H. Alexander.

2. NORFOLK AND ENVIRONS: A LAND USE PERSPECTIVE by Robert H. Alexander, Peter J. Buzzanell, Katherine A. Fitzpatrick, Harry F. Lins, Jr., and Herbert K. McGinty III.

3. TOWARD A NATIONAL LAND USE INFORMATION SYSTEM by Edward A. Ackerman and Robert H. Alexander.

4. GEOGRAPHIC INFORMATION SYSTEM DEVELOPMENT IN THE CARETS PROJECT by William B. Mitchell, Robin G. Fegeas, Katherine A. Fitzpatrick, and Cheryl A. Hallam.

5. INTERPRETATION, COMPILATION AND FIELD VERIFICATION PROCEDURES IN THE CARETS PROJECT by Robert H. Alexander, Peter W. DeForth, Katherine A. Fitzpatrick, Harry F. Lins, Jr., and Herbert K. McGinty III.

6. COST-ACCURACY-CONSISTENCY COMPARISONS OF LAND USE MAPS MADE FROM HIGH-ALTITUDE AIRCRAFT PHOTOGRAPHY AND ERTS IMAGERY by Katherine A. Fitzpatrick.

7. LAND USE INFORMATION AND AIR QUALITY PLANNING: AN EXAMPLE OF ENVIRONMENTAL ANALYSIS USING A PILOT NATIONAL LAND USE INFORMATION SYSTEM by Wallace E. Reed and John E. Lewis.

8. APPLICATION OF REMOTELY-SENSED LAND USE INFORMATION TO IMPROVE ESTIMATES OF STREAMFLOW CHARACTERISTICS by Edward J. Pluhowski.

9. SHORE ZONE LAND USE AND LAND COVER: CENTRAL ATLANTIC REGIONAL ECOLOGICAL TEST SITE by Robert Dolan, Bruce P. Hayden, and C. Lenwood Vincent.

10. ENVIRONMENTAL PROBLEMS IN THE COASTAL AND WETLANDS ECOSYSTEMS OF VIRGINIA BEACH, VIRGINIA by Peter J. Buzzanell and Herbert K. McGinty III.

11. POTENTIAL USEFULNESS OF CARETS DATA FOR ENVIRONMENTAL IMPACT ASSESSMENT by Peter J. Buzzanell.

12. USER EVALUATION OF EXPERIMENTAL LAND USE MAPS AND RELATED PRODUCTS FROM THE CENTRAL ATALNTIC TEST SITE by Herber K. McGinty III.

13. UTILITY OF CARETS PRODUCTS TO LOCAL PLANNERS: AN EVALUATION by Stuart W. Bendelow and Franklin F. Goodyear (Metropolitan Washington Council of Governments).

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Note--Illustrations originally in color are identified in their caption by an EDC-01000_ number. Copies of the original color are available for purchase from the EROS Data Center, Sioux Falls, South Dakota 57198, using the EDC number. Prices are available on request.

Tables

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CENTRAL ATLANTIC REGIONAL ECOLOGICAL TEST SITE: A PROTOTYPE REGIONAL ENVIRONMENTAL INFORMATION SYSTEM

By Robert H. Alexander

Abstract

The Central Atlantic Regional Ecological Test Site (CARETS) project, was a demonstration project for introducing data from Landsat and high-altitude aircraft sensors into regional land planning and management. This report summarizes the CARETS project results and describes its output of maps, reports, computer tapes, and other products. CARETS used a geographic information system model under which land use maps were prepared from sensor data, then digitized, processed, and linked to other environmental and social data sets, and to environmental consequences such as air pollution, stream runoff, local climatic factors, and coastal erosion. Landsat data showed the test region in 1972 to be nine percent urban and built-up land, 38 percent agriculture, 50 percent forest, three percent nonforested wetlands, and less than one percent barren land, exclusive of water-covered areas. User surveys, conferences, and workshops involving 65 agencies facilitated widespread distribution of data products and produced evaluations concerning their usefulness. We found a heterogeneous user community with diverse information needs, largely preferring aerial photographs rather than satellite multispectral scanner data. Among project recommendations are establishment of a network of regional land resource information centers, working toward improved compatibility of Federal, State and local information programs supportive of land use decisions. "Color of illustrations EDC-010136 to EDC-01042 are available from the EROS Data Center."

CHAPTER 1

SYNOPSIS: EXECUTIVE SUMMARY

The Central Atlantic Regional Ecological Test Site (CARETS) was selected as a region for developing an experimental environmental information system incorporating remote sensing data from satellites and high-altitude aircraft. During its 5-year lifetime CARETS functioned as a cooperative demonstration project involving organizations having research, planning, and management responsibilities supportive of land use decisionmaking. The goal was to improve the quality of the environment affected by those decisions.

Sponsored by the National Aeronautics and Space Administration (NASA) and the U.S. Geological Survey (USGS), the CARETS project employed an interdisciplinary methodology based on the remote sensors' capability to observe both physical environmental phenomena and surface features that result directly from human actions. This methodology enabled the project to address environmental relationships surrounding the issue of land use change.

Project investigators received remotely sensed data as input to the information system, and transformed those data into land use maps and quantitative representations of the information contained in the maps. Then both analyzed and unanalyzed data products were produced by the information system to assist in making decisions affecting future changes in the region. The CARETS "information systems" approach was intended to facilitate communication among scientists and nonscientist data users; scientists providing information on consequences of land use decisions and other elements of the complex environmental management process; and nonscientist administrators of local, State, and Federal government agencies with responsibility for making decisions such as changing a parcel of land from one use to another. More than 65 co-operating agencies were able to share in the experience of learning about the potential of the new remote sensing technology and associated computer processing methods.

TARGET AUDIENCE OF THIS REPORT

This report and the other 12 volumes of the final report documenting the results of the CARETS project may be useful to a broader audience than just the two sponsoring agencies. The intended audience includes those individuals and organizations having the following concerns:

- land use mapping
- computerized methods for handling land use information
- environmental planning
- applications of spaceborne and airborne remote sensor systems
- improving coordination of environmental programs at all levels of government

We expect that these concerned organizations would include local government agencies, regional councils of government, various State government agencies, river basin commissions, Federal regional commissions, multi-State organizations, and cabinet-level departments of the Federal Government, especially those having environmental data-gathering research or management functions. Because of the possible benefits from interagency coordination in the land use data field, the reports and/or summary recommendations are also addressed to appropriate functions within the Executive Office of the President.

Besides those interested in the CARETS results for policy reasons, an additional target group consists of those who may have use for the maps and data sets--land use and related data for portions of the mid-Atlantic seaboard covering the 74,000 km^2 of the test region (figure 1.1).

SUMMARY OF CARETS PROJECT ACHIEVEMENTS

The CARETS project developed and tested a regional environmental systems model for applying remote sensing data to the solving or mitigation of environmental problems. It developed experimental data products for input into land resource information programs. Tasks requiring the expertise of different specialists were organized into four experiment modules, closely related and integrated with each other.

The geographic information systems module employed digitizing and improved computer techniques for preparing the basic data sets in quantitative form. Cooperation with the Canada Geographic Information System (CGIS), an agency of the Government of Canada, made possible the use of their digitizing and area measurement capabilities via a polygon overlay technique, so that information on each land use type as mapped from aircraft and Landsat data could be made available to users, in numerical or graphic form, at any geographic level of aggregation or disaggregation.

The land use information module included the complete mapping of land use and land cover within the 74,000-km^2 test region from both aircraft (map scale 1:100,000), and Landsat (map scale 1:250,000) data. Other maps representing land use change were prepared, along with correlative maps indicating the location of drainage basin boundaries, landforms and surface materials, census and county administrative areas, and

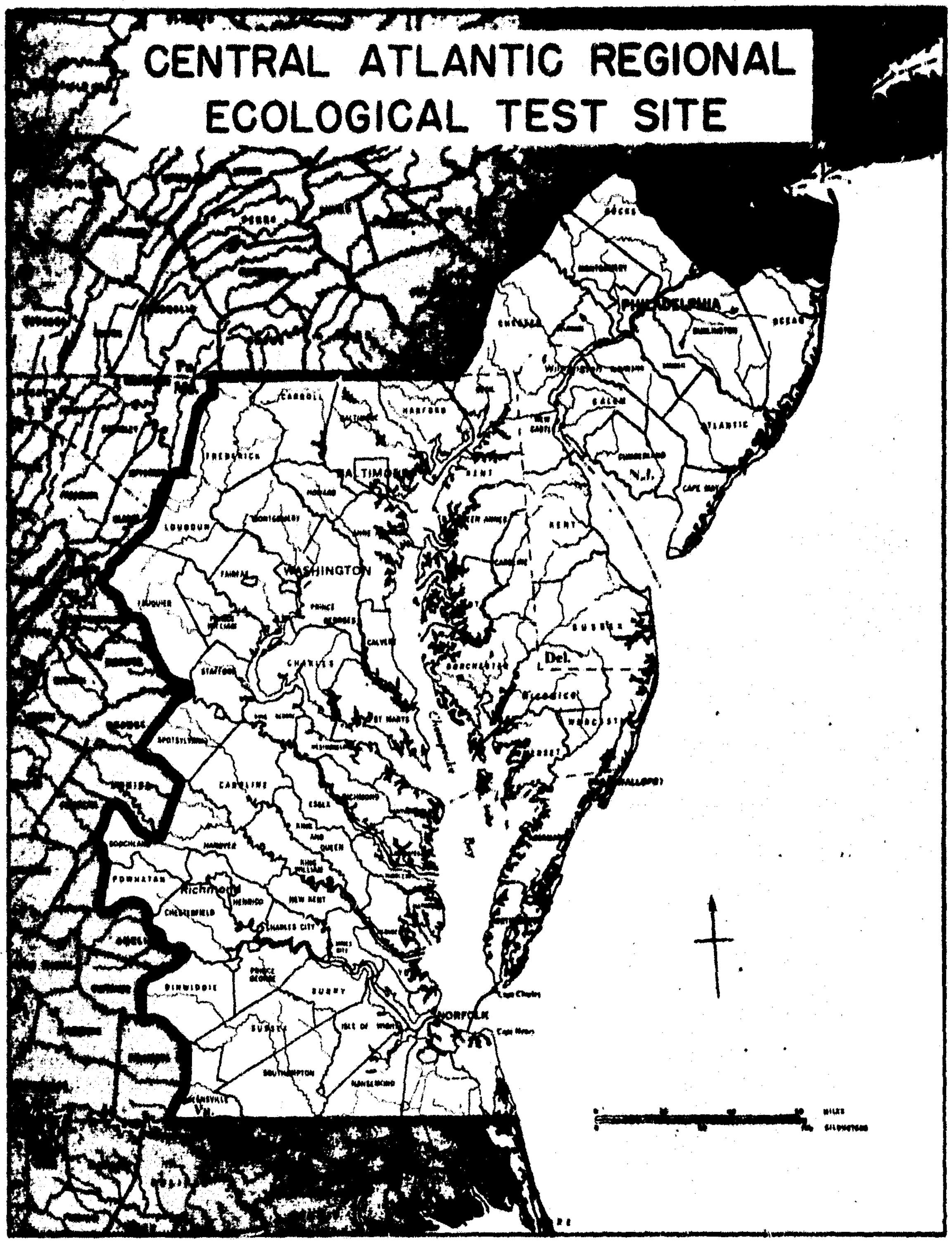
CENTRAL ATLANTIC REGIONAL
ECOLOGICAL TEST SITE
PHILADELPHIA
BALTIMORE
WASHINGTON
Richmond
NORFOLK
Del.
N.J.
Va.

Figure 1.1

cultural features and place names. Selected special purpose maps of smaller portions of the test region were produced to test various sampling methods, scales, and levels of classification for deriving land use information from remote sensor data. Accuracy and cost assessments were made of the various maps and data products.

The environmental impact module sought to identify and quantify linkages among land utilization processes and some of the corresponding responses in water and air resources systems, as well as constraints to land development imposed by surface geological conditions. A capability to improve streamflow estimates was demonstrated, based on adding land use data to standard estimation equations. This module also demonstrated applications of land use data to air quality management, coastal management, and in writing environmental impact statements.

The user interaction and evaluation module included contact with user institutions throughout the CARETS investigation. Conferences, workshops, interviews, and an experimental regional information center were utilized to familiarize users with the range of products and services available, or potentially available, from a system such as CARETS. The users commented on usefulness of the CARETS products with respect to agency functions. A comprehensive user evaluation revealed greatest demand for high-altitude aerial photography and the detailed maps and data products that could be derived therefrom. These metropolitan area agencies found relatively little use for Landsat imagery at 1:250,000 scale and corresponding manually-interpreted land use maps.

SUMMARY OF RECOMMENDATIONS

The CARETS project investigator, after a thorough evaluation of both the successes and failures of the 5-year demonstration project effort, recommends two types of procedural changes in the way the Federal Government directs its programs in remote sensing and land use information. The first recommendation is to address the immediate needs of public agencies at all levels of government for land use and related environmental impact information. The second set of recommendations calls for longer-range research and development aimed at adapting the content of future resource data systems, including land use and land cover mapping based on remote sensing sources, to emerging societal needs and abilities to assimilate the information.

Immediate Needs: Operational Remote Sensing Program

This recommendation calls for the establishment of an operational remote sensing program at the Federal level, made up of existing unclassified operational mapping programs plus the NASA high-altitude aircraft program which is at present assigned to research functions. It is believed that such a program could be created by adding a high-level coordination function and several regional-level information centers patterned after the CARETS project model, without changing existing legislation, adding to Federal employment totals, changing agency responsibilities, or increasing present budgets.

The most immediate remote sensing need in metropolitan regions is for aerial photographs, but the proposed operational system might soon be expanded to include satellite data. At the present time (1978) the major emphasis within NASA is on the research-oriented Landsat satellites and for a Landsat follow-on system in which resolution and sensor capabilities are increased somewhat. A requirement for an operational program has now been demonstrated; such a program should begin by supplying high-altitude aerial photographs immediately for data that are already required by Federal legislation and by those who must make land use planning and management decisions in metropolitan regions.

A coordinated system of regional information centers built along the lines of the CARETS model is recommended, to improve the likelihood that the Nation's large remote sensing and land use data-collecting capability will be applied where the needs are greatest. Along with a Federal-level directorate, these information centers would assure that the flow of users' requests into the system reach the scheduling operation of data producers, and conversely, that timely and coordinated information on Federal data-collection programs reaches the users. The regional information centers could also provide a much needed coordination of the rapidly proliferating computer software and hardware systems being adopted by Federal, regional, State, and local agencies--with scant attention presently given to data exchange or to overall effectiveness within a larger system of data producers and users.

Also recommended are immediate steps to fill a major gap blocking full acceptance of remote sensor systems. The gap is knowledge of how the data and land use information derived from remote sensors are put to use in the land use decisionmaking process. Increased effort is needed to help land use decisionmakers (individual, corporation, government agency) incorporate the information into environmentally beneficial

decisions. Results of this effort should help evaluate benefits of data programs, aid in setting priorities for data collection, and indicate how data presentation formats can be improved.

Long-Range Research and Development

The CARETS project experience indicates need for long-range research of two different specializations: one in the social-psychological realm would delve further into the ways individuals and groups process scientific information in the making of environmental decisions; and the other would try to extend our knowledge of the ways that large environmental systems operate--encompassing processes in the geophysical, biological, and socioeconomic realms. Better understanding of those systems would enable us to select more wisely from the enormous quantities of environmental data that modern remote sensor systems are capable of obtaining; and coupling long-range planetwide environmental monitoring activities more closely with remote sensor systems would strengthen and increase the importance of the combined aircraft and satellite data-gathering programs.

ORGANIZATION OF THE FINAL REPORT DOCUMENTATION

The present report is the first volume, and also the summary volume, of a 13-volume set of reports which constitute the official final report to NASA and USGS on the CARETS project. Relationships of the material covered in each chapter of the summary volume, and each volume of the 13-volume set, to the four project modules and to the overview and integration of results, are indicated in table 1.1.

Table 1.1.--Organization of major topics in CARETS summary report (volume 1) and in 13-volume set containing final report

Report Volumes and Chapters	Topics Covered: Project Summary, Overview, Integration of Modular Elements, and Recommendations	Geographical Information Systems	Land Use Information and Regional Data Base	Environmental Impact Applications	User Interaction and Evaluations
Volume 1 (This report)	Chapters 1, 2, 7, 8, 9	Chapter 3	Chapter 4	Chapter 5	Chapter 6
13-Volume Set	Volumes 1, 2, 3	Volume 4	Volumes 5, 6	Volumes 7, 8, 9 10, 11	Volumes 12, 13

Organization of This Report (Volume 1)

Chapter 1: Executive summary, containing CARETS project summary description, intended target audience for the report, project achievements, and selected recommendations.

Chapter 2: Introduction to the main body of the report, background and contributory concepts, project goals, objectives, and operational approach.

Chapters 3, 4, 5, and 6: Project results, as described under the headings of the four project modules: geographic information systems, land use information and regional data base, land use and environmental impact, and user interaction and evaluation.

Chapter 7: Analytical applications--examples of the use of CARETS products and a CARETS-type information system to assist in environmental management, planning, and problem-solving.

Chapter 8: Project critique and evaluation--critique and evaluation of the CARETS project both by expert outside reviewers and by the principal investigator.

Chapter 9: Summary and recommendations--project summary and principal investigator's recommendations based on experience as manager of interdisciplinary, interagency land use and environmental demonstration project.

Appendices: Lists of reports, data products, data summaries, comparisons of Landsat-derived data with data from other sources.

The Thirteen Volume Series Constituting the Final Report

Volumes 1, 2, and 3: Reports containing summaries, recommendations and integrative presentations of all modular components of the CARETS project; volume 2 being a detailed report summarizing application of project results to the Norfolk-Portsmouth SMSA, a small portion of the total test site; volume 3 being the results of a study recommending the extension of CARETS-type system to the development of a national land use information system.

Volume 4: The report of the geographic information systems module and its extension to become an operational element in the USGS Geography Program.

Volumes 5 and 6: Descriptions and summaries of the land use information module, including the procedures that were used to interpret the remote sensing data and compile and verify the land use maps, as well as a summary of the cost and accuracy information developed to better describe the final map products.

Volumes 7, 8, 9, 10, and 11: Reports dealing with the environmental impact module, including discussions of the interrelations of land use and air quality, streamflow characteristics, coastal zone eco-systems, plus a discussion of environmental impact statements in the CARETS region and their relationships to CARETS-type information.

<u>Volumes 12 and 13</u>: Summaries of the user interaction and evaluation module, with the detailed results of the CARETS project user survey, and a report on user reactions and relevant land use decisions in the area of the Metropolitan Washington Council of Governments.

CHAPTER 2

CARETS: BACKGROUND, OBJECTIVES, AND DESIGN

This chapter introduces the Central Atlantic Regional Ecological Test Site (CARETS) project, the purposes of which were to test and demonstrate the use of remote sensing systems for obtaining land use and related environmental information, and to deliver such information to users so that improved land use and environmental decisions would be possible. The chapter first presents a brief introduction to the CARETS concept followed by a discussion of its major developmental and contributory themes. Next is a brief description of the test region and the salient aspects of its geography. Completing this chapter are a definition and explanation of CARETS project objectives and goals, with a concluding section on the project methodology and research design.

INTRODUCTION TO THE CARETS CONCEPT

CARETS is one of the original regional sites designated in 1970 by the National Aeronautics and Space Administration (NASA) for comprehensive evaluations of data from what was then known as the Earth Resources Technology Satellite (ERTS), later renamed Landsat. The evaluations included use of airborne remote sensing systems both to simulate Landsat data prior to their availability, and to serve as verification and accuracy checks on Landsat interpretations. The few regional test sites contrasted with the many local or single-purpose test sites which had up to that time occupied most of the efforts of the NASA remote sensing program. In the single-purpose sites data obtained from test aircraft or from field or laboratory measurements were used in experiments on the remote detection and identification of one or a small number of environmental "target" phenomena, for example, landforms, rocks, soils, agricultural crops, forest types, etc. The regional sites were intended to economize on the use of test aircraft by concentrating many investigators in an area where fewer overflights would suffice. In addition, NASA's ecological test site concept required that the contributions of a number of discipline specialists be integrated to better illustrate how the various disciplines were interrelated and to take better into account the interactions of natural resource systems. The regional demonstrations were also expected to reach a broad segment of the potential users.

The CARETS project was carried out in the U.S. Geological Survey Geographic Applications Program (now the Geography Program of the USGS Land Information and Analysis Office), and set as its framework for testing the remote sensor systems the development of a regional land resources information system. The rationale and design of the CARETS experimental information system are based on a fact and an assumption. The fact is that land use decisions inevitably lead to environmental consequences. The assumption is that improved information on the cumulative effects of those decisions, i.e., the mosaic of observable land use patterns and changes, leads to better decisions, improved quality of the environment, and wiser use of our land resources. The CARETS project may thus be thought of as an interdisciplinary experiment examining the three component system "people/land use/environmental quality."

Objectives

The long-range goal of the project is improvement in environmental quality through improved understanding of the workings of environmental processes and interrelationships. From this goal are derived a set of 12 specific project objectives, listed in table 2.1, and linked together in a project structure called the CARETS concept, as explained and derived in later sections of this chapter.

Data Sources

Land use and land cover data extracted from the output of high-altitude aircraft and Landsat sensors constitute the primary inputs to the CARETS experimental information system. Other data are added, however, as required to make the best use of the remote sensor data to assist in the land resource management and planning processes. Examples include data on soils, surficial geology, hydrology, climate, vegetation, agricultural production, population, housing, pollution, etc. The "raw" remotely sensed data in various image formats were also treated as data products for potential use in environmental management. The intent of the experiment has been to build linkages between the technology and the users through specially prepared assemblages of remotely sensed data and comparable data sets on land use, socioeconomic factors relevant to land use planning, and related environmental quality measures.

Table 2.1.--CARETS project objectives

1. Test hypothesis that Landsat can become an operational input to the regional environmental information system in the CARETS test area.

2. Compare aircraft- and Landsat-derived data to ascertain validity of Landsat interpretation and to provide measures of accuracy of Landsat-derived land use data.

3. Establish a land use data base in graphic (map) form for the central Atlantic region, and monitor land use change.

4. Establish a regional environmental data base in digital, machine-readable format, with both numerical and graphic output capability.

5. Study environmental processes as they affect land use choices and as they affect the environmental impact of land use changes.

6. Employ an integrated ecological approach, including environmental process studies and modeling of alternative futures for the central Atlantic region.

7. Establish an experimental land use and environmental information service for users.

8. Cooperate with user agencies in supplying needed data and in seeking evaluation of experimental data products.

9. Reach the regional land use decisionmakers with accurate and timely land use information derived from the remote sensor sources and incorporated with appropriate information from other sources.

10. Improve environmental quality and mitigate environmental problems through the improved decisions that result from availability of timely remote sensing data.

11. Build the CARETS experimental information system as a prototype of a new USGS operational program.

12. Incorporate the CARETS system into a regional operational remote sensing-based information system, with appropriate linkages among agencies of Federal, State, and local levels of government.

Information Flow Through Experimental Information System

The CARETS project has a rather complex structure, with information flow modules arranged in such a way as to mimic the typical sequence of steps in an environmental problem-solving situation. The complexities of the information flow structure are displayed in greater detail in later sections of this report. The project structure is illustrated in a greatly simplified diagram in figure 2.1. Since the diagram in figure 2.1 represents a closed loop, the system can be entered at any of the parts. For example, beginning with the part on the right-hand side, "applications to regional environmental management," we define a problem or problems which are of concern to the governmental agencies or other institutions responsible for planning or managing the use of the land and other natural resources. Definition of specific problems relating to environmental management leads out of the right-hand part and over to the left-hand part of the diagram, "remotely sensed data input." Remotely sensed data from the high-altitude aircraft and satellite platforms will be acquired, run through preliminary processing, and organized into photomosaics and land use maps for delivery to the "geographic information system for processing, calibrating, and delivering processed information." A feedback loop from the right-hand segment of the diagram also goes around to the uppermost segment, "other data as required," indicating that remote sensing is only one source of the many kinds of information that will be required for solution or mitigation of the problem specified. Remotely sensed data, and other data as required, will be combined in formats which will be translatable to map

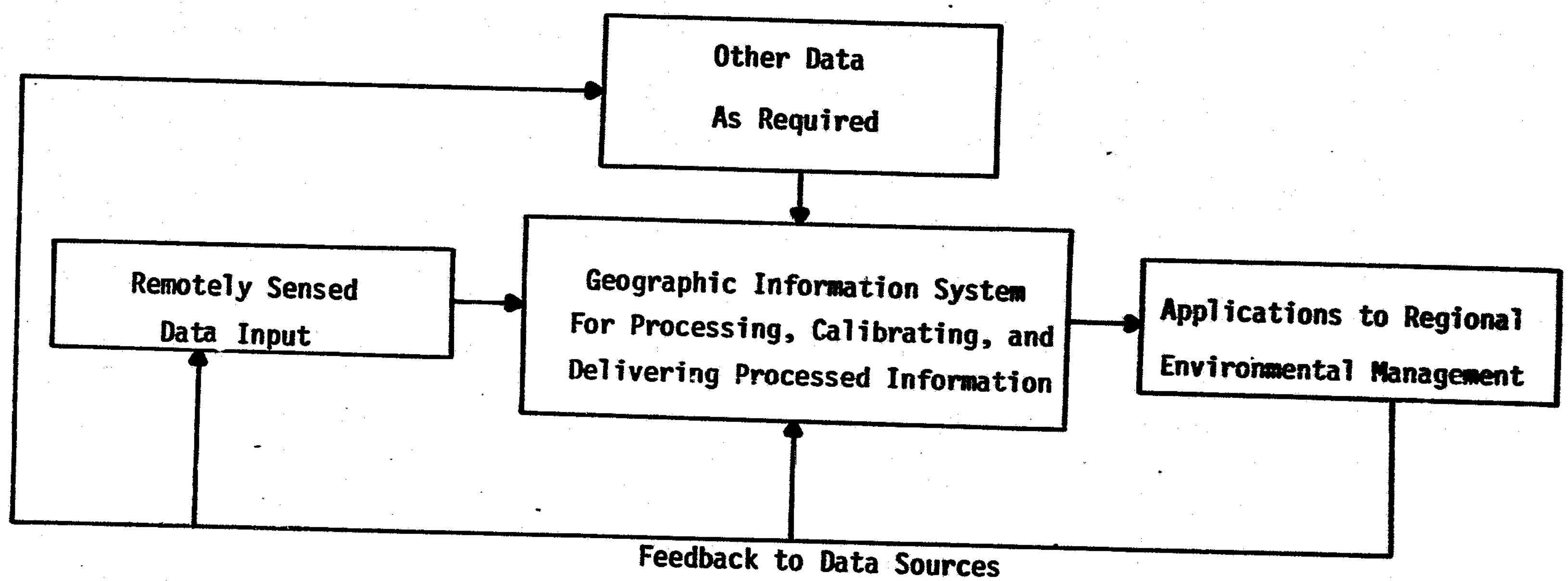

Figure 2.1.--Simplified CARETS concept diagram

scales and in conformance with other technical requirements, as specified by the users, for delivery back to the users, as indicated on the right-hand side of the diagram. As the system operates, additional information requirements would be delivered to the data input segments as well as to the geographic information system segment, with the feedback requiring adjustment of data inputs to the needs of the problem-solvers.

The CARETS project design stressed flexibility in data delivery to match the flexibility in data gathering that is potentially available from remote sensing systems. Thus, basic remote sensing data components could either be aggregated for appropriate portrayal of larger geographic areas and regions, or disaggregated for presentation in detailed form to highlight characteristics of small areas, specific sites, and land parcels. The project thus intended to bring together land use data systems with land use decision systems. The effort described here is concerned with ways of gathering, processing, and calibrating the information, and making it communicable to users in formats that are relevant to the specifications of the environmental problems they are trying to solve. A longer time span and different research methodology would be needed to test the assumption that improved information leads to better decisions and an improved environment.

While the CARETS project was conceived prior to launch of the first Earth resources satellite, it was supported largely by funds designated to explore and test uses of such satellites. Joint funding was provided by NASA and USGS, agencies that are cooperatively seeking improved applications of space technology to the solution of environmental problems. NASA's interest derives from that agency's mandate to test space vehicles and related technology, and to find useful applications of space exploration, including the observation of Earth as seen from orbiting remote sensors. USGS interests are in research and testing of procedures for developing and using new kinds of land resources information and thereby to improve and strengthen the beneficial applications of the Survey's already existing mapping and resource assessment activities.

BACKGROUND: BLENDING OF THE MAJOR HISTORICAL THEMES OR CONTRIBUTORY CONCEPTS

The CARETS concept has drawn upon two major historical themes and contributory concepts: (1) the regional approach to environmental problem-solving, with its roots in ecological and geographic analysis, and (2) remote sensing technology.

Regional Approach to Environmental Problem-Solving

Environmental decisions affecting a single land parcel have effects beyond the limits of that parcel. Decisions made by a single community have effects beyond the boundaries of that community. Problems addressed by this study--such as pollution, crowding, disturbance of ecological balances--need to be analyzed at the appropriate levels in the hierarchy of linkages connecting site with community, community with region, and region with State or Nation. Thus, we designed for CARETS a multi-level environmental data system to reflect the hierarchical linkages in the region, and to make data available at the proper level for the problems at hand.

A rough analogy of the need for a regional approach in the study of land resource systems might be drawn from the field of meteorology. In attempting to understand and predict happenings at a single local weather station the observer can go only so far by accumulating time-series measurements of temperature, pressure, humidity, etc. for that station by itself. Only when those observations are joined by those from many other stations can a broader understanding of the regional processes, the movement of pressure cells and air masses for example, be discerned, enabling the establishment of regional trends which greatly increase the power of understanding and predicting conditions at a single station.*

Similarly, looking at only the raw data on land resources for a single locality may ignore the ways that land resource developments affect and are affected by developments in other localities, and may ignore the ways that land use decisions in one place have consequences in other places. In general three kinds of linkages must be considered in the CARETS method of applying remote sensing to regional analysis: (1) the linkage between an environmental process and its response, (2) the linkage between a person's or an institution's action and its consequences, and (3) the linkage between one data set and another data set as they might both be considered for use in helping to solve an environmental problem deriving from the way we use our land resources.

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* I am indebted to Robert Dolan for this analogy as applied to the present study.

We may be dealing with either vertical linkages, i.e., those in which the responses result principally at the same place as the process, or horizontal linkages, i.e., those which have effects at a distance as well as locally. Examples of vertical linkages are those between incoming solar radiation and the temperature of the soil surface, between the vegetation of a marsh and its wildlife population, between the amount of irrigation water received and the salinity of the soil, between the vegetation cover of a locality and its microclimate. Examples of horizontal linkages are those between sewage effluent and downstream water quality, between extent of impervious surfaces and downstream flooding, between agricultural production and the urban market, between an improved transportation facility and intensity of use of beaches.

The patterns that are observed by a remote sensing monitoring system are cumulative regional effects resulting from the geographical spread of local decisions and actions. A larger than local view is needed in this "regional environmental systems" approach, allowing examination of impacts of a decision or action on other parts of the regional environmental complex.

In some respects a State is a viable region for organizing environmental data, particularly since the land within a given State is all under one political jurisdiction at that level of government. However, especially in the East where States are small, many metropolitan and environmental processes cross State lines, and their effects are consequently of greater geographic extent than the State boundaries.

There is also the question of economies of data-sharing for users of Federal data programs. Just as there are multiple and overlapping uses of our land, air, and water resources, there are multiple users for data and information needed to describe and characterize those land, water, and air resources.

In any given region there are several layers of local, regional, State, and Federal programs, as well as industry, research and educational activities, all with requirements for resource information. The same information files could serve more than one of these user agencies. Many local, State, and Federal agencies collect original information on their land, water, and air resources, or pay for the collection of such information; such information can often be used by others in addition to the collecting agencies. Fulfillment of these shared and often overlapping needs for resource information could be improved, and total costs reduced, by improving the coordination and efficiency of distribution of information among the various users within the region. There may be economies of scale in combining large numbers of local data-gathering programs into fewer State or Federal programs, taking advantage of satellites or large data processing facilities. A regional-level organization of data may logically fit within this hierarchy.

The regional approach thus may have an additional benefit in facilitating useful standardization of environmental data sets. Further impetus toward including regional level and national level considerations in decisions concerning land resources comes from the recommendations of many advisory and activist groups among which the following citation is representative: "Centralized planning authorities with implementation abilities are required to address the greater-than local impact of local decisions, and the problems of duplication. The planning process should be initiated at the local level, with public participation, and continue up through the Federal level, where national goals and priorities could be established" (U.S. Environmental Protection Agency, 1974, p. 15).

Ecology and regional environmental systems

Themes derived from the science of ecology are incorporated into the underlying fabric of the CARETS project. This application is consistent with a modern definition of ecology as "the study of the structure and function of nature, it being understood that mankind is a part of nature," and later, "the totality or pattern of relations between organisms and their environment" (Odum, 1971, p. 3). Further relevance to the CARETS subject matter is indicated in Odum's discussion on the importance of land use: "Application of ecological principles to land use planning is now undoubtedly the most important application of environmental science" (Odum, 1971, p. 420); and in considering the limitations of the Earth for determining the future of mankind: "Adequate pollution-free living space, not food, should be the key to determerming the optimum density for man" (Odum, 1971, p. 413).

Concerning the relevance of ecological science to these broader issues of man-environment relationships, Detwyler complains that "ecological studies have usually concentrated on the relations between organisms themselves (with little serious regard for the physical environment) and usually at the scale of the woodlot or single field. Furthermore, man's place in the ecosystem has been of scarce concern" (Detwyler, 1971, p. 4). He goes on to note, however, an apparent development of an applied ecology, citing seven of Dansereau's 27 "ecological laws" as appearing to have special applicability to man in environment (Dansereau, 1966, p. 459-60).

Applications of ecological concepts, combined with concepts from systems analysis and management science, have been drawn together into a large body of research funded by the National Science Foundation's (NSF) Research Applied to National Needs (RANN) program. The CARETS project has also drawn upon some of the same sources. Of closest affinity here are the projects funded under RANN's "Regional Environmental Systems" program (NSF, 1976). Examples of output from this program are major studies produced at the Oak Ridge National Laboratory, Chesapeake Research Consortium, and the University of Texas, among others. This environmental systems concept as used in the CARETS project seeks to place remote sensing technology into a logical sequence of activities leading to management decisions aimed at the mitigation of regional environmental problems, such as air pollution, water pollution, overcrowding, degradation of the quality of the land resources, and increased susceptibility to natural hazards.

Environmental and ecological concepts have been dealt with in a variety of methods and at a variety of levels of generalization, ranging from authors who have taken a "spaceship Earth" viewpoint (Boulding, 1966) to those who have been intimately concerned with planning future land uses in small regions to conform with environmentally sound principles (McHarg, 1969). Indeed, the practitioners of integrated regional planning are considered to be among the principal users of the products resulting from the CARETS project.

Geography and geographic information systems

Another major contributory theme emphasizing the regional approach to environmental problem-solving has come by way of the discipline of geography. Geography's long involvement in studies of man-environment interactions is evidenced by a landmark study, "Man and Nature; or, Physical Geography as Modified by Human Action," published by the geographer George Perkins Marsh in 1864.

Following in the same tradition of man-environment studies was the work of the geologist-ethnographer John Wesley Powell in his classic "Report on the Land of the Arid Region of the United States," published in 1878. While Marsh's study stressed the impact of man's activities on the physical environment, Powell's emphasized the other side of the coin--the suitability and limitations of the physical environment for the various uses desired by man, specifically the limits on agriculture posed by the arid climate of the western lands. Powell's interest in scientific principles of land use as exemplified in his arid lands study, plus his support of interdisciplinary land and water investigations as second Director of the U.S. Geological Survey, would justify giving him the additional title "geographer" in hindsight. Powell increased the breadth of geologic and hydrologic investigations in USGS, and consolidated all topographic work under the direction of a Chief Geographer.

Harlan H. Barrows' definition of geography as "human ecology" follows in the tradition of man-environment relationships as a major geographic theme (Barrows, 1923). Barrows declared the "mutual relations between man and his natural environment" to be a uniquely geographic field of study. Like Powell, Barrows stressed the viewpoint of man's adjustment to environment rather than environmental influence or control. Marsh's theme of man's influence and impact was the subject of a major assessment almost a century later. Many geographers had prominent roles in this assessment, a symposium followed by a published volume entitled "Man's Role in Changing the Face of the Earth" (Thomas, 1956). The volume contains numerous contributions and references reflecting the richness of worldwide studies only touched on in the present cursory review.

The CARETS project design for a regional environmental information system attempted to take account of the two major kinds of concerns in man-environment relationships: the constraints imposed by the environment, as represented by the viewpoints of Powell and Barrows; and the impact that man's activities have on the environment, as represented by the viewpoints of Marsh and "Man's Role."

The field of geography experienced a considerable revitalization in the years following World War II as "the study of man-environment systems in the context of spatial relationships and spatial processes" (National Academy of Sciences-National Research Council [NAS-NRC], 1965). One facet of this revitalized geographic science was the study of regional impacts of large development projects such as transportation systems and water resource projects. Another facet was the application of economic and sociological principles to the explanation of spatial distributions of goods, services, decisions, and land uses. Still another facet was rigorous application of climatic and geomorphological principles to people's well-being and economic activities.

These studies were characterized by a resurgence of interest in quantification and in applying mathematical concepts and models to geographic studies. Investigators such as Hagerstrand and Garrison in human geography, Wolman and Thornthwaite in physical geography, and White encompassing both physical and human components of man-environment systems, are prominent for their own publications as well as for their influence on students, teachers, and other researchers (Hagerstrand, 1965; Garrison and others, 1959; Thornthwaite, 1956; White, 1964; NAS-NRC, 1965).

The CARETS project follows this geographic research tradition in several respects. It attempts to employ the interdisciplinary (man-environment systems) approach. It attempts to increase generality of application by connecting the observational data to the appropriate theory. And it attempts quantification of location and area references in such a way as to facilitate computer handling of the large amounts of data involved.

Computer handling of geographic (map) data has received much attention and has recently made impressive advances under the rubric of a field known as geographic information systems (Tomlinson and others, 1976). The CARETS project design called for data derived from remote sensing to be tied to a coordinate reference system for digitization and subsequent processing. The geometrical and mathematical basis for digital coordinate referencing of map data derives from an ancient geographic tradition, the use of mathematics to aid in describing the Earth's surface. Map projections translate latitude and longitude references from the surface of the Earth to x and y coordinates on the flat-paper representations (maps) of that surface. In the CARETS project that principle of mathematical cartography was employed through the Universal Transverse Mercator (UTM) map projection and grid system, a system in which the grid lines intersect one another at right angles. The use of this system has been found to facilitate quantification of map data in applications involving the interpretation of data obtained from photographs of the Earth's surface (U.S. Department of the Army, 1958).

Preparation of all CARETS base maps in UTM projection was preliminary to subsequent stages in the CARETS geographic information system, as described in detail in chapter 3. In this aspect of the project, CARETS investigators were able to benefit from having close contacts with leading practitioners in the geographic information systems field. Growing out of earlier studies aimed at compiling computerized files of map data for regional planning purposes, the interdisciplinary field of geographic information systems which incorporate a location identifier with each data element) served thus as a principal contributory element to the CARETS project.

Federal laws and regulations incorporating the regional approach

An additional practical need for a regional approach in many land resource and environmental programs is contained in the cumulative effect of a trend in Federal laws and regulations dating back at least to the resource-oriented New Deal programs such as the Tennessee Valley Authority and the National Resources Planning Board. These and later programs have portions that stress the need for taking the regional effect of local actions into account. Many later laws required coordination with other Federal programs affecting land and environment (table 2.2).

Remote Sensing Technology

In addition to the above-mentioned scientific disciplines, the technology of remote sensing has been a principal antecedent and contributor to the CARETS study. This section describes some of the background developments which led to the particular method of application of remote sensor technology used in the CARETS project. These background items include discussion of benefits from applying remote sensing to Earth observation, collaboration and support of government agencies, applications development, sensor data verification, the involvement of users, and examinations of data handling systems.

Prior to the early 1960's, the field that is now called remote sensing consisted of activities ranging from the more traditional interpretation of aerial photographs to the development of sophisticated instrumentation for observing phenomena in ultraviolet, infrared, and microwave regions of the spectrum, beyond the spectral sensitivity of the human eye. Definition of these diverse activities as "remote sensing of environment" took place in the early 1960's. The growth of remote sensing as an interdisciplinary field was facilitated through the

Table 2.2.--Examples of Federal laws or regulations stressing regional approach or consideration of environmental interactions of land use

Date	Short Title	Official Designation
1954	Federal Housing Act	P.L. 83-560
1960	Federal-Aid Highway Act	P.L. 86-657
1964	Wilderness Act	P.L. 88-577
1965	Solid Waste Disposal Act	P.L. 89-272
1966	Demonstration Cities and Metropolitan Development Act	P.L. 89-754
1966	Clean Water Restoration Act	P.L. 89-753
1967	Air Quality Act	P.L. 90-148
1968	Intergovernmental Cooperation Act	P.L. 90-577
1969	National Environmental Policy Act	P.L. 91-190
1970	Clean Air Act Amendments	P.L. 91-604
1972	Coastal Zone Management Act	P.L. 92-583
1972	Federal Water Pollution Control Act Amendments	P.L. 92-500

activities of symposia, workshops, new journals, new university courses, new textbooks, and a substantial infusion of funding for research into many scientific and practical applications of remote sensing technology. See, for example, the recent monumental compendium entitled "Manual of Remote Sensing," Vols. 1 and 2 (Reeves, 1975a & b), the periodicals "Photogrammetric Engineering and Remote Sensing" and "Journal of Remote Sensing," and recent textbooks by Holz (1973), Estes and Senger (1974), and Rudd (1974).

Benefits from applying remote sensors to Earth observations

Benefits that may be realized by incorporating remote sensing data in regional environmental studies include the following: (1) Spatial and temporal uniformity in observations may be achieved over wide areas; that is, common observational units based upon physical measurement of reflected or emitted electromagnetic radiation can be employed. This may often eliminate biases obtained from different observers who are using different and perhaps even noncompatible observation systems for obtaining information about the land surface. (2) Observations can be readily revised and updated. Remote sensor data in the form of aerial photographs, for example, can be archived to produce historical records of the land as it was at given time horizons. Such records can be updated, and records of significant change can be obtained from similar photographs for later periods by comparing old and new photographic coverage. (3) It may be possible to obtain a near-synoptic view of the conditions of land and water resource phenomena over relatively large areas, for example through the use of Earth resources satellites with the capability of viewing many thousands of square kilometers of land and water surface at practically the same moment in time. This kind of capability is almost never available to a researcher making direct observations from a locality in the field. (4) A flexibility in observational scale and resolution is possible through the use of remote sensor systems chosen with parameters appropriate to the scale of the processes and problems involved. Combinations of different sensor altitudes above the terrain surface and different optics and recording media can be used to produce a level of detail in the data appropriate to the problem to be solved. Field observations, on the other hand, may produce the bias inherent in the myopic view of an observer trying to see the forest while surrounded by trees.

Geography Program development at the Federal level

The demonstration project described here has its programmatic roots in the Geography Branch of the Office of Naval Research (ONR) where in 1961 a project formerly designated "Internretation of Aerial Photographs" was renamed "Remote Sensing of the Environment," to include along with the more conventional camera systems new radiometric and imaging sensors that were already having considerable impact on environmental data-gathering for military purposes. The program redesignation in the ONR Geography Branch was the origin of the term "remote sensing."* The ONR effort resulted in an effective combination

* Evelyn L. Pruitt, oral communication.

of basic geographic research with the new sensor technology and also helped to expand multi-disciplinary applications of remote sensing and the development of associated data management procedures and information systems. One result of this program was sponsorship of the University of Michigan Symposia on Remote Sensing of Environment which have continued to the present under the aegis of first the University of Michigan, and later the Environmental Research Institute of Michigan (ERIM). The 12th International Symposium under that program was held in Manila in April, 1978.

Data from early spacecraft missions of the National Aeronautics and Space Administration, including pictures taken by astronauts, began to be examined seriously by geographers as early as 1962. Negotiations between ONR and NASA took place in 1963 and 1964 concerning the possibility of establishing a geographic research program specifically to investigate the geographic benefits and applications of the new space technology capable of obtaining remote sensing data about the Earth's surface (U.S. Office of Naval Research, 1964). This led to funding by NASA in 1964, and the beginning of a geography research program, along with discipline programs in geology, hydrology, agriculture, forestry, oceanography, and cartography.

The first major event in the geography program thus established was the 1965 Houston Conference on the Use of Orbiting Spacecraft in Geographic Research (NAS-NRC, 1966). At that conference about 80 geographers representing major discipline specialties assembled at Houston to consider technological possibilities of the new satellite instrumentation and remote sensing techniques as applied to modern geographic studies. In addition to the Houston conference, the early stages of the geography program included university contract research into urban and regional applications of the new technology, and information systems problems encountered in dealing with large quantities of remote sensing data. The studies were augmented by remote sensor aircraft missions provided by NASA, flown over documented geographic test sites. Throughout this early period the emphasis was on defining new programs for realizing the benefits to science that might be derived from the new space technology.

The next phase of the program began with t... transfer of the NASA-funded portion from the Office of Naval Research to the U.S. Geological Survey in 1966. The applications and benefits to be pursued by the new program were civilian and scientific in nature, and it was deemed inappropriate to have such a program located in one of the military agencies. The new USGS Geography Program also benefited from close association with the EROS Program and its disciplinary programs in geology, hydrology, and cartography. The mission of the Geological Survey as one of the natural resources agencies of the Department of the Interior made it a logical home for a geographic research effort which could enhance programs for studying and mapping the Nation's land and other natural resources.

In this stage of the program university research continued to be the dominant element. It was augmented, however, by industrial contract research in 1968, which began with consolidation of diverse efforts of the program into one single multisensor mission in southern California which was called Mission 73 of the NASA Earth Resources Aircraft Program (Alexander, 1968). Mission 73 provided experience with data-gathering and verification procedures for all of the prominent sensor systems then available; out of that experience came a selection and recommendation of those systems most promising for immediate land use and related environmental studies. For convenience in organizing and managing the research the second phase of the program became divided into five subject areas: (1) land use analysis, (2) urban and metropolitan studies, (3) environmental impact studies, concentrating primarily on climatology, (4) geographic information systems, and (5) program planning. Examples of research results from the phases of the program which were characterized primarily by university contract research can be found in Simonett (1969), Pease (1970), Peplies (1970), Simpson (1970), Bowden (1971), Gerlach and Kiefer (1971), Marble and others (1971), and Horton (1972).

The third stage of the geographic program began in the summer of 1970. This stage was aimed at the establishment of an operational geography program within the Department of the Interior, based at first upon the expected availability of satellite data on worldwide land use and environmental factors. Research effort shifted from contract to in-house research conducted by USGS scientists. The program was designed to develop a new Federal research capability to assist in the understanding of urban and regional land use problems and the relations of land use changes to the maintenance of an acceptable environmental quality. New products and services such as an atlas of urban and regional change were proposed and developed in prototype format as one of the early results of this program. To demonstrate the possibilities of such a research program, several projects were organized, including CARETS, the Census Cities Project (Wray, 1972), the Arizona Land Use Project (Place, 1972), and a few smaller projects conducted by contract with outside institutions. The current program for nationwide mapping and analysis of land use and land cover grew out of the above mentioned elements of the early Geographic Applications Program.

<u>Applications development</u>

Several lines of experimentation contributed to the development of remote sensing applications. Experimentation with data gathered by sensors operating in different parts of the electromagnetic spectrum resulted in information on the "spectral signatures" of environmental surfaces and materials. Laboratory and field spectrometers were employed to obtain quantitative information about these different spectral characteristics. Multispectral cameras and scanners were flown over sites where ground conditions were known. This line of research was aimed at the development of techniques that would identify the materials being observed according to the wavelengths of the reflected or emitted radiation received at the sensor.

Experimentation with a variety of sensor systems was conducted to determine most appropriate uses of each and to improve the operational characteristics of the various cameras, radiometers, radar and microwave devices, and multispectral scanners. Experts on the design and operation of such instruments were brought into close collaboration with the environmental scientists, resulting in better knowledge of the uses of each sensor system for gathering different kinds of environmental data.

Sensor platforms, the vehicles or other mechanisms for maintaining the sensor aloft during its observation period, were investigated in conjunction with the various sensors. Most used platforms were low-altitude aircraft, high-altitude aircraft, and spacecraft. More rarely, sensor experiments were performed from rockets, tall structures, balloons, and "cherry pickers"--extended arms of ground vehicles upon which sensors could be elevated a few meters above the surface being observed.

Verification of sensor data interpretations is accomplished by comparison with independently obtained observations or measurements. Field teams are often deployed during experimental remote sensing missions to make sample observations of the environmental phenomena being sensed. Low-altitude aerial observations or photography are often used to verify interpretations made from high-altitude or satellite platforms. Any one given remote sensing experiment will be conducted under particular conditions of observation including the intensity of the incoming radiation, the angle of view between sensor and ground, the sun angle, the amount of atmospheric moisture, the amount of soil moisture, the season of the year, etc. Other experiments, laboratory measurements, or calculations based on the physics of the observation system may be needed to extend interpretability to other times, places, or observation conditions.

Representatives of land and resource planning and management agencies were contacted, informed in detail of the results of the experimentation thus far, and invited to participate in expansion of the experimental program to operational applications. This resulted in a broadening of the base of individuals who were acquainted with the technology of remote sensing and its potential. Remote sensing data are taken into the user's own organization for further experimentation to determine to what extent the remote sensing data can substitute for other data that had been used, and to determine what kinds of operational modifications will have to be made to accommodate the new data source. Once this experimentation has been accomplished, and the required modifications in the system made, the technology is presumably available for actual application to a user's operational need. This technology transfer will be greatly facilitated by the user agency's willingness to reach out toward the new process and to be willing to pay a realistic cost for the use of the new data. During the experimental phase NASA program funding was available to assist in the technology transfer. Eventually, of course, it is essential that such costs be absorbed by the operational activity of the user agency.

One additional aspect of remote sensing technology development is the already mentioned need to plan for handling the large quantities of data to be produced by new satellite sensing systems. This topic was recognized by the panel reports "Urban Data and Data Systems" and "Mapping, Imagery, and Data Processing" at the Houston Conference (NAS-NRC, 1966). Several research projects were funded, representing the different discipline attempts to address the data management and information systems aspects of dealing with large-scale remote sensing capabilities. An excellent and well-documented summary is contained in Steiner and Salerno (1975). As will be explained in detail in chapter 3, the problem of data processing and information systems became one of the principal foci of activity in the CARETS project.

BRIEF DESCRIPTION OF THE TEST REGION

The CARETS region covers an area of some 74,000 km^2 on the eastern seaboard of the United States (fig. 1.1). The region was delineated so as to encompass the two major estuarine systems of the Chesapeake and Delaware Bays, and the immediate hinterlands of these estuarine systems including the major urban areas of Philadelphia, Baltimore, Washington, Richmond, and Norfolk, along with associated Atlantic coastal lands. The region falls within portions of five states at the southern end of a group of urban regions that has been collectively called "megalopolis" (Gottmann, 1961). Combining as it does the zones of interaction between major metropolitan areas and coastal and estuarine ecological systems, the region has a geographic unity that enhances its value as a locale for testing applications of new sources of land use and environmental information. We felt that the results would apply to other areas where metropolitan and/or coastal characteristics are present, as well as to areas where there is an interest in testing the relationships of land use information and environmental consequences.

Other favorable test site attributes are: (1) environmental systems and resource problems that cross State boundaries, (2) great diversity of resource use patterns and practices, (3) a large population, and (4) a rapid rate of change in land occupance and resource use. The test region was defined to be large enough to serve as a prototype for testing certain design and functional concepts that would be applicable to follow-on operational systems. On the other hand, there was a perceived need for a "micro" evaluation of all data gathering, verification, processing, display, and use factors for a small enough area or group of field sites to allow all the complexities of the project model to be fully explored. Boundaries of the test region were defined to include complete counties, so as to conform with administrative and socioeconomic data units.

The region consists of approximately one percent of the area of the conterminous United States. Its size would place it between 40th and 41st in rank among the 50 States in area, and its population would place it between second and third in rank among the States in population (table 2.3). Thus, the expertise gained in assembling land use and related environmental information for CARETS may be expected to be applicable to a populous state with a small area. Mindful of the fact that even smaller regional planning units such as the Standard Metropolitan Statistical Areas (SMSA) would be useful regions for concentrating an information-producing activity such as that described by the CARETS experience, investigators early in the project selected the Norfolk-Portsmouth SMSA, in the southeastern extremity of the CARETS test site, as a site for more detailed testing of field procedures and data processing methods. A separate report describes the results of the testing in the Norfolk SMSA (Alexander and others, 1975).

Most of the CARETS test region is made up of three extended metropolitan regions, that of Philadelphia to the north, the Washington-Baltimore metropolitan region in the center, and the Richmond-Norfolk region in the south (Ackerman and Alexander, 1975). Within these metropolitan regions are included major industrial concentrations, the Nation's political capital, some of its more important defense establishments, the oldest continuously occupied land surfaces, some major east

Table 2.3.--Areas and populations of CARETS and selected states

State	Total Area Km^2	Rank
Indiana	93,491	38
Maine	86,027	39
South Carolina	78,283	40
CARETS	74,712	
West Virginia	62,341	41
Maryland	31,865	42

State	Population 1970	Rank
California	19,953,134	1
New York	18,190,740	2
CARETS	13,404,558	
Pennsylvania	11,793,909	3
Texas	11,196,730	4
Illinois	11,113,796	5

coast recreational areas, and agricultural areas of regional significance. If an environmental information system can be designed that will be useful in the further development of this region, it should also have the capacity for application to many other parts of the United States.

Even in this highly urbanized region, the amount of land devoted directly to urban uses (residential, commercial, industrial, etc.) is small, though significant in its intensity of use and its impact on the surrounding land and water resources. Significant agricultural activity is present in the test region, especially in the Delmarva Peninsula east of Chesapeake Bay, in south central New Jersey, in southern Maryland, in counties to the north of the Washington-Baltimore corridor, and in southeastern Pennsylvania. Vegetable farming, dairying, poultry, corn and hay are important agricultural activities and products.

Forest land is the dominant cover type in CARETS. In this region of heavy but unequally distributed population, the significance of forest land is perhaps counted as much for watershed protection, wildlife preservation, recreation, and second home developments as for supply of timber. Beaches, wetlands, and other coastal environmental types, though relatively small in area covered, are critical arenas of conflict among competing demands for residential, commercial, transportation, industrial, and recreational uses, and for conflict among all of the above uses and preservation in the natural state.

CARETS PROJECT GOALS AND METHODOLOGY

Statement of Problem

The CARETS project addresses a class of problems characterized by a perceived mismatch between technological advances and environmental quality. Improvements in technology, based on advances in scientific knowledge, seem to be accompanied by decreasing environmental quality. The technology of the internal combustion engine applied to transportation in a metropolitan region produces dangerous air pollution as an unwanted by-product. Technological advances that make possible the covering of large areas with paving and other impermeable surfaces, increasing the ease of many human activities, leads to unanticipated climatic change and susceptibility to rapid flooding.

Boulding calls such phenomena "perverse dynamic processes," i.e., processes in which decisions each individual makes for the "best" bring about results which are perceived in a widespread manner to be for the worse (Boulding, 1978). He lists several examples of such perverse processes, including the "tragedy of the commons" (after Garret Hardin), arms races, population explosions, externalities in economics, etc. Harman includes environmental and ecological problems among a list of those resulting from the fabulous "successes" of modern industrial society, and he suggests that the problems represent intrinsic failures of the "industrial-state paradigm" itself (Harman, 1972).

The focus of the CARETS project is upon problems within a particular scale range--a scale appropriate to processes of urban and regional development, and to phenomena which result from those processes and which are readily observable by remote sensors. Examples are air pollution, water pollution, crowding, traffic jams, urban and rural blight, susceptibility to natural hazards, energy shortages, and a wide variety of related social and economic problems. While in some cases very obvious connections exist between the technological achievement and associated environmental problem, for example, increased air pollution derived from increased use of automobiles, many of these problems have the additional characteristic that no simple solution seems to be readily available because of the complex interconnections within the larger technology and the associated complex of resulting environmental problems. Thus, the problems addressed by the CARETS project are "systems" problems, and are judged to be those which may best be attacked through methods of integrated long-range planning and comprehensive environmental management.

Recognizing that the processes themselves may be "perverse," the CARETS approach is nonetheless more optimistic than to consider them "intrinsic" in modern technological society. A solution strategy is proposed for operation within the system; indeed, and seemingly paradoxically, the approach calls for additional and improved technology applied to data sensing and information transfer.

Goals and Strategy for Reaching Them

Long-range goals of projects such as CARETS which are addressing these systems problems are to alleviate or mitigate the problems, providing a better environment for the following generations. The CARETS design used a series of steps to arrive at a manageable subset of this long-range goal of improving environmental quality. These steps may be arranged in a logical sequence, each one representing a subgoal which is derived from the previous one in the list as follows:

Long-range goal	**Improve the quality of the environment**
Subgoal 1	**Improve environmental quality through improved land use decisions**
Subgoal 2	**Utilize regional environmental systems concept as basis for better land use decisions**
Subgoal 3	**Develop regional information service, incorporating remote sensing data, to better describe the environmental systems**

Improved land use decisions

The first subgoal focusses on the person who makes a decision affecting land use. We assumed that this decisionmaker can be identified and associated with the particular tracts of land affected by his decisions, and that the range of decisions open to him constitutes a set of alternatives which can be arrayed and categorized as "better" or "worse," including the decision to make no decision, i.e., to refrain from intervening in the natural environmental systems or the land utilization systems already in operation.

In the CARETS project a series of early choices was made to narrow the field of decisionmakers actually investigated and invited to participate as cooperating users. The first choice was that primary consideration would be given to those public agencies which have responsibility for planning or managing land resources. The rationale for this choice was that these representatives of public agencies would indirectly represent the numerous individual landowners and other private sector representatives, through the administratively- or politically-determined areas of influence of these public bodies, which areas necessarily include many of the individual landowners. The second choice was that, instead of going directly to the agency chief, we would approach members of the technical staff who have a portion of the responsibility for data collection, analysis, and recommendations to the statutory decisionmaker. The rationale for this choice was that we wanted to have various data sets, to be described later, evaluated by those who were likely to be technically and scientifically most competent to understand and interpret the relationships of our data sets to the solution of the (often difficult) environmental problems they were dealing with. These individuals also tend to constitute a professional cadre within the agencies, often having longer continuity in their positions than elected or appointed administrators.

The third choice to govern the range of decisionmaker representatives to be included in the CARETS demonstration project was that we would seek representatives from Federal, State, regional, and local land planning and managing organizations. In some cases this particular choice tended to obscure the interconnections among the various levels of the government hierarchy, as for example in the ways in which Federal legislation impacts and reverberates through State, regional, and local agencies with various kinds of requirements and constraints all having a bearing on the way in which the actual decisions are made.

The person making the decision presumably expects things to be better off, or at least no worse, than before. An individual may simply desire improved economic status or other form of satisfaction.

Public agencies may have more complex definitions of what constitutes improvement, backed by technical information upon which to base the land use decision. The definition of "improved environment" could apply to both the physical environment and to the environment which results from man's modifications of that environment, for example:

- improved air quality
- improved water quality
- improved climate
- improved aesthetics of the landscape
- improved access (to places of work, trade, play)
- improved safety from environmental hazards
- improved efficiency in land, water, and air quality management
- relief from shortages of air, water, land, minerals, food, fiber

Scales would have to be devised to quantify or rank measurements of each of the above factors in order of increasing values (so that it could be determined whether improvement has actually taken place). Some such scales have already been developed in attempts to quantify the factors that make up what is called the "quality of life" (Council on Environmental Quality, 1975).

The major portion of this study is devoted to the improvement of the quality and timeliness of information on land use and other land characteristics--information that we assert is needed by planners, managers, and others who are involved in one way or another in making decisions about land use and land use change. At the heart of the whole structure is the key assumption that better information will result in a better environment. The crucial linkage between better information and better environment is the sequence of events which must take place before the assumption becomes a reality: a decision, a will to act, and an action which sets in motion the process of change. Unless this connection can be made, the best environmental information available will be of little more than academic interest. While it is beyond the scope of the present study to deal with this crucial assumption--we merely assume that it is true--the examination of that assumption should be an essential part of the evaluation of any program that involves the collecting, processing, and delivery of land use or any other environmental information.

Regional environmental systems concept

Subgoal 2 in the CARETS design is to use a "regional environmental systems" concept as a basis for better land use decisions. Recognizing that environmental problems are composites of mutually interacting physical environment systems and human decision systems we included both in our strategy for solution. The regional environmental systems concept further states that the regional mosaics of land use patterns observable from remote sensing are results of many interacting environmental and socioeconomic processes, and thus can be integrators or indicators of other environmental and socioeconomic factors.

We would like to have the best knowledge available on the various processes that determine change in the environment, in order to be able to understand the effects of any given environmental action or proposed project. Table 2.4 contains a detailed list of the major environmental processes acting to produce the landscape patterns that are the concern of the remote sensing observation systems used in this project. Each of these processes is the traditional domain of discipline specialists who tend to produce specialized information products. The

Table 2.4.--Categories of environmental processes which act together to produce land and water use patterns and landscape mosaics

PROCESSES	SCOPE
1. Geological	Pertaining to the solid Earth, such as rock-forming, deformation, regional tectonics, weathering, soil forming, glaciation, etc.
2. Hydrological	Pertaining to the action of water, whether underground, in surface water bodies, or in the atmosphere; solution, infiltration, flow in porous media, stream flow, erosion, sedimentation, etc.
3. Oceanographic	Actions of oceans, bays, and estuaries; current motion, wave action, coastal and submarine erosion, etc.
4. Atmospheric and Climatological	Planetary wind systems, air mass dynamics, storm systems, air transportation of solids, liquids, and gases, energy exchange in the system Sun-Earth-atmosphere, etc.
5. Biological	Action of plants and animals, growth, respiration, transpiration, reproduction, energy conversion, resource conversion, including effects of both "natural" and "agricultural" vegetation.
6. Socioeconomic	Processes set in motion by human use of, and adjustment to, Earth environments, underlain by a complex of historical, cultural, racial, ethnic, and demographic factors; processes include population growth, resource conversion, urbanization, industrialization, trade, education, economic development, traportation, communication, government, and conflict resolution.

CARETS approach treats the entire test region as an ecological unit having its place in a hierarchy of larger regional and continental scale units, and in turn being composed of smaller regional and local functional units. The test region may thus be thought of as a system consisting of a number of interacting environmental subsystems, each subsystem characterized by the action of environmental processes listed in table 2.4. The six types of processes listed in table 2.4 may be thought of as creating individual "layers" of information, all of which are necessary to fully explain and understand the regional mosaic as observed by remote sensors. But because the pattern of "land use" may be related to each of the five environmental processes, the CARETS environmental systems concept employs the overlay of land use information as a shortcut measure of the other environmental processes--an indicator, integrator, or resultant of their action summed over space and time, as captured by airborne and spaceborne remote sensors passing overhead.

Regional information service incorporating remote sensing data

The third subgoal, to develop a regional information service incorporating remote sensing data, derives from the above-mentioned relationships among land use and environmental process information. It also derives from the hypothesis that better information on the causes of the problems, and on the spatial and temporal distribution of both causes and effects, can result in solution or mitigation of the problems when applied through the institutions responsible for environmental planning and management. We guided the investigation to address questions of how the emerging capability of newly developed remote sensing systems, especially Landsat, along with advanced computer methods of handling environmental data in map form, could be applied to mitigation of the environmental problems.

The regional environmental information system in the CARETS design combines technology and institutional communication so that information available from the new sensors is efficiently channeled to appropriate decisionmaking bodies. An intermediate stage between sensor and decision-maker is the scientific analysis of environmental processes underlying the basic set of "systems" problems being addressed. This intermediate stage is represented in a highly generalized form in figure 2.1 as a "geographic information system." To better illustrate its components, as drawn from the concepts presented earlier in this chapter, an expanded diagram of the CARETS concept is shown in figure 2.2.

Summarizing the CARETS concept as illustrated in figure 2.2, remote sensing data from both aircraft and satellites are collected and used as a source for a regional land use data base. The data base is to be prepared in both graphic and digital form, to facilitate a variety of user requirements for different types of information products. Then the land use data base, or portions thereof, is used in conjunction with other relevant environmental and socioeconomic data for the determination of environmental impact associated with land use changes. An accompanying environmental analysis integrates prior results, presenting evaluations of alternate land use decisions in terms of their likely environmental outcomes. These analyses would then be delivered to the user agencies, along with the accompanying data on which they were based, for use in

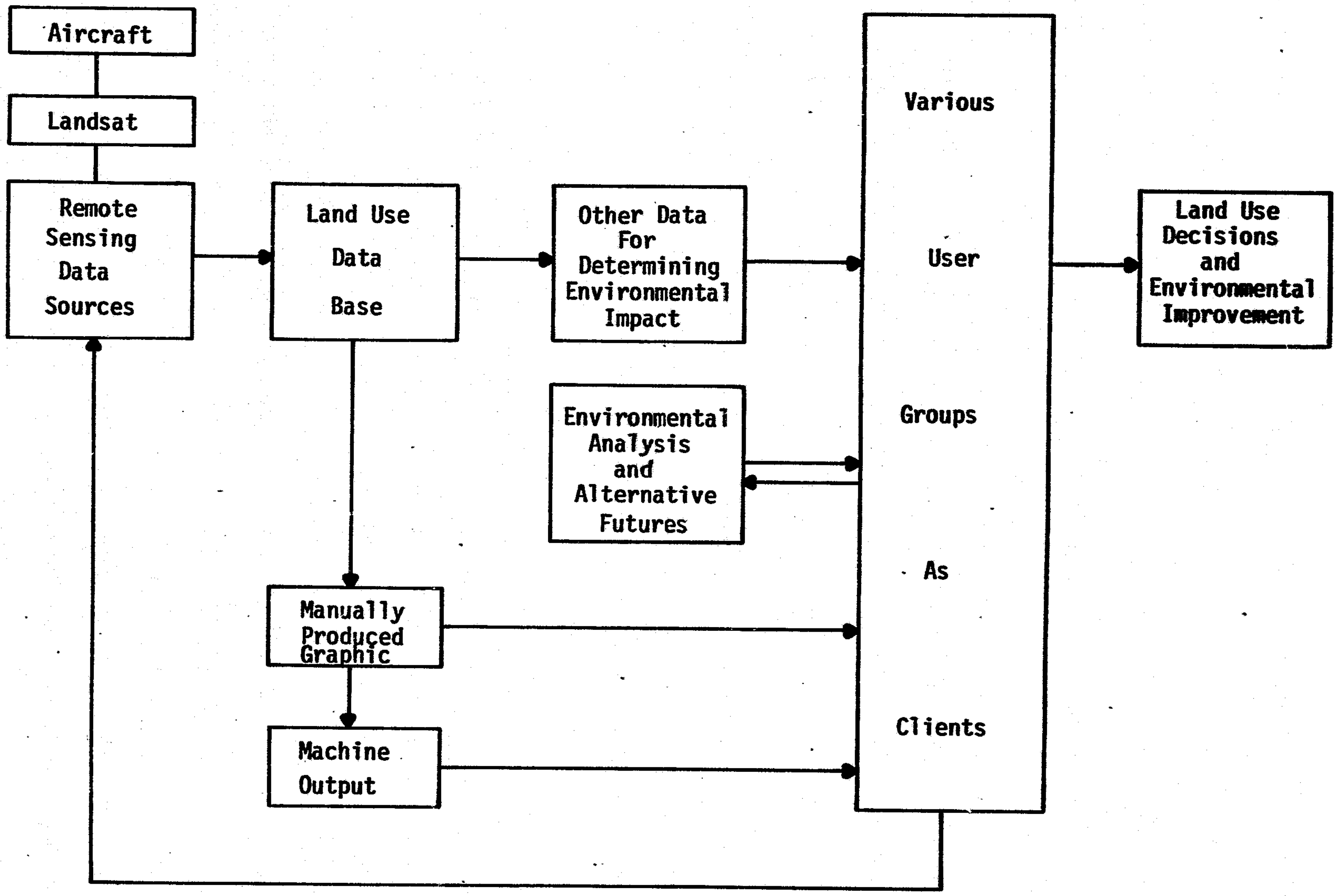


Figure 2.2.--Regional environmental information system design: the CARETS concept

decisions for environmental improvement. Feedback would be transmitted from the user agencies back to the remote sensing data sources so as to continually update and improve the information products derived therefrom, as determined by the applicability in the environmental decisionmaking arena.

Integrative or Ecological Viewpoint

The integrative, ecological, or "systems" orientation sought for the CARETS project is represented by several aspects of the project's background, objectives, and design as discussed in this chapter: the regional approach, the geographic information systems context, the interdisciplinary nature of the remote sensing programs, the focus on "land use," itself and integrative phenomenon including both physical environmental and social components, and concern for intraregional dynamics such as the impact of urban demand for recreational land on the environmental quality in the coastal zone and fringing waters.

An understanding of these processes of regional dynamics is to be used as an efficient guide to data collection. That is to say, areas that are experiencing the most rapid change would be subjected to the most detailed scrutiny. The unique advantage of remote sensing as a data-gathering tool would be exploited: a small-scale overview of the entire region can be quickly obtained, while larger-scale examinations of critical cities and subregions can also be made at different levels in the hierarchy of land use systems. The key to this concept is the availability of a regional land use data base, updated at periodic intervals, from which carefully drawn samples can be used to establish the character, amount, and direction of change.

With the regional information files that can be built up from remote sensing and other key data sets, it will ultimately be possible to examine the fundamental physical basis of the processes which govern and limit man's use of a region as a portion of Earth-space. These fundamental processes are the energy and mass transfers into the region, the energy exchange and resource conversion within the region, and the energy and mass transfers out of the region.

It was not anticipated that data sets comprehensive enough to perform this fundamental regional examination would be available during the lifetime of the CARETS demonstration project, but the concept was proposed as a useful, and in fact essential, guide to the kinds of regional studies that will soon have to be done. The Central Atlantic Regional Ecological Test Site was to be approached with these longer-range goals in mind. It was hoped at the outset that even before the end of the project remote sensing observations of the environment may provide rough first approximations for measurement of fundamental regional ecosystem parameters.

Public awareness of data resulting from the monitoring of change of the Earth's surface, as observed from the satellites and other remote sensors, can help dramatize the environmental significance of the essential unity in the planet's ecosystems. This increased awareness can lead to land resource use forecasting and the forecasting of environmental trends, eventually making it possible to better deal with environmental crises before they become crises, i.e., before they become so serious as to require drastic corrective, adjustment, or rehabilitative action.

Because of the complexities of the linkages within the socioeconomic and environmental systems, there is a need for both scientific expertise and enlightened citizen concern as to what kinds and amounts of change are going on in the region. The intention of the CARETS project model of organization of pertinent information flow is that the same regionally-focused environmental information service can be useful to both the scientific and citizen groups.

As an illustration of the desired interaction between environmental scientists and the public at large, we might trace the flow of actions to be expected in an idealized use of a CARETS-type system to achieve beneficial change in the way the people in a region use their land resources (fig. 2.3). This illustration portrays a fuzzy rather than a sharp boundary between physical environment systems and human systems.

In this idealized representation it is assumed that an undesirable environmental consequence results from the operation of an existing resource use system. Individuals or groups of people react to the undesirable environmental consequences by perceiving a problem and communicating their perceptions of that problem to an appropriate institution which is supposed to take care of planning and managing environmental matters. That institution has a staff of environmental experts who undertake appropriate modelling and data collection activities which lead to the ability to analyze the problem and predict future states of the environment. This information is then integrated with other data such as those from historical records, census, the legal tradition, etc., for policy analysis. Then a decision is made and put into action through an operational program by a planning body, legislature,

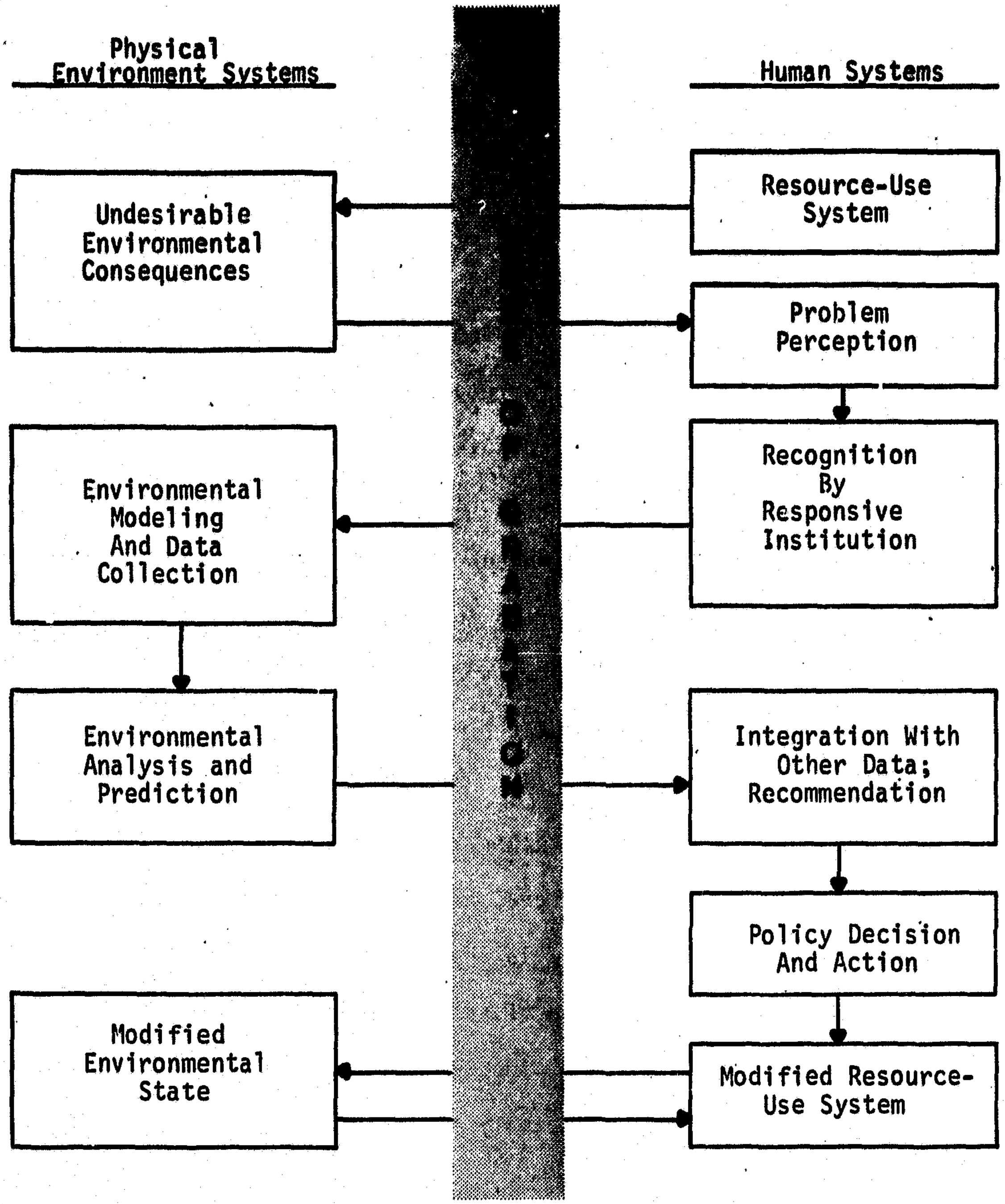


Figure 2.3--Idealized representation of achievement of change in resource-use system

etc. The result is a modified resource use system and a modified environmental state which mutually interact with each other, as indicated by the two-way arrows between the bottom boxes of Figure 2.3. If the modified resource-use system in turn produces undesirable environmental consequences the process can be repeated.

In operation, such a system should take account of differences in the ways different members of the population perceive and define the existence of environmental problems. Individuals are often not direct actors themselves, but are represented by a variety of special interest groups such as businesses, activist organizations, government agencies, the media, etc. Prior to the decision, information on costs of the environmental improvement, and who bears those costs, should be made known. Similarly, the benefits should be evaluated and beneficiaries should be identified. Clearly not all actions will fall equally as benefits upon all members of the affected population. Some may not wish to have any action at all. The larger political system may become involved, as recommended changes may involve new legislation, new issues of contention among the voters, new ways of administering the laws, and new conflicts to be decided in the courts or elsewhere.

The concluding section of this chapter describes how the operating components of the CARETS project were set up to realize the project's objectives, including especially the objective of the regional ecological viewpoint.

PROJECT OBJECTIVES AND OPERATIONAL APPROACH

The 12 project objectives listed in table 2.1 were derived from the background concepts and goals discussed thus far in this chapter. Objectives 1 through 9 were internal to the project and were approached through the mechanism of a demonstration project. Objectives 10 through 12 were external ones, and implied institutional changes, growing out of the CARETS demonstration project effort, for their realization. This final section of chapter 2 describes how the project objectives were translated into operational modules or sub-projects, the working details of which are presented in the individual chapters that follow.

Demonstration Project

The CARETS mode of operation was to demonstrate how a regional environmental information system would work, by actually setting up such a system and operating it for a while on an experimental basis in full view of the potential user community. The "demonstration project" was chosen specifically to be intermediate in nature between a research project and an operational program. This "pilot project" or "test region" approach was thought to be useful in cases where the implications of new technology to be introduced are not immediately apparent to those who make decisions on land use change and land use planning and management. Therefore, it was decided that the demonstration project would operate for a time in the region in the same way that an operational program would, carrying on both a mapping operation and an exchange of information with the user community. This effort is somewhat analogous to the

U.S. Department of Agriculture's extension programs and other demonstrations which have been used so successfully to introduce new technology into agriculture and to facilitate its adoption by a widely dispersed group of users.

Thus, the demonstration project mode for CARETS was chosen (1) to make a convincing case of proving the applicability of the new technology, assuming many users may be unfamiliar with the technology and skeptical of its value in their work; (2) to "learn by doing," that is, to check out certain proposed operational procedures for land use mapping, environmental impact assessment, etc., by actually performing the operations under conditions similar to those that would be experienced in a regular operational program; and (3) to obtain data on cost and time factors to assist in planning and budgeting follow-on operational programs (e.g., land use mapping).

The demonstration project effort was divided into four operating modules or sub-projects, plus an integrative or management function. Relationships of these project modules to the project objectives (from table 2.1) are as follows:

Integrative and management module

> Objective 1: Test hypothesis that Landsat can become an operational input to the regional environmental information system in the CARETS test area.

The integrative and management module had as its purpose to see that the proper interrelationships among the various project components were realized. It also attempted to achieve both integration and cross-fertilization among the various project components. Schedules and assignments were worked out and coordinated, aided by managment science techniques for analyzing necessary sequential relationships among activities and the implications of those relationships for production requirements and deadlines. With its attempt to build the connecting links between the new Landsat system and a regional environmental information system, this objective thus cuts across and subsumes the other project objectives.

Land use information module

> Objective 2: Compare aircraft- and Landsat-derived data to ascertain validity of Landsat interpretation and to provide measures of accuracy of Landsat-derived land use data.
>
> Objective 3: Establish a land use data base in graphic (map) form for the central Atlantic region, and monitor land use change.

The land use information module was designed to employ three basic systems for organizing and quantifying remotely sensed data for application to the environmental problems associated with land use and its change in the test region: complete land use and land cover mapping of the test region, applying uniform classification criteria and common map scales for each coverage; selected mapping of portions of the test region, using a variety of scales and levels of classification detail; and spatial sampling for statistical assessments of accuracy and cost. Also included in the land use information module were the preparation of overlay maps enabling the land use data to be relatable to and retrieved by, for example, drainage basins, census tracts, counties, and/or other areal units as may be requested by users.

Geographic information systems module

> Objective 4: Establish a regional environmental data base in digital, machine-readable format, with both numerical and graphic output capability.

The geographic information systems module was concerned with communication throughout all project subcomponents and to outside users, with its principal emphasis being addressed to the problems of how to quantify, store, communicate, and manipulate land resource information for a variety of user requirements. We felt that effective communication of this new information would be largely dependent upon establishing common methods of defining, quantifying, and transmitting such information. Because of the large amounts of information involved, the geographic information systems module sought improved computer techniques for handling such information. Digitizing the major CARETS maps, and further processing of several different map overlays, were first steps in preparing the data for general distribution.

Environmental impact module

> Objective 5: Study environmental processes as they affect land use choices and as they affect the environmental impact of land use changes.
>
> Objective 6: Employ an integrated ecological approach, including environmental process studies and modeling of alternative futures for the central Atlantic region.

The environmental impact module was based upon linkages among land utilization processes and resulting effects on land, water, and air quality systems. Operation of this module involved demonstrations of how land use relates to such phenomena as air quality, streamflow characteristics, components of the surface net radiation balance, and the surficial geological properties. Special attention was to be directed toward special problem areas such as the large metropolitan centers and the ecosystems along the estuarine and oceanic coasts of the test region, and to the application of the CARETS system to the preparation of environmental impact statements.

User interaction and evaluation module

> Objective 7: Establish an experimental land use and environmental information service for users.
>
> Objective 8: Cooperate with user agencies in supplying needed data and in seeking evaluation of experimental data products.
>
> Objective 9: Reach the regional land use decisionmakers with accurate and timely land use information derived from the remote sensor sources and incorporated with appropriate information from other sources.

The user interaction and evaluation module was designed to establish and maintain contact with selected user institutions and to determine how project results could affect the decisionmaking process. Conferences, workshops, and questionnaire interviews were designed to familiarize potential users with the range of products and services available, or potentially available, from a CARETS-type information system based upon remote sensing data. Under this module, feedback on usefulness of the experimental products, with respect to agency functions, was to be obtained from each of the cooperating users. A variety of methods of display and communication of the technical information prepared by the project staff were to be employed at the CARETS experimental information center and at user agency offices.

Institutional Changes

> Objective 10: Improve environmental quality and mitigate environmental problems through the improved decisions that result from availability of timely remote sensing data.
>
> Objective 11: Build the CARETS experimental information system as a prototype of a new USGS operational program.
>
> Objective 12: Incorporate the CARETS system into a regional operational remote sensing-based information system, with appropriate linkages among agencies at Federal, State, and local levels of government.

At the end of the operation of the CARETS demonstration project it was intended that its results would be influential in bringing about certain modest changes in the institutions responsible for planning and managing the use of the region's land resources. These desired institutional changes would include strengthening and formalizing relationships between USGS, as a producer of information important for the making of sound environmental decisions, and those individuals or agencies responsible for making those decisions. We hoped that improved decisions on future land uses might lead to some measurable improvement in the quality of the environment.

One such institutional change which we thought to be most readily accomplished was within the Geological Survey itself. Thus, one of the CARETS objectives was to conduct the demonstration project as a prototype of a new land use and geographic analysis function within the U.S. Geological Survey. We expected that this new function would include both an interdisciplinary ecological outlook and a land use map and information service for Federal, State, regional, and local level institutions with environmental decisionmaking responsibilities in the region.

After completion of the CARETS project the incorporation of remotely sensed data into resources assessment and environmental monitoring activities would be expected to be absorbed by the responsible operational agencies. Under this concept, the data analysis methods, information systems, and institutional cooperation procedures developed in CARETS, and as modified by what is learned during the project's operation, would be used as models for extending satellite-based remote sensing systems to other regions and ultimately to integrated national or international Earth resources data networks. It was felt that modest changes in existing institutions with responsibilities for data production, data use, and resource planning and management--changes stressing coordination and information linkages--could bring about the desired environmental improvement.

Operational Approach

The project's operating modules described above require different kinds of basic skills and specialties, and in each case appropriate specialists were called upon both as consultants and as members of the operating project staff. All modules were operated in close interaction with each other. In addition, close cooperation was maintained by interchanging staff members from one module to another for many aspects of the work. By this method each staff member became thoroughly acquainted with the operation of the project as an integrated effort involving all modules, and the attempt was made to further integrate the effort by periodic meetings of staff members and consultants.

The interrelations among the four experiment modules is illustrated in figure 2.4. The geographic information systems module is schematically represented in this figure by the arrows connecting the various functions and products. The topmost arrow, leading from the user module back to the remote sensing input, represents the desired feedback to the design and operation of future remote sensing data gathering systems--feedback that should result from this report and the reports of other investigators conducting similar studies of Earth resources applications of remotely sensed data. The detailed presentation of accomplishments attained under each of the four project modules is the subject matter of chapters 3, 4, 5, and 6.

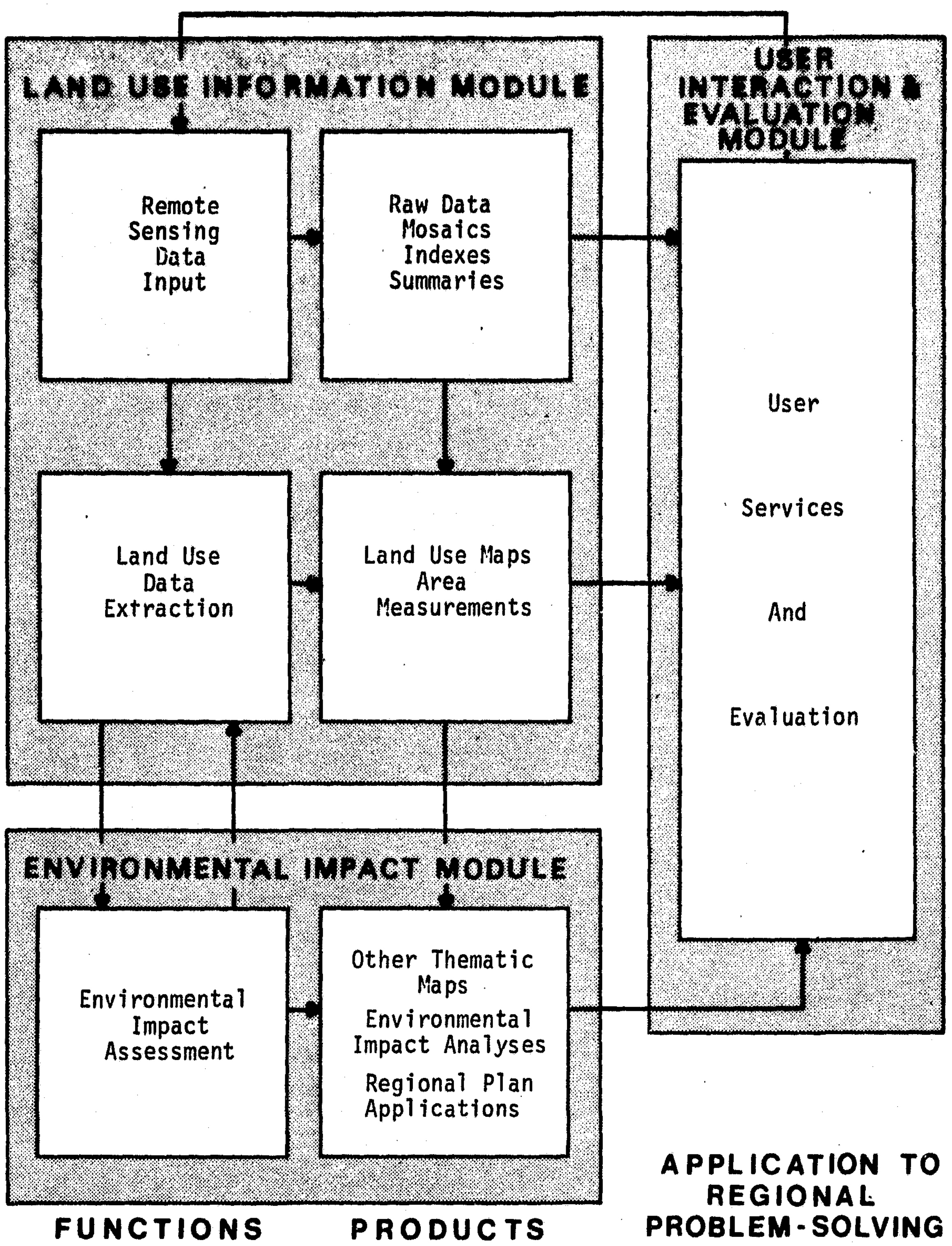


Figure 2.4--Flow of information and activities to be facilitated by the CARETS regional geographic information system

CHAPTER 3

THE CARETS GEOGRAPHIC INFORMATION SYSTEM

The geographic information systems component of the CARETS project deals with the processes of information flow from remote sensor to user. This information flow includes (1) graphic products (photographs, images, and maps) and (2) quantified land use data derived from remote sensor records. Most of the "information systems" effort went into the latter, i.e., the development of a computer capability encompassing digitizing, storing, manipulating and retrieving the information on land use maps and on other maps which facilitate the retrieval and analysis of such data. This chapter first presents a summary statement of the information flow problem including theoretical considerations and methods of quantification of map data. The remainder of the chapter summarizes the development of the CARETS computerized geographic information system, the various technological stages involved in transforming the map data into computerized format, and the role of the CARETS information system as prototype to a similar system now operational in the USGS Geography Program.

INFORMATION FLOW FROM SENSOR TO USER

The driving force behind the CARETS geographic information system was the collective information requirement expressed by user agencies, as interpreted by the CARETS project staff. After examining the methodologies used by other information systems having analogous requirements, the CARETS research staff translated the original user requirements for land use maps and data summaries into a series of project stages designed to facilitate the transfer of the basic information contained in the maps.

Major categories of CARETS information products involved in the information transfer were: (1) remotely sensed data and imagery, including both "raw" data as supplied by NASA and additional photographs or modified imagery obtained by the CARETS researchers; (2) maps derived from the remotely sensed data, including a gridded photomosaic (orthophotomap) to serve as a plotting base for other maps, and maps of land use and land use change derived from both aircraft and Landsat data; (3) maps compiled from sources other than the experimental remotely sensed data provided by NASA, used to provide correlative and overlay information to aid in quantifying and interpreting the land use maps; and (4) data summaries and area measurements obtained from computer manipulations of digitized maps of land use and selected overlay data sets.

Some maps and data summaries were prepared on a uniform basis for the entire CARETS test area. Other data products, generally those that contain greater detail or some other specialized experimental emphasis, were prepared only for smaller subregions, areas representing only partial test site coverage. Complete sets of more detailed data were prepared for two subareas that were chosen to test procedures that would have been too costly to carry out for the entire test region. These subareas were the Norfolk-Portsmouth and Washington, D.C. Standard Metropolitan Statistical Areas (SMSA) according to definitions based on the 1970 census. Table B.1* contains a listing of graphic information

* Tables and figures having designations beginning with a letter are found in the appendices.

products according to area of coverage and quantities involved. Coverages for the entire test region are of course also available for the Norfolk and Washington SMSA's, even though not additionally marked under those columns of table B.1. Table B.5 contains a listing of CARETS products made available in digital format.

Photographic Frames and Map Sheets

The first three of the four categories of information products listed in the preceding section comprise the graphic products in the form of photographs and map sheets (table B.1). While these graphic products were the sources of the quantitative data which were digitized and input into the computerized portion of the information system, the graphics themselves were also made available to users and were in fact a formidable mass of materials which constituted a significant part of the information flow throughout the lifetime of the CARETS demonstration project.

During the project operation, both CARETS project staff members and outside users needed to have access to the graphic materials. Storage consisted of conventional use of map drawers, file drawers, and looseleaf binders. Analysis and use usually involved visual examination, tracing, or the making of photographic copies. Duplicate sets were maintained at the CARETS project office, the USGS Public Inquiries Office in downtown Washington, and at the USGS headquarters library in Reston, Virginia. Other copies were made for special evaluation by selected user agency representatives. A portion of the CARETS geographic information activities consisted of arranging for the delivery of such map sheets and quasi-conventional map products to the large number of users who became involved in the cooperative evaluation of the experimental CARETS products.

The fourth column of table B.1 contains counts of the total number of "pieces" of these materials handled in the operation of the CARETS project, both for internal processing to achieve all the necessary data extraction functions, and for transmission to users, evaluators, and sponsor agency representatives external to the CARETS operating staff. The counts as listed in column four include multiple copies of some map or photo products. For example, we maintained both positives and negatives of black-and-white film copies of Landsat imagery and photo-mosaics. Maps prepared at a scale of 1:100,000 for the primary test data base consisted of an original inked sheet, four positive transparency copies of that original on stable-base film, and two opaque nonstable-base copies on ozalid material--seven sheets in all--for each of the forty-eight 50 x 50-cm sheets into which the test area was divided. Thus, the number of pieces (sheets) required to fulfill all of the information flow requirements for each type of map sheet prepared at the 1:100,000 scale (for example, for the "land use from aircraft data, 1970") would be 7 x 48, or 336 pieces handled. Added to that figure are the additional copies of some of the sheets which were made for distribution to selected users. The figures in column four do not include another complete set of copies which had to be made by the Canada Geographic Information System staff as part of the digitizing process, nor additional copies that were made by users for their own use (which they obtained from stable-base copies loaned by the library or Public Inquiries Office), nor multiple copies of certain maps that were included in printing runs and distribution copies of reports.

Information Elements in Digital Data Base

For reasons indicated in the following section, a computerized capability was built into the CARETS project from its earliest design stages. The remainder of this chapter describes that capability and how it was achieved. In the present section the bases for defining and measuring the various information elements which constituted the units of input into the computerized CARETS geographic information system are discussed.

The Landsat system has the capability of producing a stream of digital signals, each a function of electromagnetic radiation reflected from a portion of the Earth's surface. This stream of digital signals could be directly input into a geographic information system without the intervention of a human interpretation process, or without the use of a map as an intermediate stage of information processing. Such a capability was recognized by many of the Landsat experimenters as having great potential impact upon the development of future information systems descriptive of the Earth's surface and its changing phenomena. The CARETS investigation, however, was not designed to capitalize on that capability, either in assembling the kinds of scientific and technological specialists who would be required or the kinds of data handling equipment and computer software that would need to be developed. Our model called rather for the assembling of a package of interpreted information in a more conventional format that could be submitted to the users within the expected time period of the investigation. We therefore determined not to wait for the development of technology that would enable direct utilization of the digitized Landsat data. However, we monitored closely the work of investigators who were experimenting with that technology.

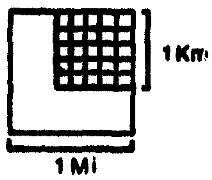
A consequence of this basic design feature of the CARETS project was the reliance on more conventional human image interpretation techniques for extracting the land use and land cover information from the aerial photography and Landsat imagery. The fact that the high-altitude aerial photography was delivered in conventional photographic form rather than in a digitized form suitable for machine comparison with the Landsat digitized signal further reinforced our decision to rely on more readily available data interpretation and information system input procedures.

Two of the most important decisions in any land resource or environmental data investigation are those on the scale of the mapping and on the size, measured in Earth-surface units, of the smallest information element to be kept in quantitative form for analysis, computation, and retrieval. These two decisions are not necessarily dependent upon each other, although the map scale chosen imposes a lower limit on the size of the information element which can be derived therefrom. This limitation arises from a mechanical cartographic problem, that of drawing boundaries around designated areas with as sharp a pencil as possible, without making the smallest of such areas indistinguishable by a map reader. The use of magnifying devices and sharper drafting instruments does not change this limitation in principle. A classification label, color, or identifying pattern must also be applied to each mapped unit. The information input to the digital data base can be chosen as an element of that minimum size, here called the minimum mapping unit, or any larger-sized agglomerations of such mapping units, such as arbitrary grid cells drawn over the complete and interpreted map.

The two basic map scales chosen for the CARETS project were 1:100,000 for data derived from the high-altitude aircraft photography, and 1:250,000 for data derived from Landsat. Associated overlay maps at corresponding scales were also input to the digital data base. We used the "two-millimeter rule" as a basic guideline for depicting the smallest units interpreted from the aerial photography and Landsat imagery, and for input into the digital data base. This rule states that insofar as possible terrain elements will be mapped and distinguished from others of a different classification if such elements have a dimension larger than 2 mm on the map, and no interpreted element will be designated on the map for an area smaller than that approximating a square 2 mm on a side. This corresponds roughly to the smallest sized unit which can be easily distinguished and identified with a code number. In practice this permits mapping of some linear features such as roads which have a width of slightly less than 2 mm. The interpreter-cartographers also use some subjective judgment in applying this rule, as for example in the degree of generalization to be incorporated in a line on the map separating two regions each of which is considerably larger than the area of the minimum mapping unit. For a rigorous treatment of problems of map generalization see Tobler (1969) and Guptill (1975), chapter 2.

Some implications that this 2-mm minimum mapping unit has for the quantities of information to be dealt with in the digital data base may be derived from figure 3.1. In this figure a square kilometer of the Earth's surface is depicted exactly to scale for each of the two basic CARETS mapping scales. The square kilometer at 1:100,000 scale (1 cm on a side) is shown divided into twenty-five 2-mm "minimum mapping unit" squares, and that at 1:250,000 into four such squares, in figure 3.1. Also shown are the surface area calculations of the 2-mm square minimum mapping units, and a larger figure to show the size of a mile square drawn to scale.

a) Scale 1:100,000



Two-millimeter minimum mapping unit approximates a square 200 meters on a side (smallest square in diagram)

Area of minimum mapping unit
= 40,000 m^2
= 0.04 km^2
= 4 ha
= 10 acres (approx.)

b) Scale 1:250,000

Two-millimeter minimum mapping unit approximates a square 500 meters on a side (smallest square in diagram)

Area of minimum mapping unit
= 250,000 m^2
= 0.25 km^2
= 25 ha
= 62 acres (approx.)

Figure 3.1.--Sizes of minimum mapping units at two basic CARETS map scales

1-2

Even though the actual map patterns used in this project did not utilize these equal sized squares, the array of elements of the minimum mapping unit size can be conceptualized as extending over the map surface in the form of an arbitrary grid, each imaginary cell of which is 4 ha or approximately 10 acres in size at 1:100,000 scale and 25 ha or approximately 62 acres at 1:250,000 scale.

The number of cells equal in size to the minimum mapping unit contained within this imaginary lattice equals the number of "information elements" in the digital data base, as tabulated in column four of table B.5. For example, for the aircraft-derived input data base at 1:100,000 scale (available for the Norfolk and Washington SMSA's plus 12 other administrative areas) the number of square kilometers of map area multiplied by 25 equals the total number of information elements in the digital data for each of the basic map input types. Similarly, the number of square kilometers in the Landsat-derived input data base (90,004 km^2) at 1:250,000 scale, covering the entire test region, is multiplied by four to obtain the number of information elements at that scale. As will be shown in a later section, these "information elements" are not the same as "information content." They are a beginning measure, however, useful for quantifying map data for input into a geographic information system. The administrative areas (counties and independent cities) for which the information elements contained in the CARETS digital data base are totaled in column four of table B.5 are indicated in table B.6 and figure B.25.

Quantification and Information Flow Modeling

In the previous section I have presented some of the bases for computation of the amount of information contained in the digital data base. Such computation is necessary for estimating system costs and when making decisions on the type of hardware and software to be selected. I use the concept of the "information element" as a basic unit of measure of the digital data base. The information element approximates in size the minimum mapping unit. Totaling the number of information elements from table B.5, we have:

Total Number of Information Elements in CARETS Digital Data Base

Scale 1:100,000	(4 coverages)	1,604,675
Scale 1:250,000	(3 coverages)	1,080,048
		2,684,723

It was originally hoped and planned that digitization could be completed for the entire test region (90,004 km^2) for both aircraft- and Landsat-derived data. However, the costs of digitizing such large amounts of data were too prohibitive for the CARETS project budget. Therefore, Landsat-derived land use data were digitized for the entire test area while aircraft-derived data and other overlay maps at the scale of 1:100,000 were digitized only for selected portions of the test area. The computation listed above does not quite cover the entire amount of digitization that was done. It does cover the areas indicated in figure B.25 and table B.6 for which data sets were complete for all counties included. If the entire test area had been completely digitized, including the surficial geology and other overlay maps, the total number of information elements would have been as follows:

Total Number of Information Elements
if all Areas Had Been Digitized

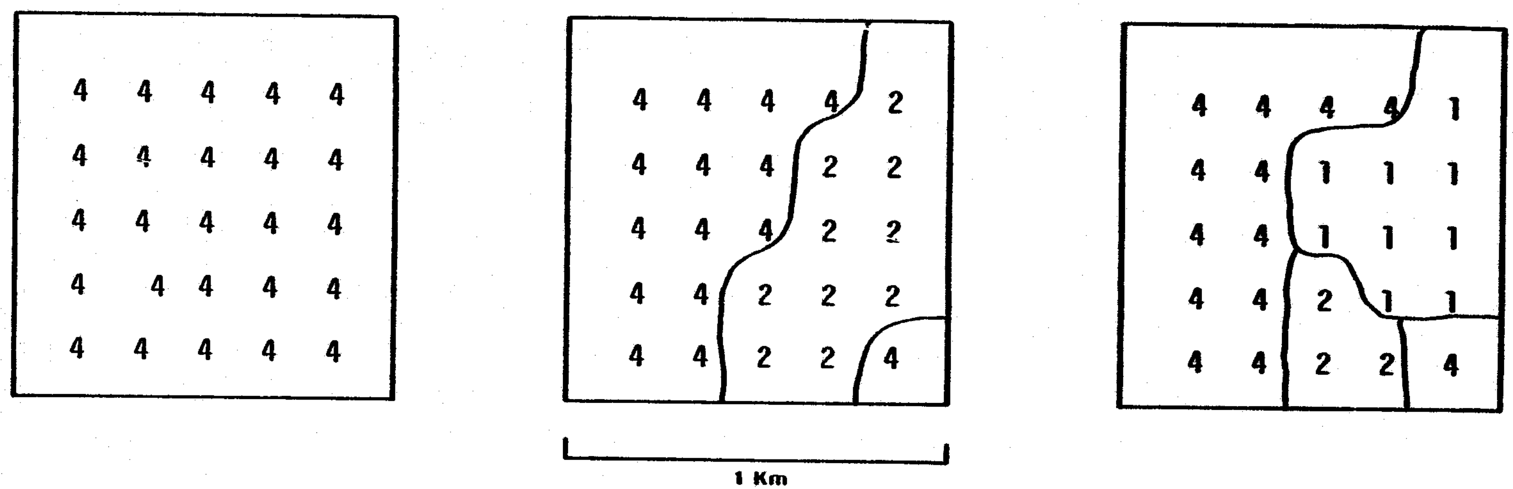
Scale 1:100,000	(4 coverages)	9,000,400
Scale 1:250,000	(3 coverages)	1,080,048
		10,080,448

From these calculations the percent of the hoped-for map digitization accomplished in the CARETS project was 26.6 percent. The figure of 10,080,448 information elements may thus be thought of as the "worst case" amount of digital information elements to be handled by the CARETS project according to the original design. This figure, and the actual data base of slightly more than 2.5 million information elements, does not however, tell the whole story. In the sections that follow, several further considerations necessary for fully understanding the quantitative aspects of this information handling problem are presented. The remainder of this section deals with the problem of quantifying data contained on land use maps, the search for applicable theory, and the need for a combined theoretical and empirical approach to deal with information handling problems in a project of this type.

The problem of quantifying data on nominal maps

The problems of dealing quantitatively with information of the type contained in land use maps is given a rigorous treatment by Guptill (1975). He discusses these problems under the heading of "nominal maps," those in which the mapped categories are classified into mutually exclusive categories of equal rank (Guptill, 1975 p. 5). Nominal maps are thus distinguished from other maps in which assignment to a class is in accordance with some numbered scale as, for example, the numerical values of regions delimited by contours on a topographic map. Specimen maps of 1-km^2 areas such as could be taken from the CARETS land use data base at a scale of 1:100,000 are illustrated in figure 3.2. The three maps are enlarged from the original 1:100,000 scale in order to more easily depict the 25 information elements into which the square kilometer could be divided. These maps are also simplified in that only a single digit is used to depict the land use categories (Level I categories) whereas in the actual CARETS 1:100,000 data base the Level II land uses were depicted, each type requiring a two-digit number for its identification. In keeping with the characteristics of nominal maps mentioned above, the code numbers assigned to each class are merely for convenience in facilitating machine handling and have no arithmetic significance per se. Nominal maps, however, can be transformed by means of a variety of techniques into maps in which the categories do have numerical significance.

The three maps show areas of increasing complexity portrayed within a square kilometer. The lines in maps (b) and (c) are of the type that would be drawn by photointerpreters directly from examination of the high-altitude aerial photography. The 25 numbers at grid square positions are of course not used in the actual mapping, but are rather shown in figure 3.2 to indicate the imaginary lattice containing the information elements of the basic maps. Three ways of quantifying the information contained on these maps are indicated in table 3.1. The first is a tabulation of the number of information elements (minimum mapping units), the second is a measure of the ground area, and the third is the area expressed as percentage. Tabulations of such totals extending over the areas mapped are common ways of quantifying the information contained therein.



Explanation

1 Urban and built-up land

2 Agricultural land

4 Forest land

Figure 3.2.--Typical 1 km^2 representations of information elements in land use data base, 1:100,000 scale

Table 3.1.--Various measures of map area cover categories, figure 3.2

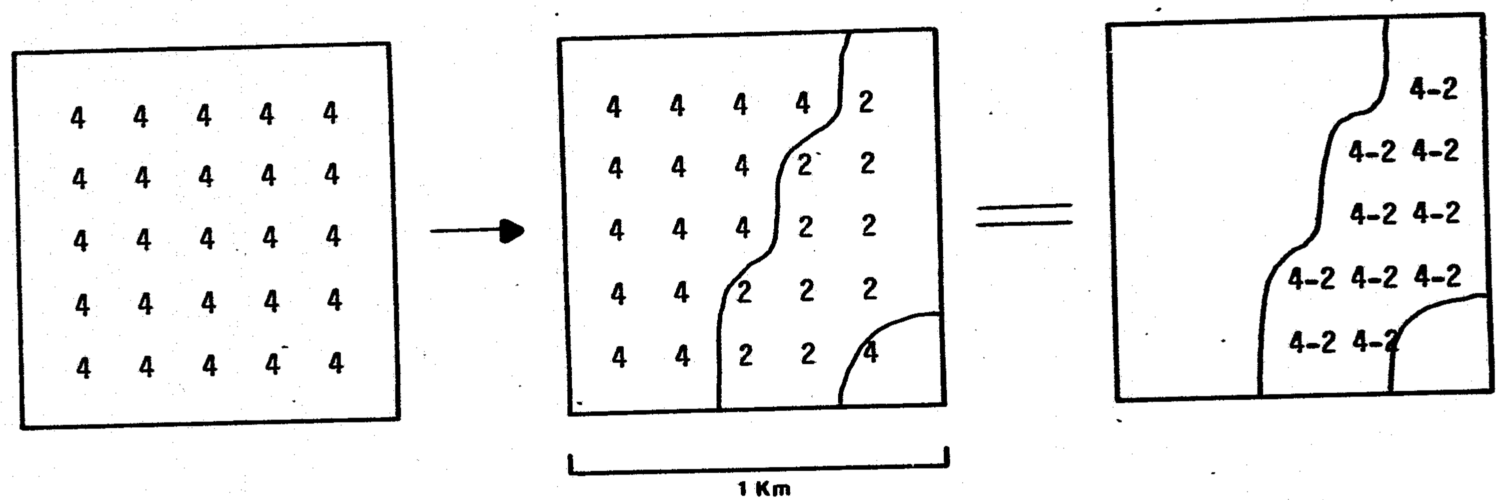
	Number of Information Elements (see figure 3.1)	Total Area in Hectares	Area in Hectares by Land Use Type			Percent of Total Area by Land Use Type		
			Forest	Agriculture	Urban	Forest	Agriculture	Urban
Area (a)	25	100	100	0	0	100	0	0
Area (b)	25	100	60	40	0	60	40	0
Area (c)	25	100	52	12	36	52	12	36

In addition to mapping of land use at any given time, the remote sensing-based information system has the capability of portraying land use change. Rather than depicting three different areas, the maps in figure 3.2 could be a representation of a sequence of change in the same square kilometer. In this instance, the first map portrays the region as being entirely covered with forest, the original land cover type in most of the CARETS region. The second map indicates that a portion of the area has changed from forest (4) to agriculture (2). In the third map urbanization has taken over parts of the land covered by forest and agricultural uses at the time of map (b). Mapping and area calculations of the changes are indicated in figures 3.3A and 3.3B.

Area measurements of land use maps are readily obtained by computer tabulations once the original maps have been digitized. Other ways of measuring such areas are with dot planimeters or polar planimeters. Such summary totals, however, collapse the two dimensions of the original map into the zero dimension of the numerical summary of each land use type. Other kinds of measures capable of taking more account of the multidimensionality of the data are discussed in the following section.

CARETS system analog with information theory

The development of appropriate theory has not been a prominent aspect of remote sensing projects connected to information systems for delivering land use and related kinds of data to users. For the benefit of long-range developments it would be valuable to seek a firmer theoretical base than exists at present. In general three kinds of theory would apply: environmental theory, based upon the processes listed in table 2.4, processes which govern the distributions and interactions of the

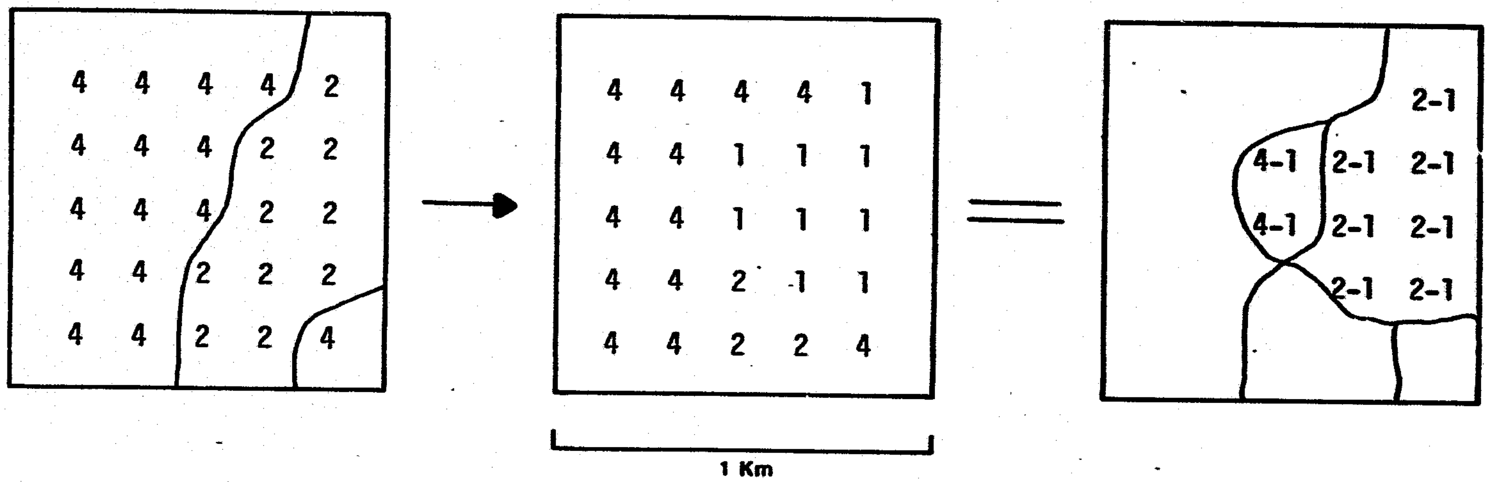


Explanation

- 2 Agricultural land
- 4 Forest land
- 4-2 Land changed from forest to agriculture

Area Measurements	Information Elements	Hectares
Area changed from 4 to 2	10	40
Area in 4 remaining unchanged	15	60

Figure 3.3A--Mapping and measurement of land use change



Explanation

1 Urban and built-up land

2 Agricultural land

4 Forest land

2-1 Land changed from agricultural to urban

4-1 Land changed from forest to agriculture

Area Measurements	Information Elements	Hectares
Area changed from 2 to 1	7	28
Area changed from 4 to 1	2	8
Area in 2 remaining unchanged	3	12
Area in 4 remaining unchanged	13	52

Figure 3.3B--Mapping and measurement of land use change

observed phenomena; theory based on energy flow, encompassing the transmission of electromagnetic energy reflected from the Earth's surface and the changes in such energy as it interacts with the various forms of matter it encounters in its path through the atmosphere to the sensor; and theory governing the flow of information through a communication channel of some sort.

A general theory integrating the three kinds just mentioned would be desirable, but is beyond the scope of this research. Environmental theory as applied to the CARETS concept is discussed briefly in chapters 2 and 5. Remote sensing theory is alluded to in chapter 2 and has received recent treatment, for example in several chapters of the Manual of Remote Sensing (Reeves, 1975a and b). In the present section some notions dealing with the third kind of theory, having to do with information flow, are presented.

The discussion draws upon information theory (or communication theory), the origin of which can almost be attributed to the publication of a single paper by Claude Shannon and Warren Weaver (1949). The publication of this paper followed work done by Shannon and others at the Bell Telephone Laboratories in previous years, addressing the problem of quantifying the information that is transmitted over telegraph and telephone lines, with the objective of making such transmission more efficient and improving the service of communication systems. Several notions from communication theory may be useful in assisting in understanding the kinds of information transmission problems dealt with in remote sensor systems. The treatment given here is only suggestive of further work that would have to be done before such theory is in fact ready to be applied to the problem at hand.

One of the useful aspects of communication theory (or information theory) is the modeling of the information flow system from origin to destination. The diagram in figure 3.4 presents the basic components of this information flow system. A message is selected from a number of possible messages at the information source. The transmitter changes the form of the message into a coded signal which is sent out over the communication system. The receiver is sort of a reverse transmitter which decodes the signal into the original message, or as much of it as possible, and delivers it to the destination. Between transmitter and receiver there may be an intrusion of noise--a random disturbance in the signal which has the characteristic of degrading the quality of the information transmitted. Suggested analogs between the idealized communication system depicted in figure 3.4 and the CARETS information processing system are presented in table 3.2. Noise is shown to intrude at several stages along the way. The representation in table 3.2 is only a small part of the complexity of the information transmission dealt with in the CARETS project, but it is indicative of the kinds of analogy which may be drawn from the principles of Shannon's theory of communication and information.

Several useful concepts from information theory may help shed light on the processes of information transmission from remote sensor to user. One is the concept of modeling the overall system, as depicted in a simplified fashion in figure 3.4 and table 3.2. Another is the concept of the intrusion of noise as a degrading factor in the message. The presence of noise in all transmission systems means that information can only be subtracted or degraded; its content cannot be increased in the

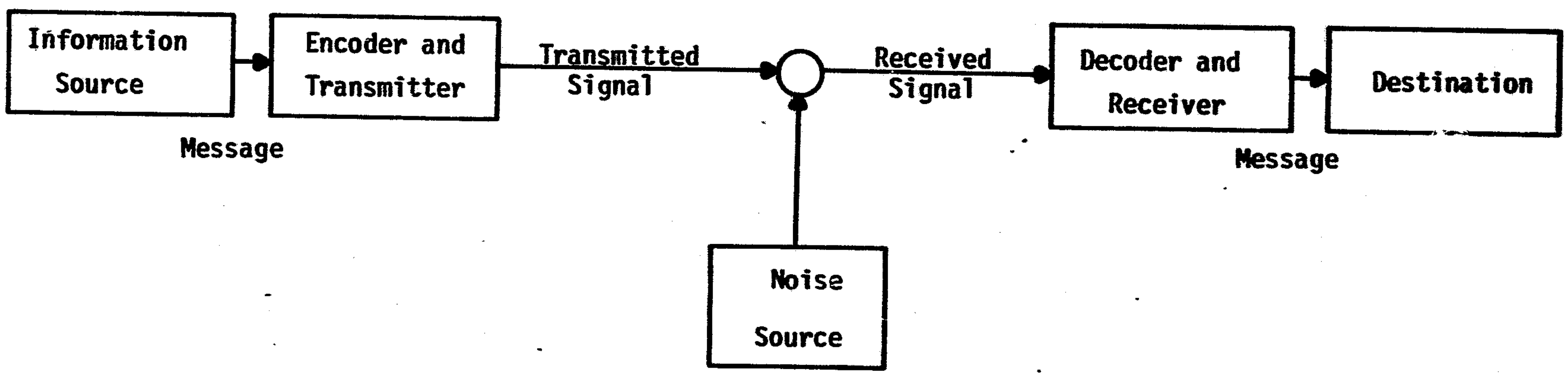


Figure 3.4.--Diagram of an idealized communication system

Source: Shannon and Weaver, 1949.

Table 3.2.--Analogs between concepts of idealized communication system and stages in the flow of terrain information derived from remote sensor (see figure 3.4)

Communication System Concepts	Remote Sensor Information Flow Stages
Information source	Earth surface environment
NOISE	Atmospheric attenuation of signal; limitations of sensor fidelity
Encoder and transmitter	Remote sensor system and intermediate storage
Secondary information source	Remote sensor record: processed film (aerial photo); processed image (Landsat data in image form); digital tape (Landsat data in digital form)
NOISE	Interpreter error in classification; map registration and other location errors; incomplete algorithm for machine classification
Encoder and transmitter	Interpreter assignment and mapping of data classes for each information element (manual interpretation); machine classification and mapping (digital processing)
NOISE	Errors in coding and digitizing; programming errors
Transmitted signal	Electronic representation of coded classes and correlative data; intermediate storage: tapes, disks, etc.
NOISE	Aging and deterioration of magnetic storage media; errors in retrieval programs; transmission interference and power failures
Received signal	Electronic readout from transmitted or stored signals
NOISE	Errors in retrieval and display programs
Decoder and receiver	Hardware-software configuration for retrieval and display of electronic signals; manipulation and printout of data in user-specified language, tabulations, or maps
Destination	User

transmission process. Another useful concept is the quantification of information. Still another useful concept is that of the structure of the information source and the analysis of the language used to convey the message.

The analogy might be clarified by presenting an example of quantitative analysis of the communication of a message written in English. One step is to construct a frequency distribution of the numbers of each symbol used. These symbols are the letters of the English alphabet plus spaces and other punctuation marks which may be considered as additional symbols in the language. An example of empirically determined distribution of symbols in written English is presented in table 3.3, where the most frequent symbol shown in this sample is the space between words. However, such a frequency distribution only begins to capture the characteristics of the language. To further refine the description and quantification of this language, its structure must be taken into account, e.g., the occurrence of certain pairs, triplets, etc. of letters in sequence. A convenient way to display such pairings is by means of a matrix depicting the proportion of transitions from one symbol to the next, as occurring in the sample of written English. A table of such transition probabilities (empirically determined) is illustrated in figure 3.5.

The problem of increasing the efficiency of telephone transmission by sending several messages simultaneously over the same wire led to more fundamental questions of just what transpires in the communication process. The inquiry developed some penetrating analysis into the nature of information itself; the result was a body of theory based on a definition of information in probabilistic terms. One statement of such a definition of information is "a measure of one's freedom of choice

Table 3.3.--Frequency distribution of alphabet symbols from an example of written English

SYMBOL	PERCENT IN SAMPLE
space	16.5
E	9.4
T	7.5
A	7.0
I	7.0
R	6.3
N	5.8
O	5.8
S	4.7
L	3.7
H	3.2
D	3.0
C	2.9
M	2.5
U	2.5
F	2.2
P	1.9
Y	1.9
G	1.8
B	1.0
W	0.9
V	0.7
X	0.2
K	0.1
Z	0.1
J	Trace
Q	Zero

Source: Hartshorne, 1959, p. 117

FROM ↓ / TO →	SPACE	E	T	A	I	R	N	O	S	L	H	D	C	M	U	F	P	Y	G	B	W	V	X	K	Z	J	Q
SPACE		4	23	17	24	4	4	12	7	4	2	8	9	9	2	5	8		6	8	6	3		–	–		
E	30	1	1	9	1	13	7	2	6	3		7	3	1	–	1	–	–	2		–	2	2				
T	18	11		3	7	2		6	2		19				4	–		3									
A	4		12		–	13	14		5	9		–	4	2	1		3	–	1					1		–	
I		2	9	3		1	20	4	9	2		1	7	5		4	–		1			1			1		
R	6	17	4	7	6	2	1	5		2		1		3	–		1	3	1								
N	20	5	7	2	1		–	4	3	1		7	3	–	–			1	4			–					
O	6		2			12	9		3	–		–	1	4	4	9	2		3		2	1	–				
S	23	6	7	1	3			1	3		1				1		1										
L	7	4	4	8	2			1	1	3		2		–	1	–		4				–					
H	4	12		5	5			2							1			2			1						
D	9	3		–	7			3	2	1					2			3									
C	1	6	3	4	1	–		4		2	4				4												
M	1	4		5	3		–	5	1					–	2		2	–		1							
U		1	1	–	–	4	1		3	6		3	2	1			2			1							
F	10	1	–	2	2	1		2		–					1	3		–									
P	2	1	–	1	1	3		3	–	3	4				1		–										
Y	19				1																						
G	4	4		1	–	7	1	1		–					–												
B		4	1		–	1		–							1			2									
W	1	3			2		1	1			1																
V		4		2	1			–																			
X	–		1	–	1																						
K	–				–																						
Z		1																									
J								1																			
Q																											

Figure 3.5--Empirical probabilities in thousandths of one-step transitions of symbols in written English.

Source: Sample of written English cited in table 3.3.

when one selects a message" from all messages possible within the given language or coding system (Shannon and Weaver, 1949, p. 100). Thus a large amount of information is associated with a large freedom of choice among many possible messages and with a small probability of any one message being selected. A small amount of information is associated with the conditions having a high degree of certainty.

Specifically, information is defined in this way: if there are a total of N equally probable events (or messages), the knowledge that one of these has happened carries an amount of information equal to $\log_2 N$ binary units (the term "bit" is used as a contraction of "binary unit"). For example, in the simplest case, when there are only two possible events, say, heads or tails, the statement that one of these has occurred carries an amount of information equal to $\log_2 2$, or one bit. If there are four equally likely messages and one of these is selected it carries $\log_2 4$ or two bits of information. The following table contains selected values of N and the corresponding amounts of information carried by the statement that any one out of N equally likely events has occurred.

Information Associated with the Statement that One Event has Occurred, out of a Total Number of Equally Likely Events N

N	INFORMATION (Bits)
2	1
4	2
8	3
16	4
32	5
64	6

When generalized to include events having unequal probabilities, information takes the form of an expression $I = \sum_{i=1}^{n} p_i \log p_i$ where p_i equals the probability that the i^{th} event will occur.

Since the information source contains all possible symbols it contains the ingredients for every possible message. In examining the ways in which symbols are put together to form messages we find that two facts become quickly apparent: first, some symbols and combinations are much more probable than others, and second, there is a definite structure in the language imposed by rules for putting symbols together. For example, there is a grammar that controls the arrangement of words into phrases and sentences, and within words there is a probability structure which governs the use of individual letters. These principles are well known to cryptographers and typesetters.

A symbol-frequency table such as that shown in table 3.3 shows only the proportions of the various elements of a language, not the way in which they are put together. To demonstrate the structure of the language we can examine the occurrence of sequences of symbols. Instead of looking at the separate symbols as in table 3.3, we look at the patterns they form when put together in messages. A simple beginning would be to examine pairs of letters. When we have arrived at a given letter in a message, what is the next letter likely to be? The sample of written English displayed as the transition matrix in figure 3.5 contains the answers. For example, when we have arrived at the letter "E" there is a 0.013 probability that the next letter will be "R," whereas there is only a 0.002 probability that the next letter will be "G." Also, it is seen in figure 3.5 that some theoretically possible transitions do not occur at all in the real world sample.

In summary, some of the advantages of using an information theory approach are the following: First, it can give a valuable "systems" perspective by examining all the steps in communication from sender to receiver and by providing a model of the total information flow process. Second, it can assist in devising an efficient way of coding information for transmission or storage. Third, it can tell something about the capacity of a communication channel for transmitting information. Fourth, it quantifies information and establishes a measure of information content. Fifth, it has useful concepts such as those of noise and redundancy which assist in understanding processes of loss of information or efficiency of information transmission. Finally, it provides an extra bonus in the form of increased knowledge of the structure of the information source.

The maps, as we are using them to code information from the remote sensor data, are information screens through which messages can be transmitted from the geographic environment to the user of the information. We might think of the Earth as sending out messages, for any who care to listen, by means of the signals transmitted into space through the "windows" consisting of patterns of the land and water surface. We have devised a language (the maps and classification schemes) but we are overwhelmed with the quantity of information available, so we try to invent a grammar and other structures that will enable us to handle the information efficiently and hopefully to learn some new things about the nature of the source itself, the Earth's surface configuration and the processes that caused it to be as it is.

Capturing and mapping a small portion of the total information being transmitted, we may ask, how much information is contained in a map? A more appropriate question would be "what is the total number of possible messages that can be transmitted for a given geographic area." This latter question has a finite answer as soon as the mapmaker specifies (a) the characteristic that he is mapping, (b) the size of the basic unit of generalization and (c) the "rules" which govern how the basic units are put together to form patterns. The size of the basic mapping unit is related to both the scale and the degree of accuracy of the map.

One of the efficiencies to be gained might be through exploitation of the concept of redundancy or "internal information" of an information source. Ideally this concept means that only part of the information output of the source needs to be transmitted since the internal information may be regarded as *a priori* information which will be possessed by the recipient of the message before any transmission has taken place. An example of this situation is the systematic deletion, letter by letter, of portions of a transmitted message in written English. Because of the recipient's knowledge of the language the actual information content can be maintained through several such deletions. Experiments have found that approximately 50 percent of the letters in English text can be deleted before the total meaning is lost. Thus, we might say that English contains about 50 percent redundancy. A practical problem is to devise a coding system which will separate out the internal information at the transmitting end and restore it at the receiving end of the communication link. The concept of redundancy will thus assist us in determining how much of the map is unnecessary as part of the transmitted message.

Simplified portrayal of a map as an information carrier

In this simplest case of the use of a map to convey information, suppose the map is one which distinguishes only two categories--land and water. Also assume that the perception unit used to convey this information is a square which must take either all of one value or all of the other, i.e., no land-water boundary crosses one of the perception units. This perception unit is thus seen to be analogous to the information elements as defined in figure 3.1. If land and water are independent and equally probable occurrences, we might expect a sequence of map units encountered in a traverse across the map to be a random succession similar to the succession of heads and tails obtained by several tosses of a coin. In reality, of course, the land and water units would seldom be equally likely (in the world-at-large water is approximately three times as probable an occurrence as land) and they are not randomly distributed over the map space, i.e., the assumption of independence among the elements of the map must be dropped. For example, if we enter the map at the west edge and make a traverse across eastward we would not expect to encounter aerial units, L and W, in a random order, but rather in a pattern of bunched L's and W's, the probability of occurrence of any one being dependent to a certain extent on the occurrence of the previous one. If the first square is "water" this information tells you more about the probability of what the second square will be than if the value of the first square is "land" or unknown.

The existence of these patterns (i.e., nonrandom distribution of the ordered elements of the map) constitutes what has been called internal information and if measured would be synonymous with Shannon's concept of "redundancy." Its effect on the numerical value of information content would be to reduce it. It is in this sense that the statement was made above that the total number of information elements is a "worst case" expression of the amount of information that has to be handled by the CARETS project.

A very rudimentary first step in attempting to account for the internal structure of a map might be obtained by examining some traverses across the simple maps that were depicted in figure 3.2. Such transitions are illustrated in figure 3.6. The transition matrices shown in figure 3.6 may be thought of as a crude way to illustrate quantitatively the components of the texture or pattern represented by west to east transitions and by north to south transitions in the specimen maps depicted in figure 3.2. The use of two different directions for the map transitions is a crude attempt to take account of the two-dimensional nature of this particular map pattern, in contrast to the one-dimensional situation in the example of telephone transmission and analysis of English text. To reduce the map to a one-dimensional scan would obscure the information contained in any directional pattern or "grain" in the landscape depicted on the map. Other more realistic means of capturing the two-dimensional nature of the map for information-theoretic purposes would be to scan with a larger template than just a pair of map elements--perhaps a square, latin cross, or some more complex scanning template. Further discussion on the application of information-theoretic concepts to analysis of maps or other two-dimensional arrays can be found in Rosenberg (1955), Pierce (1961, p. 264-266), and Olson (1972). A closely-related topic is the application of automated pattern-recognition techniques to the interpretation of aerial photographs and satellite images. For an excellent summary reference, see Rosenfeld (1969).

Another element to be considered in quantifying the information contained in the CARETS maps is the number of possibilities that enter into the choice of each mapped category. For example, the assignment of type of Level II land use is made from a list containing 26 possible

A. West-to-east Transitions

Map (a)

From \ To	4	2	1
4	20	0	0
2	0	0	0
1	0	0	0

Map (b)

From \ To	4	2	1
4	9	5	0
2	1	5	0
1	0	0	0

Map (c)

From \ To	4	2	1
4	7	2	3
2	1	1	1
1	0	0	5

B. North-to-south transactions

Map (a)

From \ To	4	2	1
4	20	0	0
2	0	0	0
1	0	0	0

Map (b)

From \ To	4	2	1
4	10	2	0
2	1	7	0
1	0	0	0

Map (c)

From \ To	4	2	1
4	8	0	2
2	0	1	0
1	1	2	6

Figure 3.6.--Cell-to-cell transitions in traverses across specimen maps depicted in figure 3.2

land use types, each represented by a two-digit code symbol (table 3.4). Twenty-five of these 26 are present in a portion of the test area constituting the digital data base. Therefore, in table 3.4 the number 25 appears opposite the heading "Land use from aircraft data" to show the variety of types of information possible. Similarly, other maps and overlay data sets are indicated according to the numbers of total units contained in the data base. In the case of the land use data and the geology data, categories may be used any number of times. However, in the case of the census tracts, county names and drainage basins, a particular unit is confined to a particular area of the map, and once that area of the map is completely assigned (e.g., county) the designation for that unit will not occur again. Thus, it would not be necessary for the system to carry the location identifier throughout all of the listings in the entire data set, but only in that of the region where the county is known to occur. Further savings in information storage may be obtained by using these principles.

Need for combined theoretical and empirical approach

The above discussion on quantification and information flow modeling was not carried far enough during the planning stages of the CARETS project to serve as a major component of the design of the information system. There were neither time nor skills available to us to pursue in a rigorous way the theoretical concepts sketched here. Therefore, as will be explained in the following section, the approach taken was to combine a rudimentary theoretical approach with an empirical "brute force" approach to data handling and delivery. This method had the advantage of leaving as a legacy the computerized files of land use and

Table 3.4.--Number of classification categories for each type of (map) data coverage in CARETS digital data base[1]

TYPE OF DATA COVERAGE	NUMBER OF CATEGORIES DEFINED IN CARETS TEST REGION
Scale 1:100,000	
Land use from aircraft data	25
Land use change from aircraft data	141[2]
Census tracts	1061
Counties and independent cities	26
Surficial geology	67[3]
Scale 1:250,000	
Land use from Landsat	29[4]
Counties and independent cities	92
Drainage basins	23

[1]Includes only counties (or independent cities) where data coverages are complete; some additional areas were partially digitized.

[2]Actually identified in CARETS; theoretical possibility = 601 ($n^2 - n + 1$, where n = number of land use categories)

[3]Actually identified in CARETS; six-digit classification used implies 1587 categories theoretically possible.

[4]Including Levels I, II, and III categories identified somewhere in the test region; only six Level I categories consistently mapped for entire region.

other kinds of data sets, which are available to other researchers who may wish to pursue further the question of quantitatively defining empirical probabilities of different land use types, according to concepts derived from information theory, and thus to measure information content of different kinds of maps. Our digital files would be well-suited to further analysis of this kind.

GEOGRAPHIC INFORMATION SYSTEMS APPROACH

The desirability of conducting an environmental information systems research effort with a sound theoretical base was stated in the preceding section. An argument could be made that going ahead with the development of appropriate theory would have been the most practical way to conduct the project. However, considerations which we called "practical" in the context of the day by day management of a government project under tight scheduling constraints dictated that the theoretical developments could not have the prominence which was desired. A methodology for proceeding with the CARETS project was chosen which was a compromise between the more desirable approach of building a sound theoretical framework and the less desirable approach of conducting a conventional mapping program with delivery of the information to the sponsors in the form of traditional land use maps. One choice intermediate between those extremes would be to employ a system of multistage sampling, the stages based upon different levels of resolution and/or generalization obtainable from the remote sensing imagery (Langley, 1969). That choice was rejected because of the desirability of having maps in graphic form as one of the types of output products available from the system.

The compromise that was selected for CARETS is the geographic information systems approach. This approach had the combined virtues of providing data in a quantified form which would later facilitate their use in furthering theoretical developments, as well as the "practical" benefits of providing a means for handling large volumes of information for delivery to the users and to serve as the basis for the calculations needed to compare the capabilities of the aircraft and satellite sensors. The geographic information systems approach, while not widely adopted by operational systems, was nevertheless widely enough known for a considerable body of systems development and tests to be available for our evaluation. In our judgment the technology seemed to be just about at the point for a "take-off" into a much more powerful and readily available tool for handling environmental information.

A geographic information system is an information system in which a location identifier, or reference to geographic position on the surface of the Earth, is carried as an implicit element. Geographic information systems are thus special cases of the broader category of information systems. The compendium edited by Tomlinson (1972) contains some helpful definitions. Quoting Thomas and Shofer's (1970) definition of a system as "a group of entities and activities meaningfully connected and satisfactorily bounded which interact for a common purpose or purposes," Tomlinson proceeds to characterize the entities and activities for any information system as being described in terms of four subsystems (figure 3.7). These four subsystems are as follows: (1) a management subsystem consisting of the organization, staff, procedures, and rules for the direction of one or more of the other three subsystems, depending on what functions are included within the information system; (2) a data

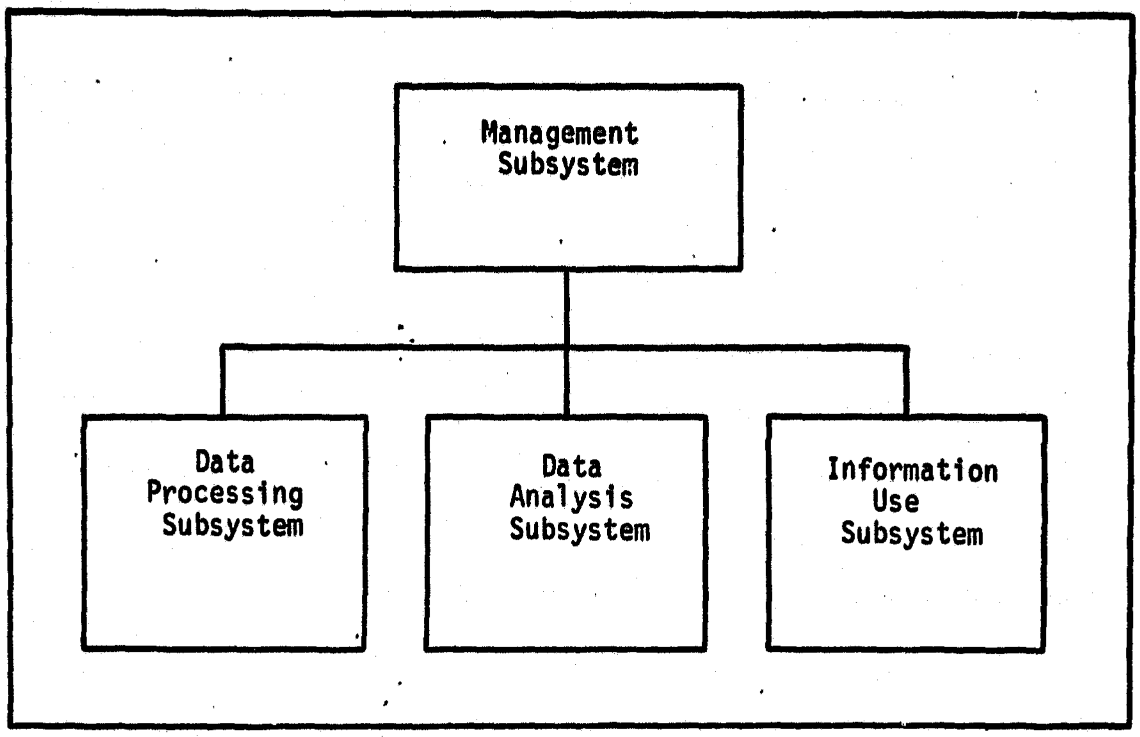


Figure 3.7--Subsystems characterizing an information system

Source: Tomlinson, 1972

processing subsystem including data acquisition, input, storage and retrieval via a sequence of operations utilizing various automated and nonautomated procedures; (3) a data analysis subsystem including any manipulation of the data such as summarization, statistical analysis, or modeling, as well as the preparations of the data for output as information in various forms; and (4) an information use subsystem, which is the user's decision system where the information is brought to bear on the problem of concern (Tomlinson, 1972).

Within the broad category of information systems, geographic information systems have the requirement that the data be referenced in a manner which will allow retrieval, analysis and display on spatial criteria, i.e., there is a required geographical reference or location identifier. Thus, according to Tomlinson "it is generally agreed that a geographical information system contains data with location identifiers, that these data are manipulated and retrieved on geographical criteria and that the output generally takes the form of graphical presentation."

For guidance in proceeding to develop the CARETS geographic information system we were fortunate to have the advice of a group of leading specialists in all facets of such systems, namely the members of the Commission on Geographical Data Sensing and Processing of the International Geographical Union (IGU). The International Geographical Union is a learned society with a membership consisting of countries represented through a national committee, a principal academy, a national research council, scientific societies, or an appropriate government department. Among the purposes of the IGU are to promote the study of geographical problems, to coordinate research requiring international cooperation, and to facilitate the collection and diffusion of geographical data and documentation in and between all member countries. Among the IGU operating bodies are commissions which may be established for the study of a specific problem or for accomplishment of a task which requires international collaboration.

The driving force behind the geographic information systems approach is the estimation of user requirements. In this project we were dealing with two major classes of users: primary users, those who made use of the data themselves; and secondary users, those who served as information brokers through which the information would pass before reaching the primary users. Since the details of the user requirements are dealt with in chapter 6 they will not be further elaborated in the present chapter. In this chapter the discussion proceeds with reasons for developing the computer capability, the selection, design, and operation of the system, and its role as a prototype within the USGS Geography Program. Implicit in these procedures is the already-discussed estimation of the quantity of information to be dealt with, the information processing requirements, the specification of hardware and software, and the carrying out of the information system development through scheduling and implementation.

Reasons For Developing Computer Capability

An early decision in the planning for the CARETS project called for the development of a computer capability to handle some of the information contained in the basic data sets (for example, see table B.5) rather than simply providing for delivery of the map sheets themselves to the cooperating users. There were several reasons for this decision to develop the computer capability.

Quantity of information

First, it became clear from early calculations that very large amounts of land use and related information were needed in quantitative form for the environmental modeling and monitoring applications envisioned at the start of the project. This conclusion was derived from a number of studies including one conducted for feasibility test and system design recommendations prior to the formal beginning of the CARETS project (Goodell and others, 1972). The Goodell study examined only a portion of the area that later became the CARETS test site and concluded that the tremendous amounts of information required for the environmental studies would preclude the use of any but a computerized processing system for handling such information. It was envisioned that research applications as well as operational use of data for monitoring and environmental impact studies would require the information in quantitative form and would facilitate the sharing of data among the variety of users.

Need for retrieval by geographic area

Second, a need existed for a considerable flexibility in land use information retrieval by a variety of geographic areas and user jurisdictions. For example, delivery of the land use maps per se would not suffice for a user who had special city, county, or regional areas of interest, and for which quantitative information summaries would be required. One approach to the problem of making land use information available for all those different levels of retrieval regions would be to provide a greatly increased number of specialized map sheets and measurements of the map units contained therein according to the anticipated demand by users at various governmental levels. However, it became clear that such an arrangement would be extremely cumbersome and would require the delivery of literally hundreds upon hundreds of separate sheets for meeting the varied user requirements in the CARETS region.

Need for map data in quantitative form

Third, a number of the users, according to the initial users' survey, would require area measurements and other quantitative summaries of the information contained on the land use maps. Manual methods for obtaining such information are of course available, but they increase greatly in cost and in time as the area and level of detail increases. Since one of the objectives of the CARETS study was to prepare the way for a national operational capability to handle land use data, the need to develop more readily useable and rapidly applicable methods for obtaining area measurements became obvious. Hence, the further recommendation for a computerized system.

Need to correlate with other data

A fourth reason for choosing a computerized capability is that the typical user of quantitative data on land use and land cover needs to use such data in conjunction with, and in correlation with, other regional data sets on a variety of environmental and socioeconomic factors, such as data supplied by the U.S. Bureau of the Census. Census data are now commonly used in magnetic tape format; correlations and overlays would be facilitated if other data could also be made available in machine-readable format.

Testing of automated map production methods

Fifth, having machine-readable map data also makes possible the display of such data in map form through use of a variety of computer-graphic output devices. We wished to test some of the display techniques as a means of providing more flexibility in supplying maps to users according to their particular needs. It also seemed possible that automation of some cartographic procedures might enable the map production process to be both cheaper and quicker, given the original data in digital form.

Comparison of Landsat and aircraft sensor performance

Finally, the experiment called for quantitative comparisons of land use and land cover data sets as obtained from aircraft and Landsat sensors, primarily for NASA's use in evaluating different sensor systems. The aircraft sensors were to be taken as a standard against which the experimental Landsat measurements would be compared. For an area the size of the CARETS test site we reached the conclusion that computerized measurements would be necessary for any but the most rudimentary efforts at quantitatively comparing the two types of data sets.

System Selection, Design, and Operation

Once having determined the need to develop a computer capability for the CARETS project, the problem facing us was how to proceed to do this in the most effective way within the constraints of the project schedules. One of the most serious problems was the lack of experienced staff who could begin with the tasks of system analysis and computer operations according to the project's requirements. As mentioned earlier, we decided to deal with that problem by securing the advice of a group of expert consultants from the IGU Commission on Geographical Data Sensing and Processing.

Role of the IGU advisory group

The IGU advisory group assisted us in analyzing our information handling problems and advised us on various computerized approaches. They were able to tap specialized professional expertise and apply it to the various component parts of our overall information handling problem. Thus, the IGU group functioned not only as a consultant for total system development, but also as a source of specialized knowledge on component parts of the desired computer system. While there were some existing information systems in operation at the time we began this effort, it became clear that none was sufficiently far advanced for complete adoption in its existing form to satisfy our project's needs. Therefore, we needed to do some surveys and evaluations of these systems before proceeding with development of our own.

The IGU group was well qualified to undertake this task, having just completed a report on geographic information systems that was the output of a symposium held 2 years earlier in Ottawa (Tomlinson, 1970). In addition, a two-volume compendium of the results of a second symposium held at the time of the International Geographical Congress which met in Canada in 1972 (Tomlinson, 1972) had presented perhaps the most detailed compilation and critique of the various components of geographic information systems to that time. Most of the same individuals who were task leaders on those earlier efforts were made available to assist in the development of the CARETS geographic information system and the follow-on Geography Program operational system. The overall role of the IGU advisory group was defined as fulfilling three functions: (1) assisting in the solution of immediate problems arising from the requirements of the CARETS project and other then-current projects in the Geography Program; (2) at the same time, begin the specification of the longer-range operational USGS Geography Program geographic information system, based upon the input of land use information, making that system compatible with and derivable from the experiences of the CARETS project insofar as possible; and (3) determination of the cost effectiveness of the developing USGS system in comparison with alternative existing or experimental geographic information systems.

A working mode was developed in which members of the appropriate specialization within the IGU advisory group met at USGS headquarters with the appropriate managerial and technical staff members of the Geography Program including investigators of the CARETS experiment. The advisory group operations are given detailed treatment in Mitchell and others (1977). Suffice it to say for the purposes of the present summary, the effects of the IGU advisory group were felt throughout the operation of the computerized CARETS information system, and even of other aspects of the CARETS investigation where their expertise could be called upon for assistance.

In summary, the IGU advisory group undertook to assist the CARETS project obtain access to the data derived from remote sensing, along with necessary correlative data, in digital form so that certain required quantitative manipulations could be performed. Among the latter were the comparison of measurements made from aircraft and satellite data sources so as to test each for applicability by user agencies with land use management and planning responsibilities. The IGU group addressed all four of the subsystems illustrated in figure 3.7. Under the management subsystem they attempted to provide their advice in the context of bureaucratic and funding limitations, including the difficulties of obtaining procurement approval for new automatic data processing equipment under government regulations. They also addressed the training and personnel needs implied by our commitment to the computerized geographic information system activity. The other subsystem tasks were conducted in close communication with the USGS staff, and with full cross-communication amongst the various IGU specialists. Schedules which were imposed by the requirements of the NASA investigation were also integrated into the planning.

Their advice on tasks falling under the data processing subsystem included the specification of hardware and software to transform (digitize) data from map form into machine-readable form. Also included under the data processing subsystem were the various programming innovations that were needed to enable the digitized data to be assembled into polygon form for further manipulation.

Tasks under the data analysis subsystem included devising the software necessary to manipulate and display the data in a form most suitable for the needs of the cooperating user agencies. This, of course, included feedback from the data use subsystem. The tasks under the data use subsystem included close interaction with representatives of the user community, preparation and administration of questionnaire-based interviews with those representatives, and analysis of the results in terms that could be translated back into specifications for data processing and data analysis subsystems. Even though components of the required information system were available from other sources, an integrated system that had the ability to do all of the tasks in an operational fashion was not available for transfer to the CARETS project. Facts of life throughout the entire effort were the complexity of the system requirements and the need for the various pieces to be integrated with each other so as to produce a working system in the end.

Survey of existing systems

One of the tasks of the IGU advisory group was to survey existing geographic information systems with respect to the applicability of individual components and overall approach to the needs of the CARETS project and the longer-range USGS operational system. The systems included were:

Existing Geographic Information Systems Surveyed by IGU Group

1.	The Canada Geographic Information System (CGIS)	Fine polygon,* drum scanner
2.	The Oak Ridge Regional Modelling Information System (ORMIS)	Small grid, flying spot scanner
3.	The Minnesota Land Management Information System (MLMIS)	Medium grid, manual grid overlay
4.	The New York Land Use and Natural Resource Information System (LUNR)	Large grid, manual coding
5.	The San Diego Comprehensive Planning Organization's Polygon Information Overlay System (PIOS)	Coarse polygon,* manual digitizer

* Fine and coarse polygon systems are differentiated by the number of points used to define a polygon.

The following conclusions from the survey of existing systems are drawn largely from the principal CARETS report on geographic information systems (Mitchell and others, 1977). There are probably more problems on the management side of the design and development of an information system than on the technical side. Possibly the most critical problem in the management of a developing system is the timing related to obtaining approval for the system, obtaining staffing slots and hiring personnel for them, acquiring the necessary equipment, obtaining fiscal support, and finally, implementing the system in the face of significant time delays. All of the above listed problems were encountered in the CARETS investigation. The advisory group also emphasized the need to estimate probable time delays in system design and implementation plans. A system design should be structured to minimize the adverse effects of time delays. Opponents of a system development project will capitalize on delays, and therefore underestimating the time periods necessary in system development will adversely affect the implementation of its various parts.

Considerable attention was given to the personnel needs of a developing information system. Recommendations were made that long-term job descriptions be written with the total development time of the system in mind, possibly as much as 8 to 10 years. Wherever possible the most experienced people in any given technical requirement should be used. An alternative to staffing with such skilled people is the utilization of outside personnel on a contract or consulting basis. When using such outside sources, it is imperative that the work that they do be closely integrated with the remainder of the operation so that a totally integrated project results.

A major technical constraint in the development of geographic information systems is digitization of data, and especially the processing or converting of an error-prone manuscript map into an acceptably error-free computer file. The significance of an error-free digital file is particularly important since in the present state of computer development the computer cannot intelligently ignore nonlogical errors. The process of creating an error-free file includes: (1) pre-editing of graphic data, (2) digitizing, (3) detection and correction of errors, and (4) file structuring. The use of interactive cartographic data manipulation capabilities can be of considerable benefit in the error-correction process. In order for the users to fully appreciate and utilize the geographic information system, there is a need for education of users in the employment of spatial data manipulative techniques and statistical methods of analysis. The IGU group believed that the best way to approach this was through a "go-between" process which places persons knowledgeable in spatial manipulative and statistical methods between the actual user and the information system itself. Those go-betweens would have the task of interpreting or translating the user's problem into quantitative terms to which the system could respond. The advisory group concluded that "it is incumbent upon the system designer to include personnel capable of understanding the user's problem and to be able to translate that problem into terms suitable to use the system's capabilities for spatial data manipulation and statistical analysis."

Choice of polygon over grid system

The CARETS project requirements to quantify areas of mapped units, sum those areas over larger areas or arbitrary regions defined within the total map, and compare areas of similar categories from different maps could have been met through either a grid or polygon data encoding system. In a grid system an arbitrary grid would be overlayed upon a mapped area and the category assigned either according to the location of grid intersections or grid square centers for the entire area of the grid cell. Another way of assigning the category to the grid cell would be to compute the areas of the different categories that fell within each grid and assign the grid definition to that category having the largest such area. In any case, a single cell of a grid encoding system would carry a single classification category.

Alternatively, a polygon system would enable the encoding of the line data from the original map. Categories of the map (e.g., land use) which were distinguished one from another would be so distinguished in the polygon encoding system, i.e., the line dividing two such categories would be digitized by some means enabling the recording of a sequence of points making up that line along with the identifier describing the category on each side of the line. The lines would then be put together into polygons, each polygon consisting of a circumscribed map unit of a single classification category.

The grid system has the advantage of a much simpler file structure within the computer, enabling manipulations to take place with simpler computer operations and therefore at less cost. If fine detail is required, however, the grid system has a disadvantage in the large amounts of input data and in the expense of preparing for input the very large number of grid cell definitions required. On the other hand, the polygon-type input system has the advantages of efficiently capturing the detail contained in the original line map, along with the capability to reproduce it as output in the form of line maps. The disadvantage of the polygon system is the higher cost of computation in polygon form within the computer.

The various problems and benefits of polygon and grid systems are illustrated in the sequence of figures 3.8A through 3.8D. In figure 3.8A we have an example of an unretouched manuscript map prepared directly from manual interpretation of a high-altitude aerial photograph of a portion of the Norfolk SMSA test site, with the mapped units separated one from the other into distinct units (polygons). An early experiment in the CARETS project was performed to test capabilities later desired in the larger system. The map contained in figure 3.8A was digitized by means of manually tracing the boundaries of each polygon with a digitizing cursor on a flatbed digitizing table. Each line thus traced was transformed into a series of x and y coordinate values for a sequence of points close enough together to approximate closely a continuous line. A plot program was developed in which arbitrary patterns were assigned to each of the map units, so that replay of the data from the computer made the various types of land use easily distinguished visually from each other, as indicated in figure 3.8B.

One of the problems of the polygon system of recording such data can be seen by close examination of the patterns in figure 3.8B, namely the problem of the operator having to retrace the boundaries when digitizing a polygon from the opposite side of each line segment. Since very few operators can exactly reoccupy the same line when tracing it, little "slivers" of unassigned data sometimes appear on playbacks of such maps.

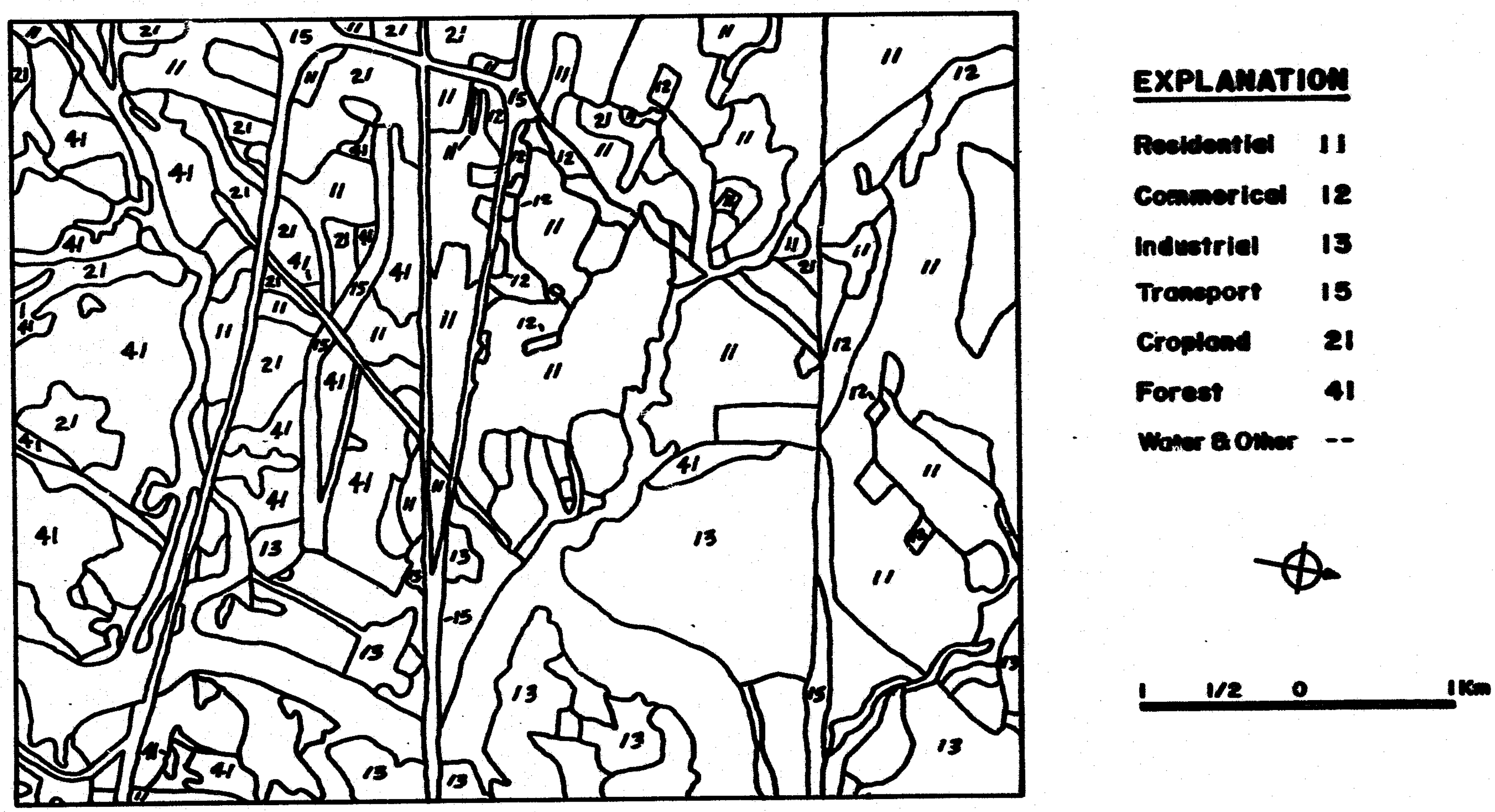


Figure 3.8A.--Land use map for computer experiment, hand-drawn from aircraft photography, portion of Norfolk SMSA

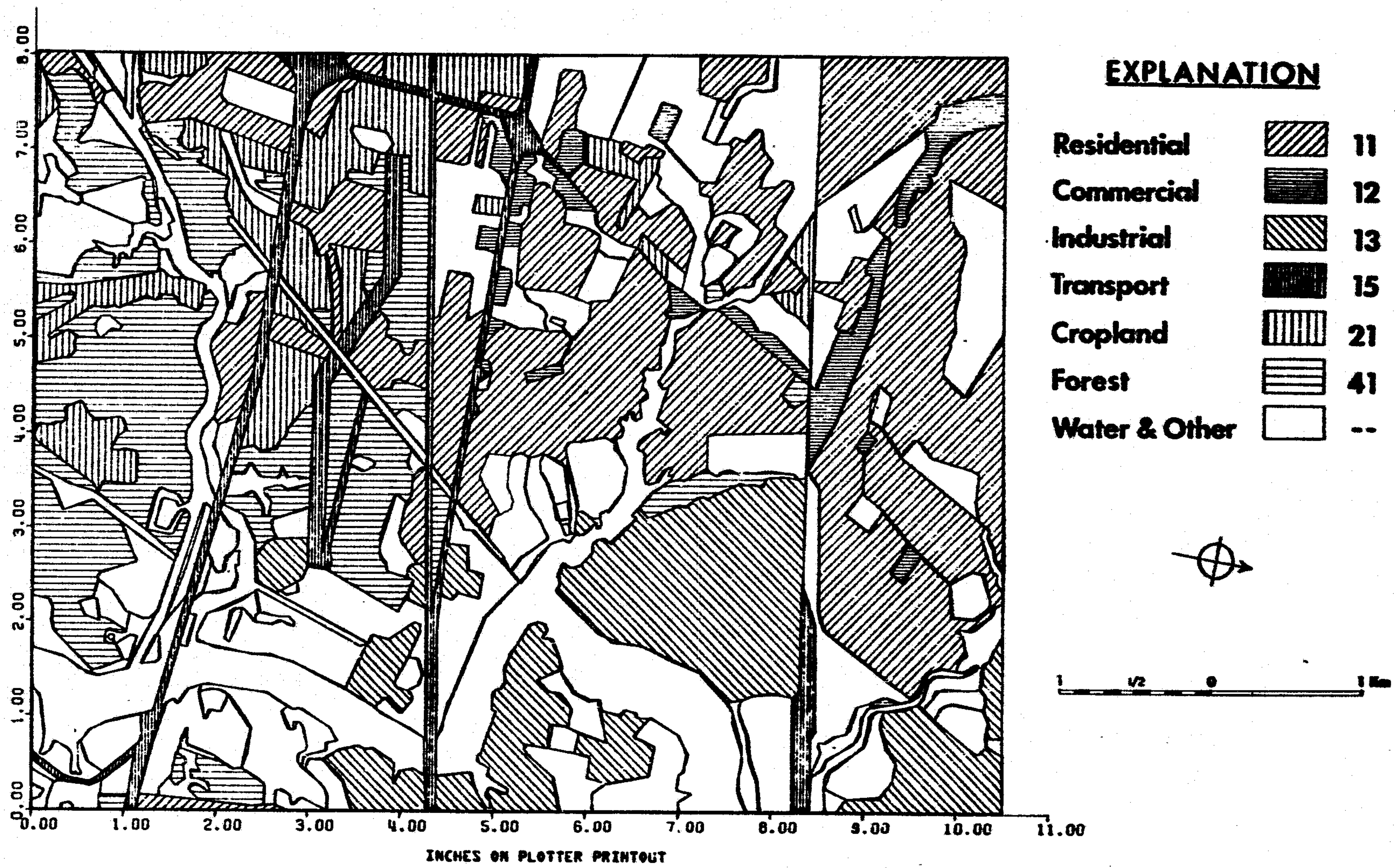


Figure 3.8B--Computer-generated polygon plot of land use map, portion of Norfolk SMSA.

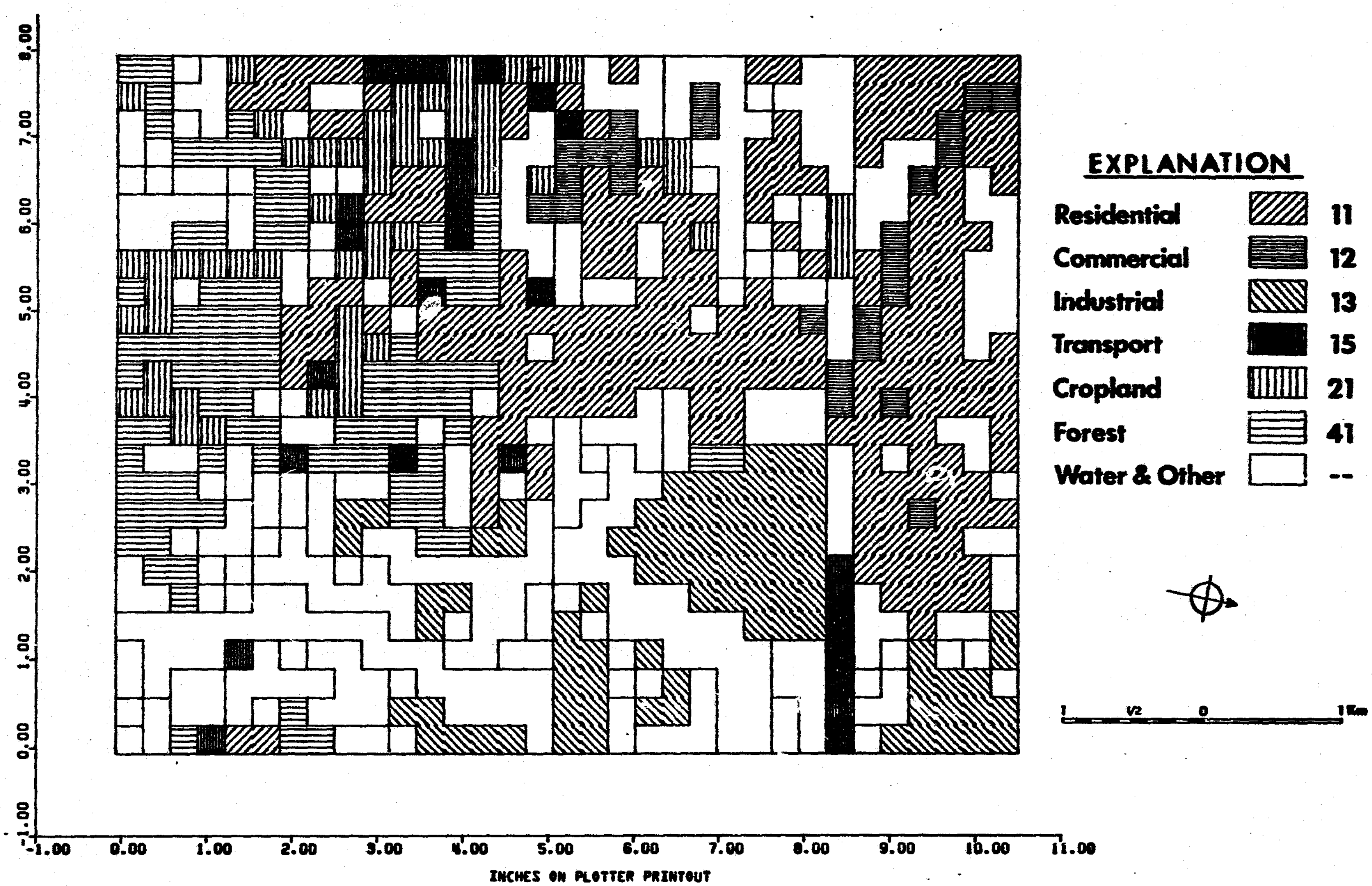


Figure 3.8C--Computer-generated plot of land use map by 10-acre grid cells, portion of Norfolk SMSA.

3-52
120

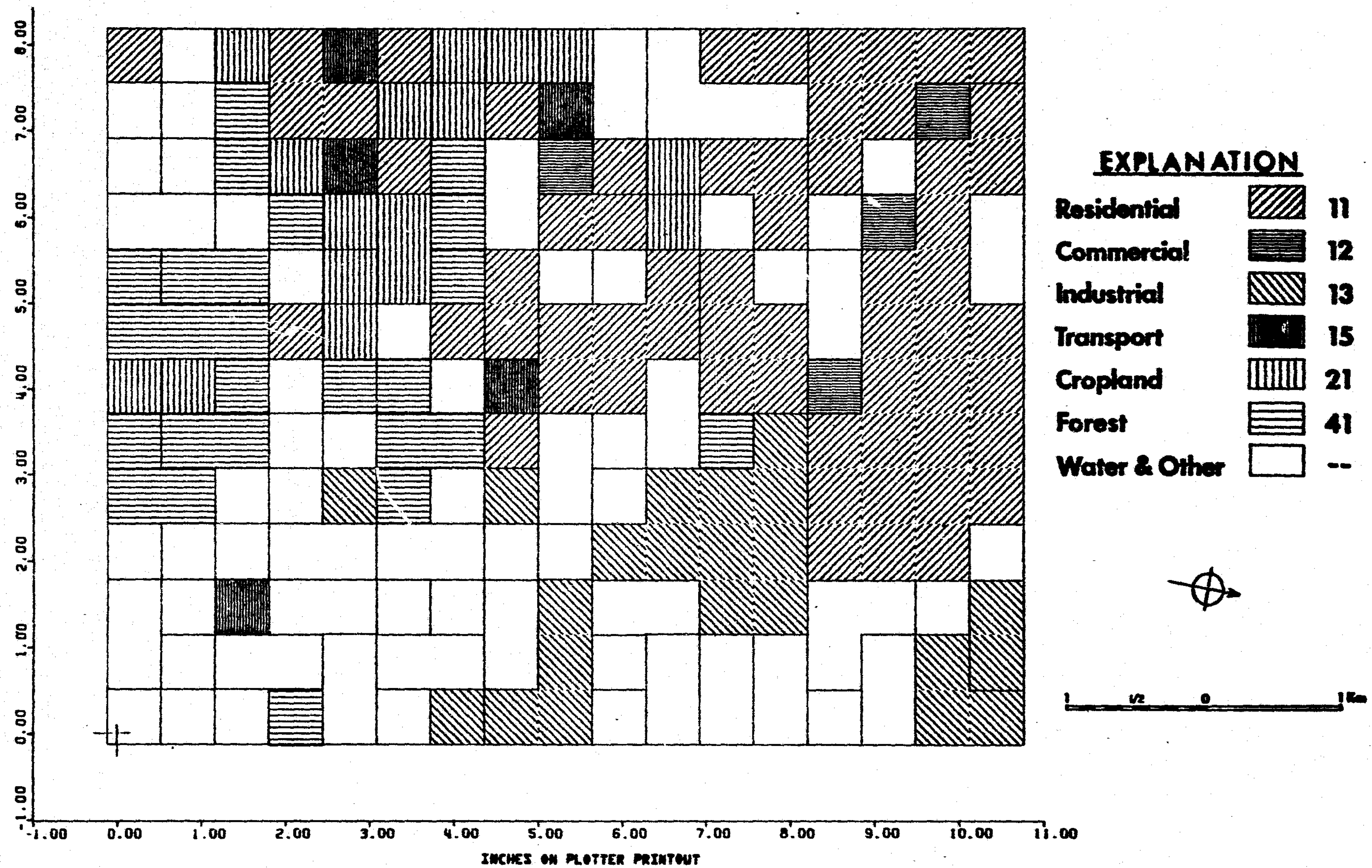


Figure 3.8D--Computer-generated plot of land use map by 40-acre grid cells, portion of Norfolk SMSA.

These slivers are shown in the diagram in figure 3.8B, although they would be removed as errors in any final system output. The Canadian system of digitizing with drum scanner and associated software surmounted this sliver problem, as did the USGS Geography Program operational system which employed a process of digitizing once each line segment (arc) between nodes, and then creating polygons by computer manipulation of the line segment data.

To enable comparison with a grid system, grid cells of two different sizes were overlayed on the data used in this experiment. The overlay process was accomplished in the computer by arbitrarily assigning to the entire grid cell the category as it appeared at one of the cell vertices. Of course, the smaller the cell size, the more nearly the map approximates the appearance of the polygon map. A cell size of 10 acres each is illustrated in the map in figure 3.8C, in which the major patterns are easily comparable with the patterns of the polygon map. A 40 acre cell size map prepared by the same methods is illustrated in figure 3.8D. In this figure the resemblance to the original map is less apparent although still visible in the gross patterns. The question of map accuracy is an important one in determining whether polygon or grid cell manipulations are to be used. The experiment described in figures 3.8A-D also developed a program for summing the areas of each of the digitized map representations. The area measurement from the polygon representation was of course the most accurate since each of the originally mapped units was represented in the area calculation. It would be expected that areas would be less accurate as the grid cell size got larger. This is illustrated quantitatively in table 3.5. Examination of data such as that presented in table 3.5 would assist the user in determining what system to adopt. If a high degree of accuracy is not required the user could

Table 3.5--Area calculations by polygons and by cellular aggregations: Portsmouth-Chesapeake sample area

Land Use Type		% of Total Area by Polygons	% of Total Area by 10 Acre Cells	% of Total Area by 40 Acre Cells
Residential	(11)	25.12	24.24	27.60
Commercial	(12)	2.58	3.03	1.81
Industrial	(13)	10.54	10.06	9.95
Transport	(15)	4.17	3.27	2.26
Cropland	(21)	6.72	7.03	7.24
Forest	(41)	11.96	11.52	11.31
Water & Other	(--)	38.91	40.85	39.83
Average error by cells			6.7	14.0

perhaps settle for a grid cell system which contained a modest amount of error but which was less expensive to operate on the computer system.

The IGU advisory group, after surveying the available hardware and software systems, concluded that a grid system, though simpler to handle with present computer processing capabilities, would be too costly for handling the large amounts of input data given the size of the CARETS region and the mapping scale and minimum mapping unit (4 ha at 1:100,000). Another disadvantage of the grid system which was a corresponding advantage of the polygon system was that output would be available in line map format similar in accuracy and representation of detail to the input data. This characteristic was particularly important for one of the objectives, namely to test the system for possible use in producing, directly from computer output, map plates for use in the printing process. Also, with polygon input it would be possible to generate grid cells of any arbitrary size by relatively simple computer manipulation, while data input as grid cells could not be used to regenerate the original polygons. It was therefore decided to use a polygon-type input system in which the boundaries between land use categories, as drawn by the original interpreters, would be digitized directly and input to the system with as little loss in accuracy as possible. The next step in the planning process was the search for a capability to digitize the requisite amount of information and to perform all the various data analysis, manipulation, and display tasks required by the investigation.

Selection of Canada Geographic Information System

Since no capability existed within the USGS for volume digitizing of the number of maps required for CARETS, external digitizing capability was sought. A competitive request for proposals (RFP) for digitizing services from commercial firms was issued based on the CARETS map requirements, and on the additional requirement that error-free digitized tapes be produced. A requirement for the bidders under the RFP was that a sample map provided by USGS would be digitized and submitted as a portion of the proposal. After a thorough evaluation of all proposals received, not a single one was able to meet the requirements set forth and therefore none were awarded the digitizing tasks for CARETS.

In the meantime, tests had been run on the Canada Geographic Information System (CGIS), Department of the Environment, Government of Canada. Facilitated by the advice and administrative arrangements of the IGU advisory group, further discussions with CGIS were undertaken concerning the possibility of that system being used for the volume digitizing of CARETS maps. In addition to the already proven operational capability of CGIS, use of that system had a further advantage in that their manipulative software and overlay capabilities would also be available for further processing of the CARETS maps after digitizing. In view of the fact that the USGS Geography Program software development was not likely to be far enough along to perform the required tasks according to the CARETS schedule, the CGIS system was selected for the processing of CARETS maps. This was an experiment in itself in the technical collaboration with a foreign government for conducting computer mapping experiments and seeking solutions of mutual interest to the two countries to problems of analysis of geographic information.

Data input into the CGIS system is by means of a drum scanner on which a hand scribed map is mounted. The scribing process has separated "line" information from symbols and all other map notations. A moveable carriage moves the scanning head across the face of the map as the drum turns. The scanning head passes over the map sensing the amount of light reflected from the maps every 1/250th of an inch and records the information that a line is present by a series of bits on a magnetic tape. A normal full-size map sheet takes from 10 to 15 minutes to scan on the CGIS system. This scan produces the "image" data set.

A manual process is used to compile the numbers which go with the image data, i.e., the classification information. This classification information is then entered into another magnetic tape which comprises the list of polygon numbers and classification data called the "descriptor" data set.

Thus, by a combination of manual and computer methods, a complete description of the information on the map, in the form of the image and descriptor tapes, is compiled. Figure 3.9 contains a simplified illustration of linkage of these data sets. The data reduction is accomplished by a unique set of software in the CGIS system. In this system, lines are closed and the several points identifying the width of a line are reduced to a single point so that each line is only one point wide and all lines have the same width. Polygons are checked for closure and corrected if not properly closed. The digitized coordinates of the map corner points and the points within each polygon are transformed to latitude and longitude coordinates. The map image data are also converted from the arbitrary x, y coordinates of the scanner to latitude and longitude coordinates. Image and classification data are edited for missing lines, gaps in lines, extraneous lines, and erroneous classification data. The list of errors produced is then corrected in the manual error

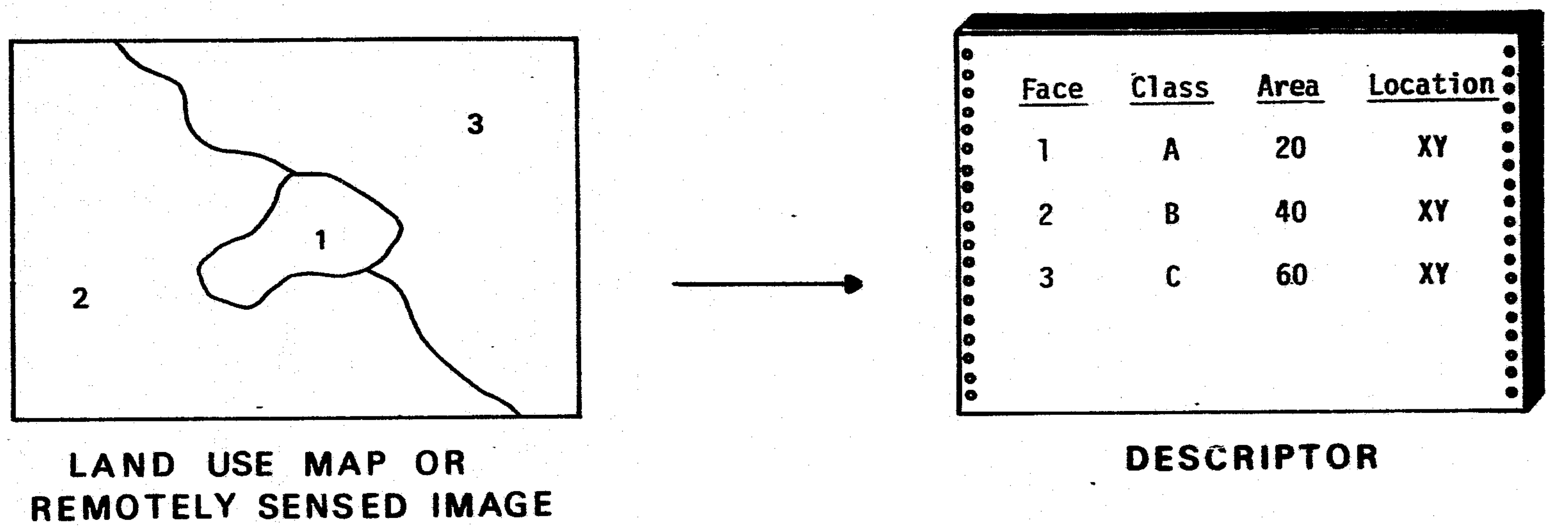


Figure 3.9--Image and descriptor data sets: simple linkage. After Tomlinson, 1970, p. 86.

correction subsystem. The map edges are identified and during the late phases of data reduction the polygons that may cross map borders are matched and assigned a new polygon number in both the image data set and the descriptor data set. The image data set and descriptor data set comprise the data bank. Each polygon in the image data set is identified by a numerical descriptor. The image data are stored in a series of frames. A frame is the basic unit of coverage used by CGIS. The CARETS data were stored in frames 3.75 minutes on a side which resulted in 128 frames per map sheet at a scale of 1:100,000 and 512 frames per map sheet at a scale of 1:250,000.

The CGIS retrieval subsystem can retrieve the various map coverages, including overlays of different coverages or data sets applying to the same map area and display them in either graphic or tabular form. Once the maps are in the data bank the options for retrieval format are very large.

CGIS information may be accessed through a graphic display terminal. Using such a terminal the user may interrogate the system and manipulate the data. A visual display can be presented on a viewing screen of either the graphic or tabular data for any coverage or set of coverages, and the device can produce the display as a hard copy printout. For example, a single land use for a given county on a map sheet or a set of map sheets may be displayed as a plot and the area may be output in tabular form as well. An enlargement of an example of such a land use plot is shown in figure B.10. For purposes of speed and economy in producing such visual displays on cathode ray tubes, not all the system's spatial resolution capability is used; therefore such displays are coarser than those produced by regular plotters.

The capability to overlay two or more maps of the same area, for example land use and county boundaries, was one of the advantages of our use of the CGIS system. In later sections of this report examples of data output from this system are presented.

Experiments were performed to determine errors in area measurements obtained by the CGIS system. In general these errors were less than one percent, i.e., measurements of areas obtained from the CGIS system differed by less than 1 percent on most tests from errors produced by generally accepted manual methods (Mitchell and others, 1977). It was generally felt that the accuracy of the system was extremely high, higher than the accuracy of the basic data sets that were input.

System operation

The CARETS map sheets, as listed in tables B.1 and B.2, were prepared manually from the aircraft and Landsat data. Each sheet was also inked by hand and this inked sheet became the master from which other stable-base film copies including those used for CGIS processing were made. This stable-base film copy of each sheet was sent from Reston to Ottawa for CGIS processing. Because of the CGIS use of the latitude-longitude system, rather than the UTM coordinate system, for determining map sheet boundary for input data it was necessary for CGIS to reassemble our map sheets to conform with the parallels and meridians used in their system. Each sheet was then hand scribed at CGIS to prepare the actual copy that was used on the drum scanner. Other correlative information taken from the map was also input into the CGIS system. During the data input operation it was necessary to maintain close technical contact between CARETS and CGIS staff. This was necessary because of a number of errors that were found by the digitizing process. That process is an excellent way to perform final map editing and to discover and correct the errors that inevitably creep into complicated maps of this type. The USGS received both magnetic tape and tabular printout for the various CGIS digitized data sets.

Prototype Role for USGS Geography Program System

As was stated earlier, CARETS became a major test for system development of the geographic information system of the USGS Geography Program. While it was never intended that the Canadian system would be used to satisfy the operational USGS program requirements, CGIS nevertheless provided the largest single volume of digitized data available for experimentation in the USGS up to that time. Thus, the experiences acquired during CGIS operation were valuable learning experiences for application to the development of the operational USGS system.

Under the guidance of the IGU advisory group, while the activities of the CARETS project were under way, a parallel development of the Geography Program geographic information system began. This system is ultimately intended to be operational and to handle the land use and associated overlay data for the entire United States. It is designed to input, store, manipulate, and retrieve digital spatial data developed from land use and land cover maps at a compilation scale of approximately 1:125,000, as well as overlay maps showing Federal landownership, river basin and subbasin, counties, and census subdivisions. Graphic output would be in the form of maps at 1:250,000 and 1:100,000 scales. In addition, the system is expected to accommodate maps at other scales. Computer-generated products from this operational Geography Program system, when it is completed, will include digital data base tape, graphic and statistical data, and specialized statistical and spatial data analysis. The basic data units of the system data base are (1) boundaries identified as to categories of land use and land cover and the other overlay categories, (2) polygons identified as to the categories that are inside the boundaries, and (3) boundary lengths plus the areas of the polygons. Boundaries are stored as strings of points defined by geographic coordinates (latitude and longitude) and are organized by 1:250,000-scale quadrangles and 7 1/2-minute quadrangles.

At the present writing the USGS does not have the capability to do the volume digitizing for the operational information system, so this digitizing has been done by outside contract arrangement. A variety of computer programs including map overlay, scale and projection change, contiguity or proximity analysis, generalization, extraction of data from composited files, spatial searches, and point radius and corridor searches are being prepared for eventual availability to users of the system. Present capabilities of the system include (1) coordinates may be converted to UTM, State plane coordinates, or any other rectangular or spherical frame of reference; (2) polygons may be converted to grid cells of any size and in any frame of reference; (3) data may be plotted back on any projection at any scale and with a wide range of selection criteria; (4) data may be retrieved on the basis of individual polygons or boundaries, type of boundaries or polygons (e.g., individual land use, county, etc.), or combinations of land use by census, land use by drainage basin, etc.; (5) data may be retrieved by geographic location; (6) data may be retrieved by any combination of the above.

Graphic outputs of the system will include editing plots, custom plots of single or composited data sets for users, and scribed and peelcoat stable-base plastic film, produced directly from computer output for publication purposes. A continuing aspect of the operational Geography Program geographic information system will be the support of State cooperative users and others within and outside USGS in the utilization of the system as well as the provisions of spatial data, plots and statistical analysis, and exportable computer programs.

PRODUCTS OF CARETS GEOGRAPHIC INFORMATION SYSTEM EFFORT

This concluding section describes products of the CARETS geographic information system effort: computer tapes, statistical area summary tabulations, graphic (map) displays, and demonstrations of a rudimentary manipulative analytical and potential user interactive capability. In addition to these tangible products, we may claim credit for a less tangible but nonetheless real product consisting of a workable system model for incorporating computer data-handling capability into a regional environmental information system based upon remote sensor data sources. Also, as a prototype of a new operational land use and land cover information program in the USGS, the CARETS project left a body of skills and experience residing in personnel occupying key positions in that new operational program. The co-principal investigator of the CARETS project in its early stages (William B. Mitchell) is now the manager of the USGS geographic information systems effort, reporting directly to the Chief of the Geography Program. Other geographers have moved on to positions in the new program encompassing systems analysis, programming, training, subsystems management, and liaison with user agencies, the foregoing being examples of the kinds of tasks they are performing.

Computer Tapes

One type of product produced by the CARETS geographic information system effort is the output computer tapes from the CGIS system. These consist of "image" and "descriptor" data sets, as illustrated in figure 3.9, as well as tapes containing area totals resulting from machine overlay of land use maps with other maps containing boundaries of subregions for which land use area compilations are desired. The data on these tapes are for areas and types of coverages shown in tables B.5 and B.6, and in figure B.25. In addition to being used by CARETS investigators to produce summaries and plots as described in this report to demonstrate system capabilities, the tapes were used in a major user assessment of applications to regional planning (Metropolitan Washington Council of Governments, 1976).

These computer tapes are being made available to the public through the USGS National Cartographic Information Center (NCIC). Before placing them in NCIC for public use, the format of the CGIS tapes was changed to conform to that of the USGS Geography Program computerized output, now called GIRAS (Mitchell and others, 1977).

Statistical Area Summary Tabulations

Another set of products from the CARETS geographic information system is the tabulation of area summaries of the measurements performed by the CGIS software based upon the digitized input of land use and overlay maps. These area summaries are available both in the tapes, as mentioned above, and in tabular printouts. We obtained tabulations for internal use in the CARETS investigation for only a small portion of the large number of possible "cuts" through this vast store of data. Figures 3.10A through E contain selected examples of these tabulations.

Graphic Displays

We experimented with a variety of forms of map output available from the basic CGIS data. One such example of graphic output, the direct display of a map segment via graphic terminal with cathode ray tube, was mentioned above in the section describing the CGIS (fig. B.10). Other types of output are possible from standard drum or flatbed line plotters, such as the plotters which produced the experimental map segments depicted in figure 3.8B, 3.8C, and 3.8D. For these output products it is necessary to employ the CGIS image and descriptor tapes along with software as required for each specific graphic display device. The image tapes are the ones that provide the actual map locations of the various lines differentiating one type of land use from another. The descriptor tapes carry identifying information for each polygon or "face." CGIS did not provide us directly with final graphic output products, so we obtained the services of a commercial contractor to do the additional programming necessary to carry the data through for use in some selected display devices. For program listings and further descriptions of the display systems, see the reference by Environmental Systems Research Institute (1976). The process illustrated in figures 3.11A and B utilizes a color display system in which color assignment by land use class is made automatically by linking a raster (line by line) version of the digitized map with a color film recording device. Two of

	Land Use	47029 VA--Fairfax		47030 VA--Fauquier		47036 VA--Gloucester		47037 VA--Goochland		47040 VA--Greensville	
		acres	hectares	acres	hectares	acres	hectares	acres	hectares	acres	hectares
1	Urban and Built-up	82,470.6	33,375.4	0.0	0.0	4,998.9	2,023.0	870.7	352.4	4,809.7	1,946.4
11	Residential	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4,847.0	1,961.5
111	Residential-Single Family	3,902.9	1,579.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12	Commercial & Services	1,062.4	430.0	0.0	0.0	0.0	0.0	115.1	46.6	409.5	165.7
13	Industrial	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14	Extractive	1,726.9	698.9	0.0	0.0	0.0	0.0	138.0	55.8	0.0	0.0
15	Transprtn, Cmmctns, Utlts	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
151	Hwys, Prking, Bus Term, Etc	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
152	Rlrds, Asctd Facilities	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
153	Airports	414.4	167.7	0.0	0.0	0.0	0.0	0.0	0.0	251.3	101.7
16	Institutional	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17	Strp & Clustered Stlmnt	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18	Mixed	296.2	119.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19	Open & Other	509.8	206.3	0.0	0.0	0.0	0.0	218.6	88.4	0.0	0.0
	Total for Land Use 1	90,383.3	36,577.6	0.0	0.0	4,998.9	2,023.0	1,342.4	543.3	10,317.4	4,175.4
2	Agricultural Land	17,220.0	6,968.8	10,630.5	4,302.1	11,708.6	4,738.4	0.0	0.0	43,345.9	17,541.8
21	Cropland and Pasture	21,765.7	8,808.5	266,939.9	108,029.1	20,894.3	8,455.8	42,196.5	17,076.7	0.0	0.0
22	Orchrds, Grvs, Bsh Frts Etc	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Total for Land Use 2	38,985.7	15,777.3	277,570.4	112,331.2	32,602.9	13,194.2	42,196.5	17,076.7	43,345.9	17,541.8
4	Forest Land	115,224.6	46,630.8	141,094.4	57,100.1	3,685.5	1,491.5	0.0	0.0	1,790.0	724.4
41	Hvy Crwn Cvr (GT 40 %)	0.0	0.0	0.0	0.0	96,934.8	39,229.0	141,272.8	57,172.3	132,571.5	53,651.0
42	Lght Crwn Cvr (10 % - 30%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3,887.2	1,573.1
	Total for Land Use 4	115,224.6	46,630.8	141,094.4	57,100.1	100,620.3	40,720.5	141,272.8	57,172.3	138,248.7	55,948.5
5	Water	924.0	373.9	297.7	120.5	665.8	269.5	0.0	0.0	647.9	262.2
51	Streams & Waterways	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
52	Lakes	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
53	Reservoirs	0.0	0.0	0.0	0.0	0.0	0.0	45.9	18.6	0.0	0.0
54	Bays & Estuaries	10,619.9	4,297.8	0.0	0.0	155,847.1	63,070.5	0.0	0.0	0.0	0.0
59	Ocean	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Total for Land Use 5	11,543.9	4,671.8	297.7	120.5	156,512.9	63,339.9	45.9	18.6	647.9	262.2
6	Non-forested Wetland	0.0	0.0	0.0	0.0	1,840.5	744.8	0.0	0.0	0.0	0.0
61	Vegetated	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Total for Land Use 6	0.0	0.0	0.0	0.0	1,840.5	744.8	0.0	0.0	0.0	0.0
7	Barren Land	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
72	Beaches	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Total for Land Use 7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Total Land Area by County	244,594	98,986	419,615	169,816	140,063	56,683	185,143	74,926	192,016	77,708
	Total Water Area by County	11,544	4,672	298	120	156,513	63,340	46	19	648	262
	Total Area by County	256,138	103,657	419,912	169,936	296,576	120,022	185,189	74,945	192,663	77,970

(Land Use / States and Counties)

Figure 3.10A.--Area summary of land use by County, derived from Landsat data: example of CGIS output for the CARETS project, July 1975, 1:250,000.

Note: All level I totals can include Levels I, II, and III interpretation.

Fairfax, Virginia

Geology Code	Land Use 1970 Code	Acres	Hectares	Land Use 1972 Code	Acres	Hectares
	41	831.5	336.5	41	831.4	336.5
	51	160.5	65.0	51	160.4	64.9
	15	28.3	11.4	15	28.2	11.4
Total 2222		1,280.5	518.2		1,280.5	518.2
	21	9,193.0	3,720.3	21	9,086.2	3,677.1
	11	23,315.2	9,435.5	53	517.9	209.6
	19	1,884.5	762.7	11	23,503.0	9,511.5
	41	27,148.2	10,986.7	19	1,699.3	687.7
	42	1,027.3	415.8	41	26,867.8	10,873.2
	16	1,528.6	618.6	42	1,022.8	413.9
	12	1,973.8	798.8	16	1,528.5	618.6
	51	197.0	79.7	14	213.0	86.2
	15	815.0	329.8	12	2,016.3	816.0
	53	384.8	155.7	51	197.0	79.7
	13	46.5	18.8	15	815.0	329.8
	17	54.2	21.9	13	46.4	18.8
		0.0	0.0	17	54.1	21.9
Total 2228		67,568.0	27,344.4		67,568.0	27,344.4
	41	213.6	86.5	41	213.6	86.4
	16	32.9	13.3	16	32.8	13.3
	11	106.5	43.1	11	155.0	62.7
	19	55.6	22.5	19	18.2	7.3
	12	36.4	14.7	12	36.3	14.7
	21	222.1	89.9	21	210.9	85.3
Total 222811		667.1	270.0		667.1	270.0
	41	463.5	187.6	41	458.5	185.5
	11	198.9	80.5	11	198.9	80.5
	19	47.8	19.3	12	54.2	21.9
	42	46.2	18.7	19	24.5	9.9
	16	16.7	6.8	42	45.8	18.5
	21	277.9	112.5	16	16.7	6.7
	12	25.8	10.4	21	277.8	112.4
	15	8.1	3.3	15	8.0	3.2
	51	22.7	9.2	51	22.7	9.2
Total 2311		1,107.6	448.2		1,107.6	448.2
	42	772.0	312.4	42	772.0	312.4
	41	16,786.1	6,793.3	41	16,460.3	6,661.3
	16	397.3	160.8	16	432.1	174.9
	11	4,589.3	1,857.3	11	4,640.8	1,878.1

Figure 3.10B.--Geology and land use by county, derived from aircraft data: example of CGIS output for the CARETS project

Fairfax, Virginia

Land Use Code	Land Use 1970		Land Use Code	Land Use 1972	
	Acres	Hectares		Acres	Hectares
11	50,779.0	20,549.9	11	51,688.6	20,918.0
12	4,570.5	1,849.6	12	4,721.6	1,910.8
13	280.5	113.5	13	315.9	127.8
14	1,170.5	473.7	14	1,701.9	688.7
15	3,008.0	1,217.3	15	2,926.5	1,184.3
16	4,977.2	2,014.2	16	5,075.0	2,053.8
17	754.7	305.4	17	929.2	376.0
19	8,458.3	3,423.0	19	8,310.0	3,363.0
Total	73,998.9	29,946.9	Total	75,669.0	30,622.8
21	46,318.1	18,744.7	21	45,884.4	18,569.1
Total	46,318.1	18,744.7	Total	45,884.4	18,569.1
41	114,055.7	46,157.7	41	112,604.5	45,570.4
42	6,671.7	2,700.0	42	6,652.0	2,692.0
Total	120,727.4	48,857.7	Total	119,256.6	48,262.4
51	551.5	223.2	51	551.5	223.2
53	787.7	318.7	53	1,028.6	416.2
54	5,467.0	2,212.4	54	5,460.5	2,209.8
Total	6,806.2	2,754.4	Total	7,040.7	2,849.3
61	848.1	343.2	61	848.1	343.2
62	92.4	37.3	62	92.4	37.3
Total	940.5	380.6	Total	940.5	380.6
75	471.8	190.9	75	471.8	190.9
Total	471.8	190.9	Total	471.8	190.9

Figure 3.10C.--Land use by county, derived from aircraft data: example of CGIS output for the CARETS project

Fairfax, Virginia

Land Use Code	Land Use 1970		Land Use Code	Land Use 1972	
	Acres	Hectares		Acres	Hectares
19	305.4	123.6	11	305.4	123.6
19	13.3	5.4	13	13.3	5.4
41	138.1	55.9	21	138.1	55.9
41	22.1	8.9	13	22.1	8.9
41	451.9	182.9	11	451.9	182.9
41	476.3	192.8	14	476.3	192.8
41	47.9	19.4	16	47.9	19.4
41	101.5	41.1	17	101.5	41.1
54	6.4	2.6	11	6.4	2.6
11	6.3	2.6	16	6.3	2.6
41	59.9	24.2	12	59.9	24.2
16	9.5	3.8	17	9.5	3.8
19	63.8	25.8	17	63.8	25.8
21	49.3	20.0	53	49.3	20.0
19	62.2	25.2	53	62.2	25.2
21	23.2	9.4	14	23.2	9.4
21	237.4	96.1	11	237.4	96.1
19	10.4	4.2	14	10.4	4.2
11	21.5	8.7	14	21.5	8.7
41	133.2	53.9	53	133.2	53.9
21	127.6	5[illegible].6	19	127.6	51.6
41	108.8	44.0	19	108.8	44.0
16	0.9	0.3	12	0.9	0.3
42	1.9	0.8	11	1.9	0.8
42	13.3	5.4	19	13.3	5.4
42	1.2	0.5	12	1.2	0.5
19	33.1	13.4	12	33.1	13.4
11	30.3	12.3	41	30.3	12.3
11	22.4	9.1	12	22.4	9.1
12	3.6	1.5	41	3.6	1.5
21	38.5	15.6	16	38.5	15.6
15	10.1	4.1	12	10.1	4.1
21	54.6	22.1	12	54.6	22.1
21	41.2	16.7	41	41.2	16.7
53	7.1	2.9	19	7.1	2.9
42	3.3	1.3	53	3.3	1.3
11	24.6	10.0	19	24.6	10.0
12	11.6	4.7	11	11.6	4.7
19	15.5	6.3	16	15.5	6.3
19	13.3	5.4	41	13.3	5.4
17	0.3	0.1	11	0.3	0.1
12	15.9	6.4	19	15.9	6.4
15	71.5	28.9	19	71.5	28.9

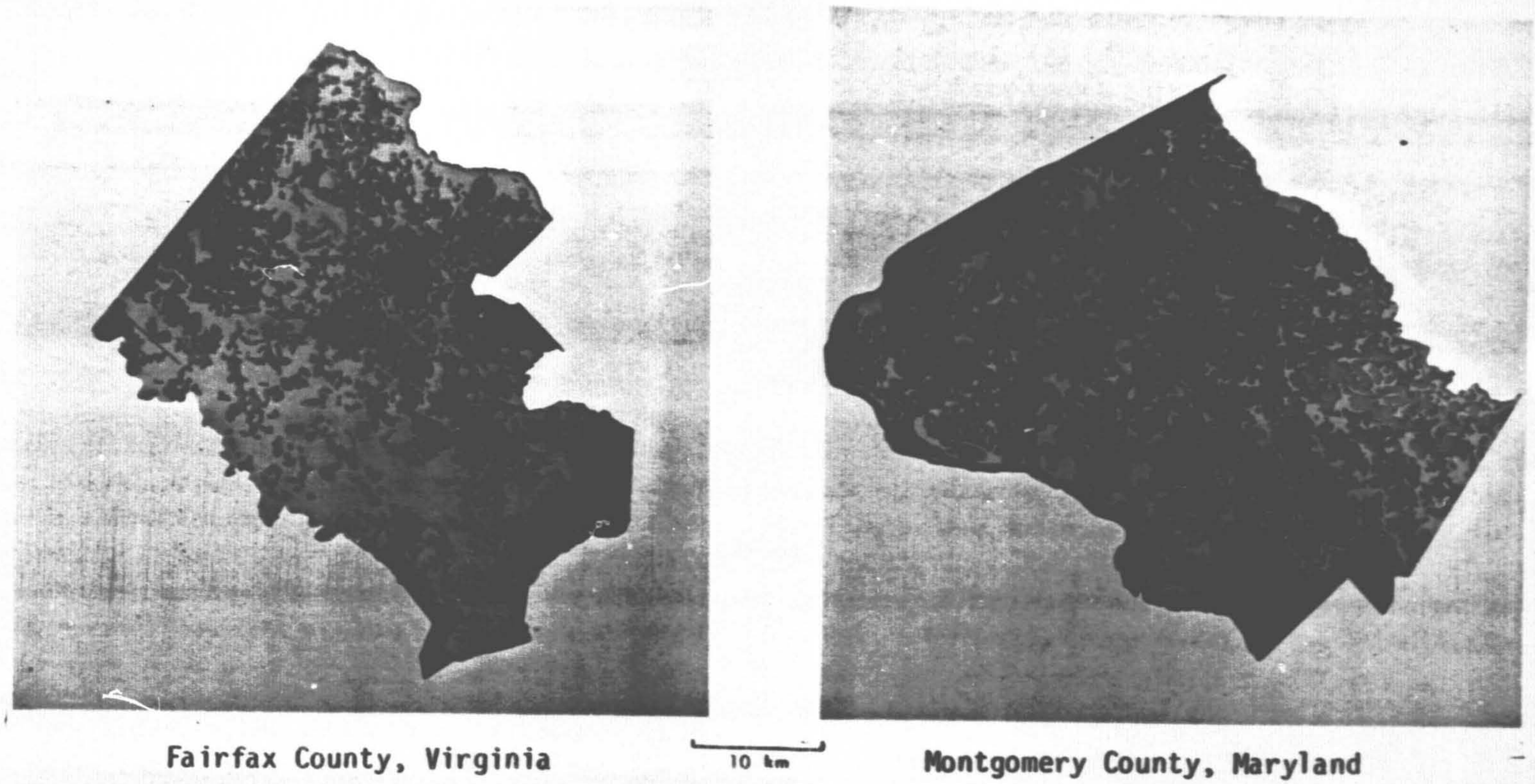
**There are 125 faces which are classed different in USo1 (1970) and USo2 (1970), the area is 690.42 acres

Figure 3.10D.--Land use change by county, derived from aircraft data: example of CGIS output for the CARETS project

Present Land Use by Census Division and Subdivision

Census Division	Census Subdivision	P.L.U. Class Data	No. of Occur. P.L.U. in Subdivision	Area (Acres)	% P.L.U. of Subdivision Area
Norfolk	68	11	2	70.27	18.4
	68	11	1	161.87	42.3
	68	12	2	42.36	11.1
	68	16	1	26.84	7.0
	68	20	1	21.92	5.7
	68	21	4	46.33	12.1
	68	41	1	12.88	3.4
*Area of Above Subdivision	68 is	382.48			
Norfolk	69 01	11	1	75.60	7.3
	69 01	11	4	222.07	21.3
	69 01	12	5	441.13	42.4
	69 01	15	5	48.64	4.7
	69 01	16	1	34.00	3.3
	69 01	19	3	41.75	4.0
	69 01	21	2	178.29	17.1
*Area of Above Subdivision	69 01 is	1,041.54			
Norfolk	69 02	61	1	47.84	6.6
	69 02	11	2	331.20	45.8
	69 02	12	1	64.09	8.9
	69 02	15	4	94.45	13.1
	69 02	16	1	32.11	4.4
	69 02	19	3	52.76	7.3
	69 02	21	2	79.01	10.9
	69 02	54	2	21.52	3.0
*Area of Above Subdivision	69 02 is	723.05			

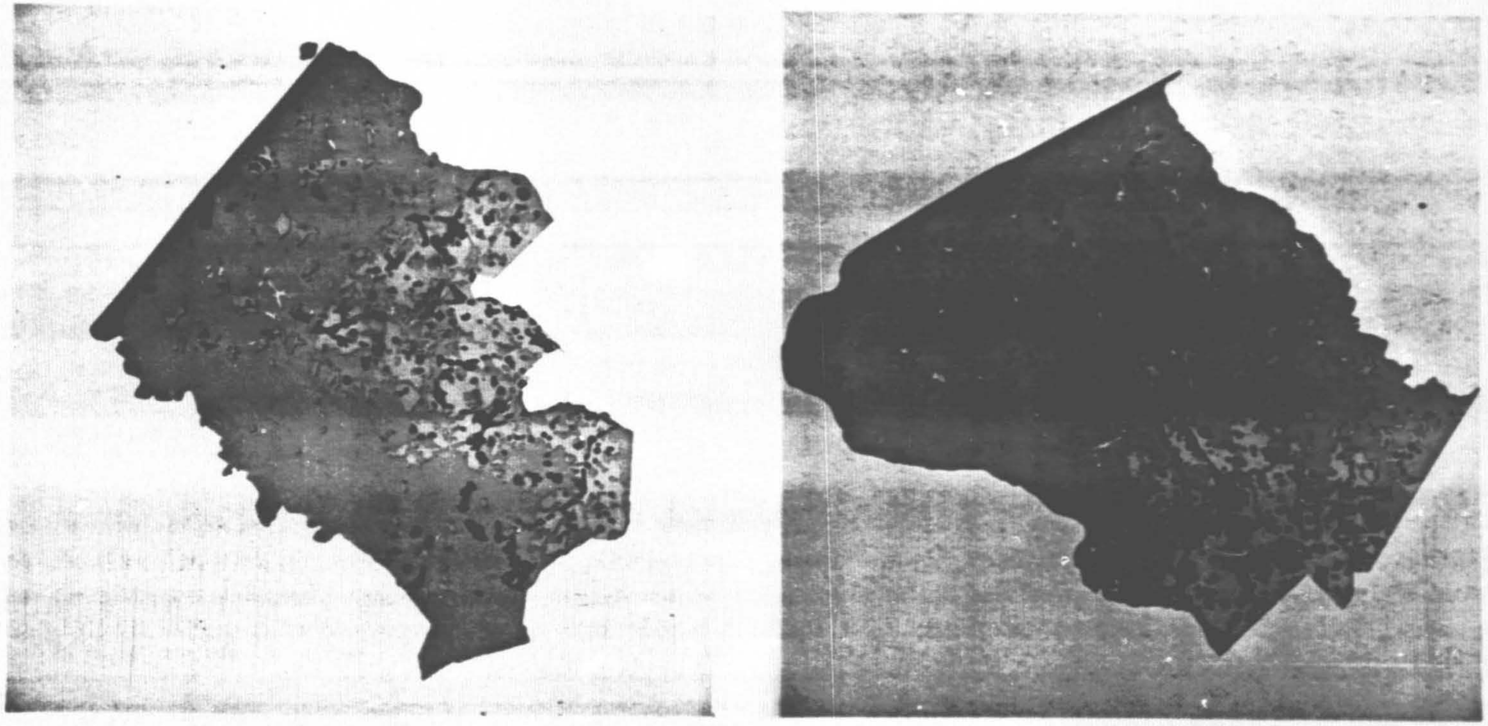
Figure 3.10E.--Land use by census tract, derived from aircraft data: example of CGIS output for the CARETS project



EXPLANATION

Red-Brown	Urban and Built-up Land
Olive Drab	Agricultural Land
Green	Forest Land
Dark Blue	Water
Light Blue	Non-Forested Wetland
Gray	Barren Land

Figure 3.11A--Fairfax County, Virginia and Montgomery County, Maryland: Level I color rendition of digitized land use map. EDC-010137



Fairfax County, Virginia — 10 km — Montgomery County, Maryland

EXPLANATION

Yellow-Orange	Residential
Brown	Commercial and Services
Purple	Industrial
Olive Drab	Transportation, Communications and Utilities
Blue	Institutional
Yellow	Strip and Clustered Settlement
Green	Mixed
Gray	All Other Classifications

Figure 3.11B--Fairfax County, Virginia and Montgomery County, Maryland: Level II color rendition of digitized land use map. EDC-010138

the many possible formats for presentation of the land use data are illustrated. In the first (fig. 3.11A) the land use is played back through the recording system with a different color code assigned to each Level I class of land use. Colors were selected to match those suggested for the standard land use color assignment (Anderson and others, 1976, p. 22). The other mode of playback is illustrated in figure 3.11B in which the urban and built up Level I category is broken down to include seven of its component Level II subcategories (residential, commercial, industrial, transportation, etc.). Areas in other Level I categories are not further differentiated from each other and are illustrated by the gray color, a procedure that permits a particular land use type or types to be highlighted in the display. Thus, the land use mapped as red in figure 3.11A is expanded into the various color components according to the legend key in figure 3.11B. The user has the option of selecting any other color or combination of colors to display his area of interest according to the land categories he wishes to emphasize.

A black-and-white process obtained through the use of an electrostatic printer-plotter produced the illustrations shown in figures 3.12A and B. This is a much larger-scale presentation of a portion of the same data used to produce figure 3.11A. Patterns are selected for each of the Level I categories and assigned automatically to the data as contained in a modified version of the image tape. The electrostatic plotter can very rapidly print wallpaper-sized sheets of maps such as those illustrated in figures 3.12A and B. Both the color and black-and-white displays require additional programming before the connection is possible between the output CGIS tapes and the input to the various

Figure 3.12A--Sample electrostatic printer output of digitized land use data, portion of Fairfax County, VA.

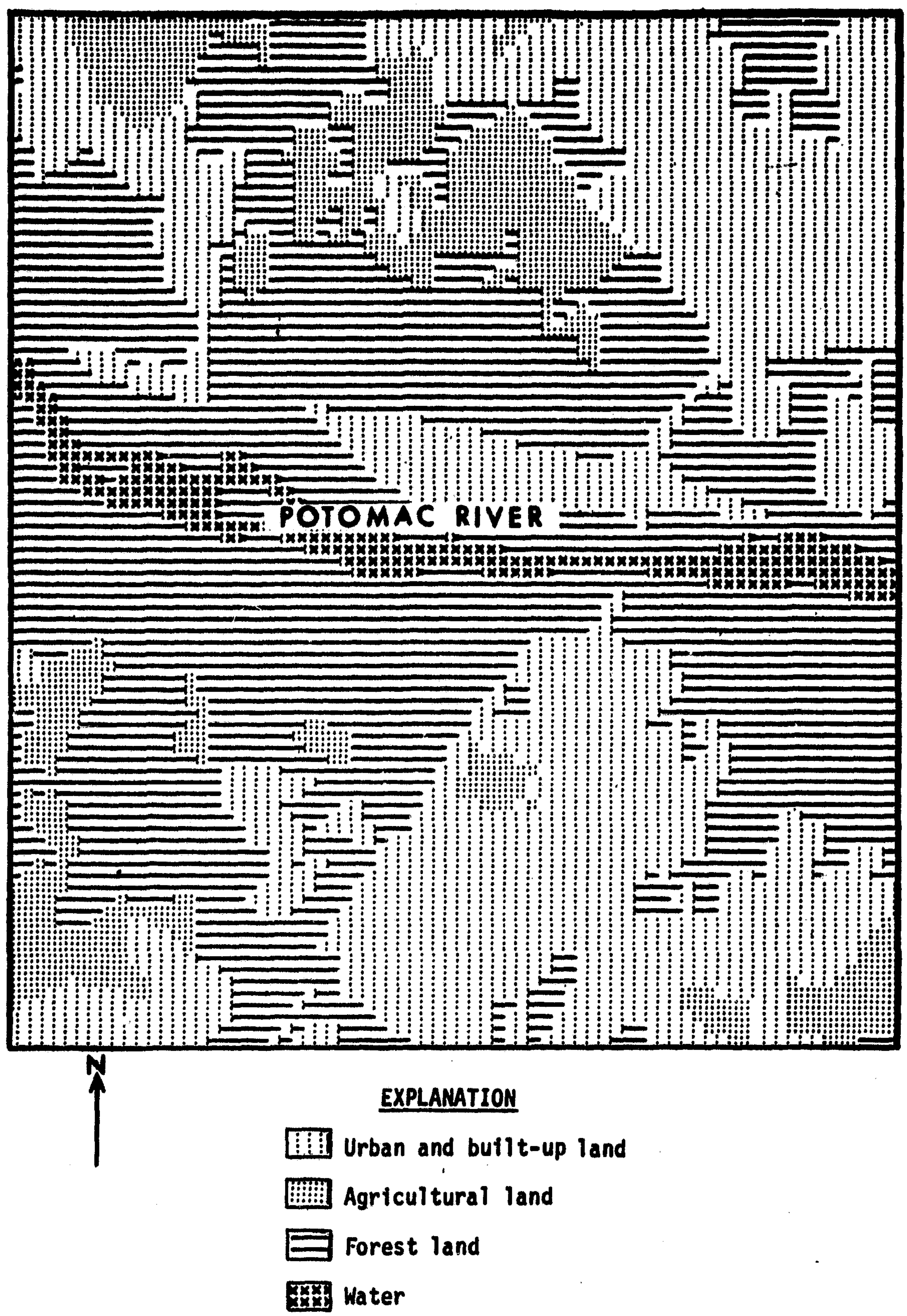


Figure 3.12B--Sample electrostatic printer output of digitized land use data, portion of Fairfax County, VA and Montgomery County, MD.

types of plotting hardware. However, the CARETS/CGIS tapes, used with the software package written by Environmental Systems Research Institute, are readable in polygon form, usually just one short programming step away from the raster format as required by most plotting devices. One plotting program, suitable for use on a widely-available drum plotter, is provided along with the other conversion programs (Environmental Systems Research Institute, 1976).

Rudimentary User-Interactive Capability

As described above, and illustrated in figure B.10, the CGIS system can be accessed by means of a remote display device operated by the user. We ran an experiment in Reston in which we queried the CGIS files by long distance telephone line between Reston and Ottawa. This procedure enables the user to view portions of the data before deciding whether to request the more expensive displays such as those presented in figures 3.11 and 3.12. We found that a high-quality telephone line was required. Our first attempt to contact the CGIS system was by use of the Federal Government's Federal Telecommunication System (FTS) lines. After several attempts had failed (noise in the system was generating false commands to the computer in Ottawa) we switched over to the commercial telephone lines which were of much higher quality and we were able to implement the entire data link between the two cities. It is recommended that the highest-quality available telephone transmission facilities be used for such graphic interaction between a user and a computerized data bank for the display of map data.

Manipulative and Analytical Capability

The final product in this listing is the capability to analyze, manipulate, and display the data from the CGIS system. This capability exists now in Ottawa and has been made indirectly available to users who are able to obtain the basic CARETS data tapes and who possess a modest spatial data handling capability. In a major experiment utilizing this capability we compared land use area measurements obtained by the CGIS area summation system with land use measurements obtained by an entirely different process (Metropolitan Washington Council of Governments, 1976).

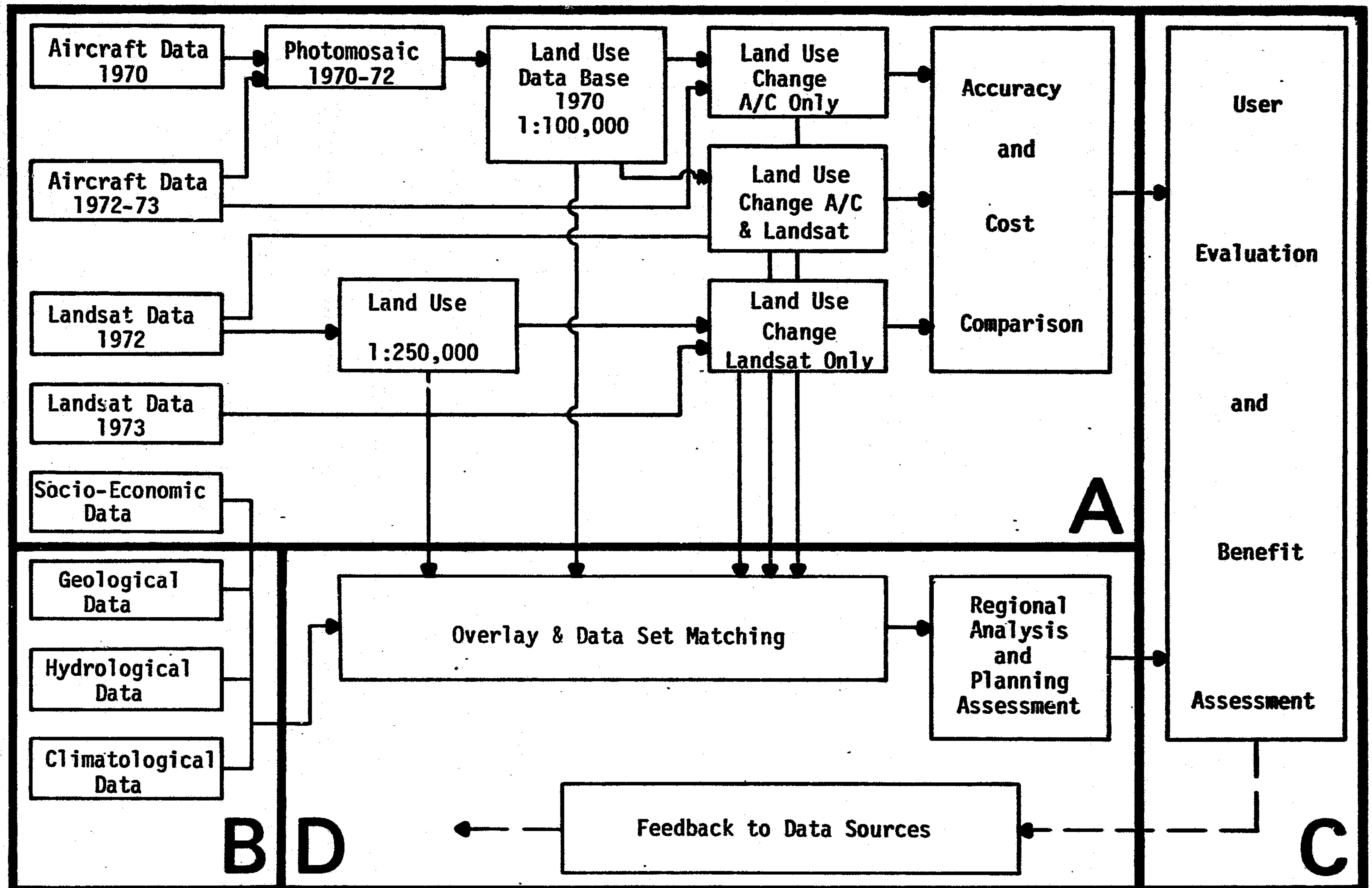
CHAPTER 4

LAND USE INFORMATION AND REGIONAL DATA BASE

This chapter describes the CARETS land use data base and its derivation from NASA's Landsat and aircraft sensor systems. Much of the detail contained in the remote sensing data was condensed by manual image interpretation into land use maps employing up to three levels of a hierarchical classification scheme. Other maps produced by the CARETS project permit calculations of land use change and correlations with environmental and socioeconomic data. Interpretation and mapping tasks are described in the context of the information systems framework and the interrelationships with the other project modules. The chapter includes a discussion of costs and map accuracy estimates, as well as other bases for comparing the performance of Landsat and aircraft sensors.

ACTIVITY FLOW AND RELATIONSHIPS WITH OTHER MODULES

Details of the CARETS project are presented schematically in figure 4.1. Aircraft data are used first to produce a photomosaic mapping base and then as a source of the land use data for the 1970 mapping at a scale of 1:100,000. Photographs taken 2 years later are used to map land use change. Landsat data are used as the source for 1:250,000-scale maps and data summaries. Both aircraft and Landsat results are then subjected to an accuracy and cost comparison. The large block marked "A" in figure 4.1 represents the topics treated in the present chapter.



Large blocks represent chapter coverages of the various components: Block "A"--Chapter 4; Block "B"--Chapter 5; Block "C"--Chapter 6; Block "D"--Chapter 7.

Figure 4.1.--Detailed CARETS activity flow chart

Simultaneously with the preparation of the land use data base, the socioeconomic, geological, hydrological and climatological data are being prepared. The land use information derived from aircraft and Landsat data, combined with the various environmental data sets, constitute the input into the regional analysis and planning assessment. The resulting analysis, as well as the various component data sets, go to users for evaluation and benefit assessment. Feedback from the user evaluation is directed toward the data producing agencies so that their data programs can be updated and made more realistic in terms of the region's priority problems. Block "B" of figure 4.1 indicates items dealt with in chapter 5; blocks "C" and "D" represent material dealt with in chapters 6 and 7, respectively.

REMOTE SENSING DATA INPUT

The material presented thus far in this report is background intended to explain the framework for introducing remote sensing data into the CARETS project. This project's contribution to the solution of regional environmental problems was to be through the utilization of the evolving remote sensing technology as exemplified by NASA's aircraft and satellite systems.

Prior to the launch of Landsat 1 scientists in the NASA-sponsored Earth observation programs experimented with many remote sensing systems such as multispectral photographs, black-and-white photographs, color photographs, color-infrared photographs, thermal-infrared imagery, radar imagery and passive microwave imagery. NASA aircraft flying at various altitudes produced these data. Many investigators obtained superior results from high-altitude color-infrared photographs taken with mapping cameras flown aboard NASA RB-57's and U-2's. The photographs had sufficient detail for observing some phenomena with dimensions no larger than 3 or 4 m. They also had the ability to penetrate atmospheric haze better than films lacking infrared sensitivity. For these and other reasons, CARETS investigators selected the high-altitude color-infrared aerial photographs as the primary remote sensing input to the presatellite data base.

High-Altitude Aerial Photographs

Each frame of the color-infrared photographs consists of a square photograph 22.9 cm (9 in.) on a side. Given the 9-in. format size and the camera focal length of a little over 15 cm (6 in.) used in most of the missions flown for the CARETS project, along with the most usual flight altitude above terrain of a little over 18 km (60,000 ft.), the length of a side of one of the frames of photographs represents approximately 27 km (17 mi.) on the ground. The camera and film are of such high resolution, however, that enlargement to 10 times or more is possible without destroying the interpretability of the resulting image. Figure B.3 displays a sample of the high-altitude photographs.

CARETS investigators shared with other investigators in the same test region the task of planning and coordinating aircraft missions over the test region. Where portions of the coverage were unusable for any reason (usually because of cloud cover) later flights were scheduled to complete the coverage. Index maps and further details on the aerial photographs are contained in CARETS final report volume 5 (Alexander and others, 1975a).

While the high-altitude aerial photographs constituted the first step in processing the CARETS land use data base, to be described later, these photographs were also suitable for direct delivery to users in the format provided by NASA. In cases where users required copies of photographs for extended testing in their own facilities we made such copies available on loan or provided information concerning ordering and purchasing such frames from the EROS Data Center in Sioux Falls, South Dakota.

Photomosaic for Mapping Base

A central concern of the CARETS investigation was the necessity for quantifying the "view" of the region provided by the remotely sensed data sources. The first step in such quantification is to provide a method for relating the data derived from the remote sensors to a precise location on the Earth's surface. To accomplish this we chose the method of plotting interpreted data on a base map containing a grid for Earth surface locations. A great deal of discussion went into the selection of the scale for that base map. We had to compromise between smaller-scale representations which would be more in line with what was thought to be the capability of the first Landsat, and larger scales which would be of more use to urban planners. An intermediate or "regional" scale of 1:100,000 was chosen as a result of those deliberations, with input recommendations from a prior study done under contract with the University of Virginia (Goodell, 1970; Goodell and others, 1972). The 1:100,000 scale was convenient for direct utilization in the metric system, which was coming under adoption by the Geological Survey during the course of the CARETS experiment.

A base map at a scale of 1:100,000 did not exist for this part of the country. Therefore, we asked the Topographic Division of the USGS to prepare a black-and-white controlled photomosaic at that scale, using the NASA high-altitude color-infrared photographs. The photomosaic was prepared using photogrammetric equipment and rectified to a Universal Transverse Mercator (UTM) projection with a fine line kilometer square grid overlay keyed to UTM zone 18. Geographic tick marks at 5-minute intervals were also provided to enable the user to determine locations in latitude and longitude. A sample of one of the photomosaics is presented in figure B.2. An accuracy test revealed that 90 percent of the well defined points were estimated to be within 1 mm of their true positions on the map. This translates into 100 m on the ground, which means that the error is two times that permitted by U.S. national map accuracy standards. The accuracy was determined to be quite within the range necessary for the CARETS mapping experiments.

The entire CARETS region, mapped at a scale of 1:100,000, would occupy a space about 4.5 m in a north-south direction by about 3.5 m in the east-west direction. Slightly over 7.0 m^2 of this map are actually utilized in depicting the land area and additional 2.0 m^2 are needed for depicting the water area of the region. The large size of this map required that a system be developed for dividing the area up into map sheets. The system employed in the CARETS project was designed by James R. Wray of the USGS Geography Program. Each of the sheets represents a square on the Earth's surface 50 x 50 km keyed to the UTM mapping system. An index map of the 48 sheets thus obtained is shown in figure B.1. The geographic names section of the USGS approved a new set of names to be applied to these sheets and the overlay maps keyed to them.

Landsat Imagery

Unlike the high-altitude aircraft data, data from Landsat were delivered to the investigators in a format not suitable for direct utilization either by our photointerpreters or by our users. The delivery format consisted of black-and-white 70-mm photographic images obtained from the original analog output of the Landsat system at the Goddard Spaceflight Center, Greenbelt, Maryland. These black-and-white images consisted of four different frames for each Landsat scene, one each in the green, red, photographic infrared, and near-infrared portions of the spectrum. For delivery to interpreters or users such imagery had to be enlarged either in black-and-white or color composite formats. The original delivery scale was about 1:3,000,000. The format preferred by most users was a false-color rendition obtained by a color combination process using three of the four spectral bands.. Based upon our selection of 1:250,000 as a mapping scale for CARETS Landsat coverage, we obtained enlarged color composite images in a color-infrared (false-color) format at a scale of 1:250,000 for use in preparing the Landsat land use maps. An example of Landsat imagery in this format, further enlarged to 1:100,000 for comparison with the aircraft photograph, is presented in figure B.4.

One of the most striking conclusions we drew from the earliest examination of Landsat imagery is that it provides a remarkable direct regional-scale view of the Earth's surface. A single frame of Landsat imagery represents an approximate square on the Earth's surface greater than 160 km (100 mi.) on a side. Four such frames in a north-south direction and three in an east-west direction were all that were required to provide complete coverage of the CARETS test region.

While most photointerpretation techniques that we used with the high-altitude aerial photographs had already been established by prior usage, interpreting landscape patterns from Landsat imagery was a new experience. We took a period of time immediately after receipt of the first Landsat imagery to become familiar with its characteristics. One method we used was to piece together a mosaic of Landsat frames made out of black-and-white images obtained at a scale of 1:1,000,000. A reduced copy of this mosaic is shown in figure B.23. By examining this mosaic at arm's length, one sees, almost at a glance, the major structural and drainage features of the region, the relationships of the major cities to those larger features, and patterns of spatial association of features that are clues to regional development processes. The major geological and hydrological controls to land usage (for example, the Appalachian Mountains, the Atlantic Ocean, the Chesapeake and Delaware Bays and their tributaries and estuaries) are easily identifiable by inspection. Closer examination reveals more subtle geological and hydrological controls to the land patterns, such as regional outcrop trends, folds and faults, and the major stream patterns which stand out prominently because of vegetation differences.

Superimposed on these patterns controlled by the major geological and hydrological features is another level of landscape patterns, visible at the regional scale as distinctive tones and textures, which represent the integration of myriads of separate forested tracts, farms, towns, and roads. We identified distinct mappable units in this overall landscape pattern, each unit containing a homogeneity of tone and texture. Thus, the farmland patterns of the Shenandoah Valley at the western margin of the CARETS region are distinctly different from those of the Piedmont area which are in turn distinctly different from the more forested, more sparsely settled area on both sides of the lower Potomac estuary. The major metropolitan areas of Washington and Baltimore have in turn a distinct lighter pattern in the black-and-white rendition of the red (multispectral scanner 5) band, or a blue appearance in the color combined view analogous to color-infrared film.

An early hypothesis of the CARETS investigation was that these landscape units would provide a valuable stratification for areal sampling to determine where the more detailed aircraft or ground measurements might be taken, following the "photomorphic region" concept used by MacPhail and others (1972), and Peplies and others (1970). A small-scale rendition of such photomorphic regions is shown in figure B.24.

The initial tests with Landsat imagery included its use with a multispectral viewing device. For the actual land use mapping at a scale of 1:250,000 we found it more convenient to use color transparencies enlarged to that same scale. Such enlargements proved to be almost direct overlays to the standard 1:250,000 USGS quadrangle maps of the region. This near-congruence made it possible to use, with only slight adjustments, the enlarged Landsat imagery directly as a mapping base for registering the land use map units to the Earth's surface grid. Further details concerning our analysis of the Landsat imagery are contained in Alexander (1973, 1973a and b) and in final reports volumes 2 and 5.

Other Aerial Photographs

In addition to the basic high-altitude color-infrared photographs, NASA also supplied some photographs in a multispectral format taken by a cluster of six Hasselblad cameras. Each of the Hasselblads contained a different type of film and all were pointing at the same scene on the Earth's surface. Another camera tested was a Zeiss mapping camera with a 12-in. focal length which produced more detailed coverage than that of the standard 6-in. cameras that were used for the basic data set for the entire region. Discussions of these cameras and their products are contained in volume 5 of the final report (Alexander and others, 1975a). Also, we obtained photography from the U.S. Air Force and the U.S. Department of Agriculture for specialized purposes as part of the CARETS experiment. The Air Force photographs for the year 1959 were used to determine change during an 11-year period for the Norfolk-Portsmouth region as compared with the 1970 photographs supplied by NASA. In addition a large number of photographs taken from hand-held 35-mm cameras were obtained from low-altitude aircraft as part of the data verification effort. One such series of missions was flown by a NASA helicopter provided by the NASA Wallops Island Station to test a sampling method using the photomorphic region concept mentioned above.

Data from Skylab Experiment

The associated CARETS-Skylab experiment, carried on during the same period of time as the Landsat experiment, made available additional material for use in describing the region and evaluating remote sensing potential. Two data sources from Skylab were used in the study of land use climatology in the Washington-Baltimore area, namely that from the high-resolution camera (Earth terrain camera) and that from the multi-spectral scanner operating in both visible and thermal-infrared range. These data are also a part of the archives of remote sensing data available for the CARETS project. Details of their use and results of the Skylab study are contained in the CARETS-Skylab final report (Alexander and others, 1976).

LAND USE MAPPING

The land use maps produced from aircraft and Landsat data served as both the vehicles for comparing the two data sources, and as the source of surrogate measures to be compared with various environmental factors in accordance with the CARETS concept model discussed in chapter 2. Though intended to be intermediate products for those purposes, the land use maps also served as "final" products for which cooperating users provided evaluations in terms of their own planning and regional analysis functions.

Land Use Classification Scheme

The CARETS definition of "land use" developed from the activities of the Inter-Agency Committee on Land Use Information and Classification and a Washington conference of selected user representatives held in June 1971 (U.S. Geological Survey, 1972). The conference's purpose was to suggest a land use classification that could be used with the new remote sensing data sources. That classification was slightly revised after comments were submitted by many reviewers, including the CARETS project investigators, and subsequently published in USGS Circular 671 (Anderson and others, 1972). CARETS mapping activities were already committed to the earlier version, so not all the map categories are the same as later USGS land use maps. Further improvements were incorporated into the classification scheme presented in USGS Professional Paper 964, which is used by the USGS operational land use mapping program (Anderson and others, 1976).

As pointed out by Anderson and others (1972) and Anderson and others (1976), several concepts have been traditionally combined in defining or describing the phenomenon known as land use. In order to permit widest possible use with remotely sensed data, the standardized classification system used in the CARETS and USGS classifications employs primarily "cover" (or more properly "surface expression") and "activity." Activity can often be inferred by means of the photointerpretation process, but strictly speaking the remote sensor responds to the physical properties of surface materials. In referring to land use information as derived from remotely sensed data, the usage "land use and land cover" has come into prominence. In this report the term "land use" is synonymous with "land use and land cover" unless otherwise specified in the text. When different activities overlap and different covers overlap or grade into one another in transitional situations, somewhat arbitrary mapping rules have to be set up which enable analysts to make decisions in assigning each land or water element to one of the classification categories. Knowledge of those rules and decisions is essential to the user of the resulting map or information system if the process is to be replicated or change determined. Dimensions of the land surface description, other than cover and activity, for example, the ownership of land parcels, the time of observation as in seasonal variations, and the size of the fundamental mapping or observational unit, also complicate the mapping task. All of these may be significant with respect to users' requirements.

Any particular land use map or information system is necessarily a compromise between desired level of detail and limitations of program resources which dictate the degree of detail contained in the final product.

The CARETS project philosophy was to exploit the flexibility of multi-scale satellite and aircraft remote sensing data collection systems, while trying to strike a balance between cost factors and priorities as determined by the urgency of problems to be solved. The adjustment of the developing information system to the region's problems and priorities should be an adaptive process. The resulting land use classification scheme itself is but one of a number of sampling strategies to be used in applying the very large amounts of data available from the remote sensor systems.

In table B.3 the hierarchical nature of the classification system employed in the CARETS project is displayed. In this system Level I categories are those major categories (urban, agriculture, forest, etc.) which while made up of more detailed components were thought by the Interagency Committee to be the categories most readily discerned from satellite imagery. Level II categories were those thought to be most readily determined from high-altitude aircraft imagery. Level III and more detailed categories were intended for use with low-altitude photography and other sources, an approach to land classification which is similar to that used by urban and regional planners. After examining a variety of remote sensor systems we believe that the classification should be independent of the type of platform used to carry the sensor; that is, Level I, II, etc., should be distinguished on the basis of logical principles and users' needs rather than whether the categories can be identified by satellite or aircraft data sources. Further detail on the land use classification scheme and principles for using it are contained in Alexander and others (1975a and 1975b) as well as Anderson and others (1976).

Interpretation and Map Compilation

Aircraft data

Using a process of manual photointerpretation and land use mapping which is described in detail in volume 5 of the final report (Alexander and others, 1975a, p. 36-45), the CARETS investigators compiled land use maps at 1:100,000 scale from 1970 high-altitude aerial photographs for each of the 48 sheets in the test region. These basic land use maps constituted one of the primary data sets for the experiment, both for user evaluation and for comparison with results which were obtained from Landsat and Skylab sensors. We employed Level II of the land use classification scheme for these maps (table B.3), using the minimum recording unit of 2 mm, as explained in figure 3.1. Further details on the method of encoding the land use data and on the quantities of information as obtained can be found in chapter 3 of this report. See also figure B.11 for a reduced specimen of one of the 48 land use maps, and figure B.5 for a full-scale segment of the specimen map.

Landsat data

Land use maps were derived from Landsat data by manual interpretation of 1:250,000-scale false-color imagery, as described in volume 5 of this final report series (Alexander and others, 1975a, p. 75-109). Consistent coverage for the entire test region was obtained at Level I of the classification scheme. However, in order to test the degree of detail discernible from Landsat imagery, interpreters identified and mapped Level II and III categories, where reasonably certain of their identity. Some Level II and III categories, for example single-family residential suburbs, extend over a large enough territory to be shown even at the 1:250,000 mapping scale chosen for the Landsat imagery. For compilation of the data tabulations of the entire region, these Level II and III measurements from Landsat data were collapsed into the corresponding Level I categories (tables C.1 and C.2). A reduced specimen of one of the eight Landsat-derived maps is shown in figure B.18. The detailed Landsat map segment shown in figure B.6 was enlarged to 1:100,000 scale so it could be readily compared with the same area as mapped from the more detailed high-altitude photographs (fig. B.5).

Change detection and mapping

From the earliest planning and preparation for the first Earth Resources Technology Satellite, obtaining information on the dynamics of the Earth's surface was recognized as one of the tasks of primary importance for a worldwide satellite observation system. The CARETS project design also incorporated a land use change detection and mapping objective into its earliest plans. Information on land use change proved to be of great interest to our cooperating users; many had land use maps of some type, but few had maps of the change in land use over a period of time.

Conceptually, the determination of change using remote sensing data is extremely simple. The interpreter simply examines the photographs or imagery representing the most recent time period and compares it with imagery of the same area for an earlier time period. Where differences between the two images occur and can be identified as involving actual land use change (rather than differences due to conditions of viewing, time of day, or quality of the reproduced image) such change is marked by drawing a line around the area that has experienced the change and giving it a code classification containing information on the land use before and after the occurrence of the change. See the discussion in chapter 3 above for examples.

In actual practice, however, the determination and mapping of change was a task that was fraught with many difficulties. CARETS interpreters had a large land area to examine, necessitating the handling of many different pieces of aerial photographs and Landsat imagery. The photographs for the earlier period as well as the land use map had to be made available. There were many chances for error, for example, errors in locating the areas depicted on the new imagery with respect to the same areas as depicted on the old imagery, and transferring the information to still another record, the change map. Some apparent changes were later determined to be caused by errors in the original interpretation, and correction required a double editing procedure. One of the recommendations of the CARETS study was to do further research on procedures that would aid in the accurate detection, identification and mapping of land use change (Fitzpatrick-Lins, 1978).

The procedures that were developed by the CARETS team involved the use of either 1-km^2 or 25-km^2 templates (windows) which could be systematically moved across the imagery to be examined for change indications. If the photographs or maps are of different scales it is necessary to use magnifying or projection devices to bring them into approximately the same scale for ease of interpretation. The logistics of the operation and the amount of materials that need to be handled by the interpreter make the mapping of change a much more complex operation than the initial preparation of the land use map. In fact, early discussions raised the possibility of obtaining information on change by simply remapping the entire area a second time with the imagery from the more recent of the two dates. Without careful cross-checking of the two prepared in manner, this procedure would also be subject to many errors as the interpreter performs the rather tedious work of identifying and comparing land use types. Details of the procedure used in the CARETS project are found in Alexander and others (1975a).

For the 2-year period 1970-72 land use change maps were prepared for the entire set of 48 CARETS map sheets. An example of one such sheet is contained in figure B.12. The change sheets covering the Washington and Norfolk SMSA's area were also sent to Canada to be digitized along with the maps of land use. The quantitative summaries of change measurement thus obtained are among the final products of the CARETS geographic information system (tables B.1, B.5, and B.6). Thus, interpreters prepared a complete set of 1970-72 land use change maps for all 48 CARETS sheets.

Change between 1959 and 1970, Norfolk-Portsmouth SMSA.--Photographs taken by the U.S. Air Force 11 years prior to the first NASA test site coverage for CARETS were used as a base from which to measure change in the 11-year period. The Air Force photographs were not sufficiently similar to the NASA photography to justify our carrying the change determination experiment beyond Level I. Using procedures similar to the ones described above, the changes for the 1,911-km^2 area were identified, mapped, measured, and tabulated (Alexander and others, 1975). The results indicated a total of 184 km^2 of change detected out of a total of 1,911-km^2 area for the SMSA. Of the amount of change detected nearly 90 percent occurred in only four sets of changes; 43.5 percent from agricultural to urban, 18.5 percent from forest to urban, 17.9 percent from forest to agriculture, and 10.3 percent from agriculture to forest. The structural components of this change are displayed in table 4.1.

Table 4.1.--Land use change, Level I 1959-1970, Norfolk-Portsmouth SMSA (in km^2)

From (1959 Category)		To (1970 Category) (1)	(2)	(4)	(5)	(6)	Total (1959)
Urban	(1)		2	1			3
Agriculture	(2)	80		19	1		100
Forest	(4)	34	32		2	2	70
Water	(5)					3	3
Wetland	(6)	2	1	5			8
Total (1970)		116	35	25	3	5	184

Source: CARETS project

Aircraft-Landsat change, 1970-72.--Another experiment involving change in the Norfolk-Portsmouth SMSA was performed using aircraft data for 1970 along with aircraft and Landsat data for 1972. In the first part of the experiment 1970 aerial photographs were compared with 1972 Landsat imagery and the interpreter mapped all change or apparent change without reference to the 1972 aerial photographs. Then another complete mapping of change was performed using 1972 high-altitude aerial photographs. The change measured from photograph to photograph was considered to be the standard against which the accuracy of the Landsat measurement was compared. The results of this experiment are summarized in table 4.2.

In this case both Level I and Level II changes were accounted for. Level II changes include those that occur within a Level I category as well as those that occur between Level I categories. The Level I measurements provide a basis for comparing this experiment with the one reported previously involving the period 1959-70. At Level I the 1959-70 change averaged 16.7 km^2 per year, while Level I change in the 1970-72 period averaged 18.1 km^2 per year. Thus the two measurements seem to be reasonably consistent in terms of rate of land use change detected. Even in this rapidly-growing urban area, however, the total land use change detected per year was only 1 percent of the total area of the SMSA. In this experiment "false" changes were those which were suggested by the Landsat imagery but which upon checking with the aircraft photographs were found not to have actually occurred. Most of the false change was due to bare fields which in the late fall Landsat imagery used in this experiment had a bright appearance similar to that of urban and built-up areas. Improved results would be expected from Landsat data taken during the growing season when such errors would be less likely to occur. This experiment, however, along with others conducted on

Table 4.2.--Land use change 1970-72, Norfolk-Portsmouth SMSA, aircraft and Landsat data compared

Area analyzed (SMSA total)	1911 km^2
Aircraft-verified change, Level I	36.2 km^2
Landsat-verified change, Level I	26.5 km^2
Percent of Level I change identified with Landsat	73.2
Aircraft-verified change, Level II	39.2 km^2
Landsat-verified land use change, Level II	22.4 km^2
Percent of Level II change identified with Landsat	57.3
"False" changes (erroneously indicated by Landsat)	64.3 km^2

Source: CARETS Project

Landsat imagery from other parts of the test site, leads to a caveat regarding the use of Landsat data alone for detecting and identifying change. Landsat would certainly be useful for detecting apparent change and then indicating which areas were to be examined more carefully with aircraft photographs or other data. Our results do not warrent recommendation that Landsat data alone be used for detection and verification of all land use change. A summary of these results is reported in Alexander (1973b).

OTHER OVERLAY MAPS

To facilitate use of the land use maps and to assist with environmental impact applications, the CARETS project also produced a series of overlay maps for the entire region. These maps were keyed to the same 48 index sheets as were the mosaics and maps of land use 1970 and land use change 1970-72, all at a scale of 1:100,000. The overlay maps included those showing census tracts, county boundaries, drainage basins, cultural features and place names, and landforms and surface materials.

Census Tracts and County Boundaries

We wished to be able to locate and retrieve the information contained on the land use maps according to certain geographic areas of interest to the users. The basic geographic area for which we wished retrieval for the entire test site was the county (an independent city in Virginia). Therefore, overlay maps were prepared showing the county boundaries, as determined from other USGS published maps, for the entire region. In addition, we wished to have more detailed retrieval capability within SMSA's, and in these areas (fig. C.6) we prepared overlay maps showing the location and boundaries of census tracts. The source for the census tract maps was the U.S. Bureau of the Census, Census of Population and Housing. The scales of map publication in that source were different, however, and maps had to be brought into the same scale and projection as our basic map set. A reduced specimen sheet of one of the census tract and county boundary maps is shown in figure B.15, with full-scale detail of a portion of the sheet shown in figure B.7.

Drainage Basins

To allow the association of land use information with regions of hydrologic significance we compiled a set of maps showing major drainage basins for the test region. Data for these maps were obtained from the USGS Office of Water Data Coordination, and we used their numerical designation system. The actual compilation and redrawing of these boundaries at a scale of 1:100,000 required reference to topographic maps in some cases since the boundaries shown on the water resources maps were not always in sufficient detail. A reduced specimen of one of the drainage basin maps is shown in figure B.13, and CGIS calculations of Landsat-derived land use for each basin and subbasin are shown in table C.5. Drainage basin designations for the entire CARETS area are shown in figure C.4.

Cultural Features and Place Names

A map containing only land use boundaries is not easy to relate to the location of familiar features in the region unless the map reader has had considerable experience doing this. To aid map users in so locating themselves we prepared overlays showing names of the major towns, the location of major highways and railroads, and the names of other familiar features that would help the map reader determine the locations and areas shown on the land use maps. The cultural features maps, like all of the others, were prepared in transparent overlay format, which facilitated their use in conjunction with one or more other maps in the series. An example of a cultural features map is shown in reduced format in figure B.16, and a full-scale excerpt in figure B.9.

Landforms and Surface Materials

To test the usefulness of surficial geological information in association with land use data we planned to provide a complete set of geological overlay maps keyed to the 48 CARETS sheets at a scale of 1:100,000. However, we were able to obtain the services of a USGS geologist only long enough to complete part of the region, those sheets indicated in table B.2. We did complete the entire coverage for the Washington and Norfolk SMSA's for insertion into the digital data bank. A reduced specimen of one of these sheets is shown as figure B.14 and the classification scheme used is shown in table B.4. A more detailed discussion on this part of the CARETS experiment is contained in the following chapter dealing with environmental impact.

SENSOR DATA VERIFICATION

The confidence with which the image interpreters were able to identify and map the land use varied considerably from one land use type to another and with different geographical settings. Some land use categories such as heavy crown cover forest were easily detectable and identifiable from photographs at all scales examined and from Landsat imagery. Later verification checks in the field bore out this interpreter confidence. Other land use types such as many within the urban and built-up category and Level II types within the agriculture category, were detectable with more difficulty or needed some additional information to verify the interpretation.

Most of the interpreters who worked on the CARETS project lived in the area and were familiar with its regional characteristics and geographical features. At the end of their CARETS experience they were noticeably more familiar with these characteristics. Even with this familiarity interpreters found it advantageous to use additional materials in the initial mapping. Such materials included topographic maps, planning maps, and other source materials that we were able to gather from the various planning offices and other agencies having detailed knowledge of portions of the test region. A standard source was a complete set of USGS topographic maps covering the test region, both at a scale of 1:24,000 and 1:250,000. Road maps from auto clubs and oil companies were also used for obtaining some more recent information which was helpful in interpreting the imagery.

After completing the parts of the map for which land use types were readily identifiable from the photographs or from the additional material, interpreters labeled the remaining questionable areas as "problem areas" and set them aside for field checking. In most cases the land use type could be readily identified by a field visit, either on the ground or with a low-altitude aircraft flight. In a few rare cases, however, even standing in front of a land parcel it was not always possible to tell whether the land use was industrial, commercial, institutional, or what. Most of the problem areas, however, were identified and mapped after the field work, which we considered to be an essential part of the land use mapping effort. Details of the field measurement procedures and the quantitative results of comparisons of the image interpretation with the field observations are contained in Alexander and others (1975a) and Fitzpatrick (1975). The low-altitude aircraft flights were found particularly efficient for covering the amounts of territory required for field checking. These flights were in most cases accomplished by the rental of a small plane which could be flown as directed by one of the interpreters carrying either a mosaic or an air photo of the region. In one case a helicopter was provided by NASA Wallops Station to fly traverses over a set of sites to help determine the accuracy of the land use maps.

DETERMINATION OF MAP ACCURACY

Because of the requirement to compare the accuracy of land use mapping using Landsat data with that obtained from aerial photographs we spent a considerable effort considering methods of measuring the accuracy of the various remotely sensed maps and data sets that were used. We discovered that standardized or widely accepted methods of describing the accuracy of land use maps were not available. One way of assessing the accuracy of a new map is to compare it visually with another map of the same area accepted as "accurate." This visual comparison method is effective because the human eye and brain combine to make a very rapid and efficient processor of two-dimensional data, but we desired a more objective and quantifiable method of comparing land use maps and assessing relative accuracy.

One method employed was to partition the land use map derived from remotely sensed data into two categories: (1) areas where the interpreter had a high degree of confidence in his interpretation accuracy, and (2) areas where the interpreter was unsure of the interpretation. Field checking, as mentioned above, determined that the areas of high interpreter confidence were also highly accurate in their classification. Areas of low interpreter confidence ("problem areas") on the other hand were found to be inaccurate in 50 percent or more of the cases. Therefore a measure of the proportion of a map in problem areas was a first crude measure of accuracy. For the land use data set derived from high-altitude aerial photographs we determined the correct classification of problem areas by direct field verification, and these "verified" maps were defined to enable the use of these data as a "correct" base against which to compare Landsat-derived land use data.

Another method of determining map accuracy was tested in the Norfolk-Portsmouth SMSA. It was to compare classifications of selected sample points and points at grid intersections selected from each of two maps being compared (Alexander and others, 1975a). For example, a Landsat-derived map of the Norfolk test site was compared with a high-altitude aircraft-derived map of the same area. One-kilometer grid intersections were used to identify sample points and a total of 1,989 such points were tested, the land use at each being recorded. By this procedure 76.5

percent of the points sampled were determined to have the same Level I classification on the maps derived from Landsat imagery as those derived from the high-altitude aircraft photographs. Of the classification differences that occurred, the most significant were of three types: (1) areas interpreted as agricultural land from the high-altitude aircraft photographs but as urban land from the Landsat imagery; (2) areas interpreted as forest land from the photographs but as agricultural land from the imagery; and (3) areas interpreted as agricultural land from the photographs but as forest land from the imagery. A separate map of the areas that were classified differently using the two data sources indicated that the major concentration of interpretation differences forms a wide belt along the urban-rural fringe separating the Norfolk-Portsmouth urban concentration from the surrounding agricultural and forest lands. Some of the errors were due to registration differences in the way the two grid systems were overlayed upon two maps. However, the largest portion of the "errors," or more properly the differences between classifications assigned by the two data sources was attributable to the greater degree of generalization with which the Landsat data depicted the elements of the terrestrial landscape.

Sharp boundaries on aircraft-derived maps were often fuzzy or transitional on the Landsat data. Land uses which could be distinguished on the basis of small land parcels on aircraft imagery were blurred on the lower resolution Landsat imagery. The first inclination of the person making interpretation of data such as these would be to simply write off the Landsat as having poorer land use discrimination capabilities than the aircraft data. However, another interpretation is that the

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generalization provided by the Landsat data is actually giving a different view of the region, perhaps a land use classification intermediate between Levels I and II. By this interpretation it is incorrect to call this difference an error. More details on the accuracy experiments are contained in Alexander and others (1975a) and Fitzpatrick (1975).

Another method to determine accuracy is to compare areas of each land or water category as measured from each of the source data sets being compared. We used a number of such comparisons, the totals being provided either by the computerized measuring system or by hand use of a dot planimeter or by other area measurement methods, for example, tables C.3 and C.4. The use of this method, however, is contingent upon one's ability to measure satisfactorily the areas involved.

After conducting the preliminary accuracy research using a variety of methods we undertook a comprehensive accuracy study using a stratified random sampling technique to select and obtain a variety of accuracy measurements. We employed a one percent area sampling procedure, using twenty eight 5 x 5-km sample sites drawn from nonurban areas and fifteen 2 x 2-km sample sites from within urbanized areas as defined by the U.S. Bureau of the Census. The locations of these sample sites are shown on figures B.1 and C.7, respectively. The stratification into urban and nonurban categories was done because earlier studies suggested different accuracy problems within the two kinds of areas.

We wished to assess the effect of generalization from larger to smaller map scales using land use maps compiled at scales of 1:24,000, 1:100,000, and 1:250,000, prepared from the same remote sensing source (high-altitude aerial photographs) and field verified by ground or low-altitude aircraft observation, or by both. The results of this experiment (see the following tables) indicated lower accuracy than expected based upon a point by point comparison using a 1-km sample grid overlay on all of the sample sites.

ACCURACY OF LAND USE CLASSIFICATION AT SAMPLE POINTS
FOR THREE SCALES, USING SAME SOURCE MATERIAL

Scale	Accuracy (percent)
1:24,000	85
1:100,000	77
1:250,000	73

The above figures obscure the dependency of accuracy on the type of land use--the Level I categories at the three test scales.

COMPARISON OF ACCURACY OF LEVEL I INTERPRETATIONS
AT THREE SCALES

Scale	Level I Category, Percent Correct Identification				
	1	2	4	5	6
1:24,000	79	88	91	98	72
1:100,000	80	83	83	88	67
1:250,000	69	75	79	78	72

Investigators also compared samples derived from Level I interpretations of Landsat imagery and Level I interpretations of high-altitude aircraft imagery at the same scale. They identified the Level I land use at the center points of each 1-km cell within each sample site on the Landsat and aircraft-derived maps, and found the Landsat maps to have an overall accuracy of 70 percent as compared to the 77-percent accuracy for the maps from high-altitude photographs at a scale of 1:250,000. The major discrepancy between the two maps was found in the urban and built-up area (Category 1). The following table illustrates accuracy as a function of Level I land use categories:

COMPARISON OF ACCURACY OF LANDSAT AND AIRCRAFT, INTERPRETATIONS, LEVEL I POINT SAMPLE

	Level I Categories, Percent Correct				
	1	2	4	5	6
Aircraft	69	75	79	78	72
Landsat	34	67	77	82	61

Major problems identified in the CARETS accuracy assessments include:

(1) The mixture of different land use categories within a small area, which is the minimum-size mapping unit;

(2) the generalization of land surface types into units covering larger areas, as in lower-resolution sensors such as Landsat;

(3) errors due to imperfect registration of boundaries between categories on the maps being compared;

(4) errors due to generalization from larger map scales to smaller map scales;

(5) errors due to differences in interpreter applications of the classification system;

(6) residual errors due to interpreter misclassification;

(7) errors due to change between the times of the gathering of the two data sets.

The efforts undertaken by the CARETS project to measure the accuracy of land use maps were forerunners of similar tasks in the operational USGS Geography Program land use mapping effort. Refinements in the sampling procedures are being developed with the goal of issuing along with each of the finished land use maps a statement on the map which tells the user some additional information about the accuracy of the data contained therein.

SYSTEM COSTS

One of the desires of the CARETS investigation was to produce cost documentation and calculations so that the results could be quantitatively compared with those of other investigators, and so that cost factors could be available for use in planning and budgeting follow-on operational efforts. For a detailed discussion of the methods and results, see Fitzpatrick (1975).

The difficulties of assessing and evaluating costs arise because of the complexity of the processes of extracting land use information, compiling maps, and delivering information products derived therefrom to users (processes that involve many intricately interwoven steps, most of which are highly dependent on the other steps in a sequence). Moreover, the monetary inflation occurring throughout the period of performance of the CARETS project increased costs in different proportions for different aspects of the labor and materials inputs. Nevertheless, the CARETS project has attempted to present the cost information in as detailed a breakdown as possible. When comparing the accuracy of various data sets derived from different remote sensor systems, one should realize that different costs are associated with different levels of accuracy. Therefore a prospective user or developer of an operational land use information system should take careful account of tradeoffs between cost and accuracy. Greater accuracy can be obtained, up to a point, by greater investment in detailed data collection and interpretation activities and in improved technology for obtaining and processing such data.

Two illustrations of documentation of costs of the CARETS project are presented in tables 4.3 and 4.4. Table 4.3 compares mapping costs (derived from sampling procedures described previously so that comparisons between cost and accuracy could be made) at each of the three scales tested: 1:24,000, 1:100,000, and 1:250,000. The costs to produce maps at these three scales from high-altitude photographs are functions of several processes in the compilation, including acquiring the data, interpretation, preparations for reproduction, and reproduction and publication. Recognizing that actual operational experiences may be quite different from those of mapping 1-percent sample sites, investigators attempted to combine the operational and sampling figures using the experience they obtained in mapping the entire CARETS region at a scale of 1:100,000. They used that experience to interpolate between costs of sample mapping at 1:24,000 and 1:250,000. The costs for data acquisition are those listed by the EROS Data Center at Sioux Falls at the time of the sampling study in 1975.

The interpretation costs are based on an average per hour cost of $20.00. Table 4.3 shows that the cost of interpretation using the same source data at 1:24,000 is approximately 2 times that at 1:100,000, which in turn is approximately 1.2 times that of interpretation at 1:250,000. The cost of interpretation, however, is only a portion of the total cost to produce a land use map product.

Table 4.3.--Production costs* per km^2 for Level II land use maps** at three scales

	1:24,000	1:100,000	1:250,000	REMARKS
Data Acquisition	$.14	$.06	$.05	Based on 50 frames for 10,000 km^2 1:24,000 each frame $28.00 1:100,000 each frame $12.00 1:250,000 each frame $10.00
Mosaic Construction	$6.00	$.70	$.16	Based on average estimate for mosaic construction by the Topographic Division (Interview with Bernard Kelley, USGS Topographic Division, 4/11/75)
Interpretation & Edit ($20/hr)	600 hrs/ 10,000 km^2 $1.20	300 hrs/ 10,000 km^2 $.60	250 hrs/ 10,000 km^2 $.50	Actual time from interpreting at 1:100,000 - estimates at 1:250,000 and 1:24,000 interpolated from sample site interpretation. Cost estimates based on USGS Topographic Division per hour rates, 1975
Cartographic ($12/hr)	200 hrs/ 10,000 km^2 $.24	100 hrs/ 10,000 km^2 $.12	80 hrs/ 10,000 km^2 $.10	Based on actual time for cartographic work at 1:100,000 interpolated to 1:24,000 and 1:250,000 and assumed to be 1/3 the interpretation time
Marginalia	$1.25	$.08	$.01	Based on actual costs to compile collars for CARETS maps at 1:100,000, and assumed to be the same per map at each scale
Reproduction	<$.10	$.01	<$.01	USGS cost to produce positive film transparencies at scale
Publication Cost	$3.00	$.18	$.06	Cost of publication by the USGS (Interview with Bernard Kelley, USGS Topographic Div., 4/11/75)
TOTAL	$11.93	$.175	$.88	

*1975 dollars

**At scales and formats conforming to the USGS 1:24,000 and 1:250,000 topographic map series and CARETS 50 x 50-km 1:100,000 photomosaics.

Source: CARETS project (Fitzpatrick, 1975, p.44)

Table 4.4--Compilation and publication costs* per km² for a Level I land use map**

	High-Altitude Photography 1:250,000	ERTS 1:250,000	Remarks
Data Acquisition	$.05	$.01	Based on 50 frames of high-altitude photography for 10,000 km² 1:250,000 (4" x 5") at $10 each and a Cibachrome transparency from commercial firm at $41.50 (20" x 24") of ERTS imagery.
Mapping base/ no mosaic	$.15	$.01	Based on rectified high-altitude photography with a transparency of the black and blue line plate at 1:250,000, and on ERTS Cibachrome print with a transparency of the black and blue line plats: 50 1:250,000 high-altitude prints $10 ea. $500/ 10,000 km² = $.05/km² prints rectification $20 ea. $1,000/10,000 km² = $.10/km² 1 black line base map $20 ea. $20/20,000 km² = $.001/km²
Interpretation $20/hr	80 hr/10,000 km² $.16	15 hr/10,000 km² $.03	Interpretation time, estimated for interpretation from 1:120,000 scale high-altitude photography and actual time for ERTS interpretation
Cartographic $12/hr	40 hr/10,000 km² $.05	8 hr/10,000 km² $.01	Cartographic time considered to be half the interpretation time, at Level I mapping
Marginalia	$.01	$.01	Based on the actual costs to compile collars for CARETS maps at 1:100,000 and assumed to be the same per map at each scale
Reproduction	($18/sheet) $.01	($18/sheet) $.01	USGS cost to produce positive film transparencies at scale
Publication Cost	$.06	$.06	Cost of publication by the USGS (interview with Bernard Kelley, USGS Topographic Div., 4/11/75
TOTAL	$.48	$.13	

* 1975 dollars

** conforming to the USGS 1:250,000 map series

Source: CARETS project (Fitzpatrick, 1975, p.49)

Table 4.4 summarizes cost estimates per km^2 for deriving land use maps at 1:250,000 from high-altitude aircraft photographs and Landsat imagery. In this example, interpreters mapped land use using USGS topographic sheets, black and blue line color separation plates, as mapping bases. The project acquired imagery for each sensor at the mapping scale. The costs that differ for the two are those to acquire the aircraft photographs and Landsat imagery, those to set up the mapping base, and those to complete the compilation. Table 4.4 also lists standardized labor costs as $20.00 per hour. The times for compilation and cartography are based on the experience of the CARETS project, and the costs of reproduction and publication are estimated from other USGS experience. Table 4.4 reveals that the cost to produce a Level I land use map from high-altitude photographs amounts to approximately $0.48 per km^2. The cost to produce a comparable Level I map from aircraft photographs is approximately four times the cost to produce a land use map from the lower-resolution Landsat imagery. The difference in the two results primarily from the greater interpreter time needed to analyze the greater amount of detail on the aircraft photographs.

COMPARISON OF LANDSAT AND AIRCRAFT DATA FOR LAND USE MAPPING

The products of the land use information module constitute the "regional data base" component of the CARETS experiment. Those products are inputs into all the other three project modules, as discussed in chapters 3, 5, and 6. The present chapter concludes with a comparison of the two major remote sensor data sources, Landsat and high-altitude aircraft.

A quick comparison of the characteristics and capabilities of Landsat and high-altitude aircraft imagery can be obtained by glancing at figures B.4 and B.3, respectively. An interpreter accustomed to recognizing features on aerial photographs has considerably less opportunity to use such skills in interpreting Landsat imagery. New techniques have to be developed to make fullest use of the Landsat. Although many features are readily identifiable on Landsat imagery (water bodies, airfields, highways, forests), others (central business districts, residential suburbs, orchards) are identifiable only after experience with matching the unfamiliar tones and textures with other information to verify the interpretation. Each Landsat interpreter worked closely with aerial photography of the same area while learning to interpret the Landsat signatures.

Boundaries between land use types are not often well defined on Landsat imagery. Also, the resolution differences between the two types of source material is significant. These differences are revealed by comparison of land use maps of the same areas made from Landsat and aircraft imagery, as illustrated in figures B.6 and B.5, respectively. High-altitude aircraft photographs can be enlarged many times without great loss in resolution capability at the enlarged scale of mapping. Optical or photographic enlargement of Landsat imagery beyond the scale 1:250,000 produces only more graininess and provides no additional aid to interpretation at the larger scale.

Landsat is less useful than aircraft photographs for the user who requires greater ground resolution. Where a generalized map is desired, however, Landsat may have an advantage. Our interpreters found that the time required for mapping Level I land use from high-altitude photographs was over 5 times that for mapping the same area using Landsat imagery. In some cases the coarser resolution of Landsat provides "instant generalization" to higher levels in the classification system. A corresponding advantage is lower cost. And Landsat imagery is becoming much more widely and more frequently available than aerial photographs. The direct computer-compatible format available with Landsat may be a growing advantage over manually-interpreted aerial photographs, as soon as a larger number of people learn how to make use of the Landsat in digital form.

Other comparisons between the capabilities of the two sensor systems may be obtained by comparing areas of the same phenomena measured by the two different methods. Examples of such area measurement comparisons can be seen in tables C.3 and C.4. Comparisons of area measurements by county were also made between Landsat-derived data and data from other sources, more or less officially available. Such comparisons of amount of land in urban, agricultural and forest uses are illustrated in figures C.9, C.11, and C.13, respectively. It became clear to the CARETS investigators, in glancing at the various sources of such data, that there are no standard or widely accepted ways to make such measurements, and it is often difficult to determine just how the measurements were made in any given set of published statistics. The differences among area measurements shown in table C.3 do not necessarily mean that the remotely sensed measures are less accurate. While we were not able to verify this, we developed a feeling that our methods may be more accurate in reporting, say, land area within a given county, than the figures used by the U.S. Bureau of the Census. A spinoff of the remote sensor programs may be establishment or improvement in standards for measuring land areas for statistical purposes.

CHAPTER 5

LAND USE AND ENVIRONMENTAL IMPACT

The linkages between land use and various factors of the biophysical environment were discussed in chapter 2 and were diagrammed in figures 2.2 and 4.1. The present chapter describes the CARETS project module which encompasses the land use and environmental impact interactions. Our objective here was to quantify the relationships among land use types and environmental responses. The material presented in this chapter summarizes works reported on at length in CARETS project final report volumes 7 through 11.

The basic formulation for the CARETS environmental impact model is taken from the assumption of a set of deterministic relationships between land use and environmental quality. These relationships can be expressed in two different formulations:

(1) $Q = f(LU)$

(2) $LU = f(p_1, p_2, \ldots),$

where Q represents some environmental quality measure expressed as a social/economic/environmental variable, LU represents land use and land cover as measured by remote sensing, including land use changes, and p represents a process variable (social/economic/environmental). The formulations assume consistent scale, resolution and time factors between the land use data and the corresponding social, economic, and environmental variables.

The first formulation states that environmental quality is some function of land use. A corollary is that land use change may in turn bring about a change in environmental quality. The second formulation states that the land use patterns we observe are themselves functions of a set of environmental process variables; this relationship concerns the physical limitations or constraints that are placed upon various land use types by factors of the physical environment.

This chapter deals first with the investigations into relationships of the first kind, where environmental quality or some environmental measure was shown to be a function of land use patterns and/or land use changes. These include predictions of streamflow characteristics, water quality and sediment yield, air quality assessments, and climatological implications of land use processes. Also relating to the first formulation is a discussion of the relevance of a land use data base such as that developed in the CARETS project to the preparation of environmental impact statements. Following that is a discussion of one relationship of the second type where land use is seen to be constrained by some factors or processes of the physical environment; in this case the study involved preparation of data to assess compatibility of land use types with underlying geological conditions. The geological variables mapped were landforms and Earth surface materials. Finally, the chapter presents a discussion of how the two kinds of land use and environmental formulations can be combined into a strategy to assist in coastal zone management.

PREDICTIONS OF STREAMFLOW CHARACTERISTICS

One of the recommendations to come out of early planning sessions on the environmental impact portion of the CARETS project was to investigate the hydrologic impact of land use patterns and changes. The faster runoff from increasing spread of impervious surfaces made problems and hazards especially acute in urban areas, as documented by a number of studies (e.g., Leopold, 1968; Thomas and Schneider, 1970).

A cooperative arrangement was worked out within the U.S. Geological Survey to make possible an investigation into some aspects of the hydrologic effect of land use patterns. The aspect chosen was the estimation of streamflow characteristics with the aid of CARETS land use information. Streamflow estimation is already a part of an operational procedure employed by the U.S. Geological Survey on a nationwide basis (Thomas and Benson, 1970). A U.S. Geological Survey hydrologist performed the study for CARETS and produced a report which became one of the volumes of the CARETS final report (Pluhowski, 1977).

The study contributed not only to the objectives of the CARETS environmental impact model, but also held promise of improving the USGS capability to appraise the Nation's water resources by improving accuracy of streamflow estimates.

The U.S. Geological Survey operates more than 8,000 complete-record stream gaging stations and several thousand partial-record stations. In addition to the information obtained at the actual gaging site, the procedure determines relationships among a number of drainage basin characteristics and the streamflow characteristics as measured at the gaging stations. Improvement in understanding those relationships could presumably lead to cost reductions by employing a smaller number of gaging stations in the future, or at least improving the efficiency of deployment of gaging stations in regions undergoing urban development or other land use changes having hydrologic effects.

The method used involved a multiple regression analysis technique which defined relationships between each streamflow characteristic and drainage basin characteristics, as well as providing measures of the accuracy of each relationship. The study design called for the selection of 49 small basins for which CARETS land use information derived from both high-altitude aircraft and Landsat sensors were available. The basins ranged from being almost completely urbanized to being nearly still in the natural state. Different mixes of urban, agricultural and forest land were well represented in the selection. After compiling the basin and streamflow characteristics for these sample basins, the standard regression equations were applied in order to compute stream flow characteristics in the usual way without remotely sensed land use data. Streamflow and basin characteristics used are listed in tables 5.1 and 5.2.

The model was applied to 39 gaged basins in the CARETS region. A control set of equations was developed based upon the standard procedures as described in Forest and Walker (1970). The regression analysis was then applied successively to each of three experiments where additional land use data were incorporated as follows, expressed as percent of total drainage area:

(1) four Level I land use categories from high-altitude photography

(2) six individual and combined Level II land use categories derived from high-altitude photography

(3) three Level I land use categories derived from Landsat-1 imagery

Comparisons were then made between the control equations and those developed for each one of the remote sensor experiments to determine whether significant improvement in the standard error of estimate had

Table 5.1.--Streamflow characteristics used in standard regression techniques

Q_a----mean annual discharge, defined as the arithmetic average of the annual mean flows,

q_n----mean monthly discharge, where the subscript refers to the numerical order of the month beginning with January as 1,

SD_a---standard deviations of the annual means,

SD_n---standard deviations of the monthly means, where the subscript n refers to the numerical order of the month beginning with January as 1,

P_T----annual flood peak discharge at T-year recurrence interval; recurrence intervals of 2, 5, 10, 25, and 50 years are denoted as P_2, P_5, P_{10}, P_{25}, and P_{50}, respectively.

$V_{D,T}$--flood volume characteristics are the annual highest average flow for 3-day periods at recurrence intervals of 2 and 25 years ($V_{3,2}$, $V_{3,25}$), and for 7-day periods at recurrence intervals of 2, 10, and 25 years ($V_{7,2}$, $V_{7,10}$, $V_{7,25}$),

$M_{D,T}$--low-flow characteristics are the annual minimum 7-day average flows at recurrence intervals of 2, 10, and 20 years ($M_{7,2}$, $M_{7,10}$, $M_{7,20}$),

D_{50}---discharge equaled or exceeded 50 percent of the time.

Source: Pluhowski, 1977, p. 29-30.

Table 5.2.--**Basin characteristics used in standard regression techniques**

A-------drainage area, in square miles as shown in the latest U.S. Geological Survey streamflow reports,

S-------main-channel slope, in feet per mile, computed by the 10- to 85-percent method (Benson, 1962),

L-------main-channel length, in miles, measured from gaging station to basin divide,

E-------mean basin elevation, in feet above mean sea level, measured from topographic maps by the grid method

S_t------area of lakes, ponds, and swamps, in percent of total drainage area, determined by planimetering such areas on topographic maps,

F-------forest area, in percent of total drainage area, measured from topographic maps by the grid method,

S_i------soil index, a measure of potential maximum infiltration capacity, in inches, estimated from data provided by the U.S. Soil Conservation Service,

P-------mean annual precipitation, in inches, determined from isohyetal maps prepared from National Weather Service records,

$I_{24,2}$---precipitation intensity, expected once every two years over 24-hour periods, in inches, estimated from U.S. Weather Bureau Technical Paper 29,

S_n------mean annual snowfall, in inches, from snowfall maps prepared from National Weather Service records,

T_1------average minimum January temperature, in degrees Fahrenheit, from National Weather Service records,

T_7------average minimum July temperature, in degrees Fahrenheit, from National Weather Service records.

Source: Pluhowski, 1977, p. 30-31.

resulted in any of the streamflow characteristic equations. Changes of 10 or more percent, whether improvement or worsening, in the standard errors of estimate between the control and experimental equations were arbitrarily deemed significant.

Portions of two of the small basins selected in the study are indicated in figure B.8, where comparison can be made with the corresponding areas as shown on high-altitude aircraft photo (fig. B.3), Landsat image (fig. B.4), and the two land use maps derived respectively from aircraft and Landsat imagery (fig. B.5 and B.6).

Results of the analysis are displayed in tables 5.3, 5.4, and 5.5. These tables show only the significant changes (those exceeding 10 percent). The "increase" column shows an improvement over the standard technique; the decrease column shows a worsening of the estimate based upon the use of the remotely sensed data. Improvement in the estimates of several streamflow characteristics were obtained from each of the experimental sets of land use data: Level I aircraft, Level II aircraft, and Level I Landsat. One of the conclusions that can be drawn is that there is little or no advantage in using the more detailed Level II aircraft data over the use of Level I aircraft data. Therefore, for purposes of estimating these streamflow characteristics the less expensive Level I aircraft data would be preferred. Using Landsat data alone, some increases in accuracy of estimating the standard error of estimate are obtained in certain flood volume characteristics and the variable which defines discharge equalled or exceeded 50 percent of the time. All of the significant changes in the remotely sensed estimates of annual flood peak discharge at various recurrence intervals were a worsening of the situation where

Table 5.3.--Significant changes in standard error of estimate by including four Level I land use categories derived from high-altitude aerial photographs*

Flow Characteristics**	Percent Change Increase	Percent Change Decrease
q_6	14.5	
q_7	20.6	
q_9	11.3	
q_{11}	17.6	
P_2		12.7
P_{25}		16.7
$V_{3,2}$	15.3	
D_{50}	26.6	

*Level I Aircraft-derived categories used:

Urban and built-up

Agricultural Land

Forest Land

Water

**See table 5.1 for definitions of terms

Source: Pluhowski, 1977, table 10

Table 5.4.--Significant changes in standard error of estimate by including six Level II land use categories derived from high-altitude aerial photographs*

Flow Characteristics**	Percent Change Increase	Percent Change Decrease
q_6	25.4	
q_7	22.2	
q_9	15.8	
P_2		12.1
P_5		10.2
P_{10}		19.1
P_{25}		17.5
$V_{3,2}$	16.3	
D_{50}	16.4	

*Level II Aircraft-derived categories used:

Urban residential

Urban industrial

Urban open and other

Agriculture, cropland and pasture

Forest, heavy crown cover

Forest, light crown cover

**See table 5.1 for definition of terms

Source: Pluhowski, 1977, table 11

Table 5.5.--Significant changes in standard error of estimate by including three Level I land use categories derived from Landsat imagery

Flow Characteristics**	Percent Change Increase	Decrease
P_2		20.2
P_5		28.1
P_{10}		36.5
P_{25}		20.1
$V_{3,2}$	13.6	
$V_{3,25}$	12.6	
$V_{7,25}$	14.8	
D_{50}	17.0	

*Level I Landsat-derived categories used:

Urban and built-up

Agriculture

Forest Land

**See table 5.1 for definition of terms

Source: Pluhowski, 1977, table 12

the standard equations were used without remotely sensed data. In other words, remotely sensed data decreased the accuracy of the estimate of these flood discharge measurements. Instead, the standard measures of forest cover obtained from topographic maps contributes more significantly to the estimation of these flood peak discharge characteristics. The interpretation of this situation is not as unfavorable for the remotely sensed data as it first might seem. The topographic maps were several years older than the remotely sensed data, more nearly matching the years of record for which the regression equations were run. In this rapidly changing area much of the forest land had been changed into other uses in the intervening years. Therefore, a longer time interval record of the remotely sensed data (for example, as would come from an operational aircraft or satellite monitoring system) would eventually provide land use data equal to or better than that which is available on the topographic maps. The conclusion from the study would seem to indicate that adding remotely sensed land use data to the procedures for estimating streamflow characteristics would result in an improvement in those estimates in the case of many flow characteristics. From this study we would recommend that the USGS Water Resources Division consider modifying its streamflow estimation procedures to include land use and land cover data derived from high-altitude aircraft photographs.

WATER QUALITY AND SEDIMENT YIELD

At the beginning of the CARETS project we hoped to be able to include measures of the impact of land use patterns and changes on water quality and sediment yield. A few studies had shown the particularly dramatic effects of construction associated with urban development upon exposure of erodible soils and changes in runoff regimes (Wolman and Schick, 1967). In the contract study by Goodell and others (1972) conducted under the auspices of the CARETS project the approach, was to seek empirical relationships between infiltration, runoff, sediment yield and water quality on the one hand and land use change on the other. That study assembled some data for the Virginia coastal plain area indicating the wide variety of sediment yields from the major Level I and Level II land use types. Quoted in that study were the U.S. Department of Agriculture estimates of soil loss from erosion in tons per acre per year in that area as the following; cropland, 3.83; cropland treated for soil conservation, 1.92; pasture, 0.85; forest, 0.28; urban, 5.78. Goodell's estimate of the annual sediment loss from the southern one-quarter of the CARETS region is 8 x 10^6 tons, 37.1 percent of which is generated from urban areas (Goodell and others, 1972, p. 43). Land use data upon which those estimates were based, however, were several years old at the time of the compilation. The availability of more up-to-date land use data through a CARETS-type information system would assist in making more accurate estimates of sediment yield, providing that the necessary "calibration" field studies can be made in representative environmental sites. Recent work by Guy (1974) at the construction site of the new USGS National Center in Reston, Virginia, combined the use of remotely sensed data and field measurements to produce sediment discharge estimates for the years 1972 and 1973. To make these estimates, however, the aerial photographs were of much larger scale (1:720) than those available in the CARETS project.

In the area of water quality we were unable to carry out actual measurements based upon the use of CARETS data. However, data of the type produced by CARETS may be of use for such water quality measurements providing the correct kind of calibration can be made. This would require correlation of measures of, for example, land use types with fertilizer and pesticide application, animal and human waste, and general drainage from urban areas, along with associated chemical analyses of water from streams and groundwater. Using data from past years, Truhlar and Reed (1975) compared pesticide residues measured in streams to four general land use types in the areas drained by those streams: forest, general farming, residential, and orchard farming. Presumably, water quality studies of this nature could be usefully related to the data from the CARETS land use information system in ways that would help make quicker estimates of the effects of different land use types on water quality.

AIR QUALITY ASSESSMENT

Under the auspices of the CARETS project, a study was conducted in the Norfolk-Portsmouth SMSA to investigate the impact of land use information on area source control strategies for air quality management (Reed and Lewis, 1975). Compiling an estimated average of the annual winter area source emmission from CARETS Level II land use categories (Level III was required for residential areas), and placing this inventory into a diffusion model, the investigators estimated sulfur dioxide emissions in the Norfolk-Portsmouth SMSA for 1972. Then, using the Southeastern Virginia Planning District Commission's map of project land uses for 1985, they predicted sulfur dioxide emissions for that year. The results of the study were that a measureable deterioration in sulfur dioxide levels is expected if the anticipated land use changes, with their attendant expansion in area sources of sulfur dioxide, actually occur. The basis of this study was the calibration of land use information in terms of its relationships to point and area emissions of sulfur dioxide and particulate matter for the time period most closely related to that encompassing the gathering and presentation of the land use data. Emission data is used as input to the Air Quality Display Model (AQDM) of the Environmental Protection Agency. During the 1971-72 winter period estimated sulfur dioxide amounts over the central section of Norfolk exceeded both primary and secondary levels.

The diffusion results for both 1971 to 1972 winter and the annual 1972 time periods showed that both primary and secondary standards for particulate matter are regularly exceeded in central Norfolk and Portsmouth. Furthermore, on the basis of current control programs, the 1985 levels of particulate matter are expected to exceed the presently established secondary air quality standards through central Norfolk and Portsmouth and in certain areas of Virginia Beach. The study also showed (Reed and Lewis, 1975) techniques which could be used to apply the procedures elsewhere. Land use activities can affect air quality by emitting both natural and manmade pollutants. These pollutants are dispersed by local, regional and global air flow. The concentration of pollutants in any one place depends on a number of factors among which is the location of emitting sources relative to the direction and stability of air flows. Land surface characteristics such as roughness, albedo, thermal diffusivity, amount of water, and amount of transpiring surface in a given area also influence the meteorological conditions affecting the stability of air flow. Each of these surface characteristics can be extensively modified by the activities or processes conducted on, and structures that occupy urban and rural land.

Particular needs for information input to the comprehensive air quality planning activities, i.e., the types of land use information needed for comprehensive plans, include: (1) activity location--for each type of process or fuel consumed, the current and anticipated location of stationary and mobile activities emitting and receiving pollutants; (2) activity behavior--for each type of pollutant the timing and intensity of emissions or reception; (3) activity physical characteristics--the geometry, albedo, and surface material of the area and the region's activities and processes affecting local air flows. Much of the needed land use information can be directly provided by a CARETS-type information system. More detailed information on the concentration of housing would have been useful for refining the area source estimates, i.e., the availability of a number of dwelling units along with the indication that the land use is of a particular major residential category would have been helpful. That amount of detail implies Level III information. Without such detailed information the investigators used an estimation procedure for determining the effects of different housing concentrations.

CLIMATOLOGICAL IMPLICATIONS

The original CARETS design called for the study of the impact of land use patterns and changes on local microclimates, particularly the phenomenon known as the urban heat island effect. It was known that the changing of an area from forest or agricultural land uses to urban uses results in generally warmer temperatures in the urban areas. Large portions of the surface are paved over and have the vegetation cover removed, particulate matter in the air increases, and vertical obstructions in the form of high buildings are placed in the path of prevailing air flow. These factors among others contribute to the changing in the energy and water balance of the urban area.

The climatological applications portion of the study was conducted under the sponsorship of the NASA-Skylab experiment, during the same time period as that of the NASA-Landsat experiment. The CARETS land use maps and other remotely sensed imagery provided by the Landsat experiment were also useful in assisting in the interpretation of data obtained from the Skylab cameras and multispectral scanner. Results of the experiment are reported in the final report on the CARETS Skylab project (Alexander and others, 1976). A computer-simulated map compared favorably with the map produced by the temperature observations of the Skylab multispectral scanner. The simulation procedure enabled assigning of different temperture values depending upon the type of land use. Temperatures displayed in table 5.6 were obtained from a combination of observed and calculated temperatures, taking into account surface thermal characteristics, albedo, transpiring surface, and roughness, as associated with different kinds of land use in the Baltimore area test site. Conclusions of the study were that the calibration of remotely sensed land use data, in terms of its climatological impact, was feasible and that the addition of a computer-simulation technique to the remotely sensed observations would enable extrapolation of sensor data to times of the day or year other than those when particular sensor observations are available. To make these applications more readily usable, however,

Table 5.6--Simulated surface temperatures of land use types, Baltimore test site, August 5, 1973, 10 a.m. local time

Land Use Type	Temperature °C
Residential	
Low-density	24.9
High-density	30.9
Commercial	30.8
Industrial	30.1
Extractive	35.0
Transportation and Utilities	36.9
Institutional	27.2
Strip	30.8
Mixed	30.8
Open	25.4
Cropland	24.2
Orchard	22.7
Forest	
Heavy (40% & over)	22.3
Light (10-40%)	26.6
Water	24.0
Nonforested Wetlands	26.3
Beaches & Sand	34.9

Source: Alexander and others, 1976, p. 3-68 increased ability is needed to map the computer-derived multispectral scanner data onto preexisting land use maps so that detailed spatial correlations can be determined by machine calculations.

ENVIRONMENTAL IMPACT STATEMENTS

Concurrently with the CARETS investigation, many dozens of individual scientists and agencies were attempting to comply with one of the requirements of the National Environmental Policy Act of 1969, namely the preparation of environmental impact statements (EIS) for proposed projects. The EIS must indicate expected beneficial or adverse changes resulting from a proposed action. Many kinds of data are required as input into the EIS process. To inquire into ways in which CARETS products might be used to assist in the process of writing EIS's, one of the CARETS study efforts reviewed the 150 EIS's filed in the CARETS region during a 4-year period (Buzzanell, 1975). Buzzanell classified these statements into seven categories:

(1) Construction of transportation and communication facilities

(2) Construction of power plants and power lines

(3) Urban renewal, new town development, and multistory building construction

(4) Construction of watershed protection and development facilities

(5) Construction of waste treatment disposal facilities

(6) Navigation improvement and beach erosion control projects

(7) Establishment of conservation areas

Maps of the distribution of these various types of EIS's are contained in the detailed report (Buzzanell, 1975). Buzzanell presents an approach to environmental assessment that applies land use and water data as central inputs into the assessment processes (fig. 5.1). Under this model each of the seven major kinds of environmental impacts being addressed would be related in some way to changes in land and water use. The immediate implication of this is the need to obtain data on present land and water use. It appears that such data could be supplied by a CARETS-type information system although many of the examples used would require land use data of a more detailed nature than that available in the CARETS data base. The timing was wrong for use of CARETS data in the EIS's surveyed. However, in the future the EIS application should be a major concern for those designing regional environmental information systems based on remotely sensed data.

Land use data of the type produced by the CARETS project can be of assistance in developing portions of many EIS's. For such information to be of continuing value it should be available operationally, in quick response to queries from the agency responsible for the EIS. Also, the existence of such a land use information system should be made widely known as EIS's are often written by consultants working under short deadlines and requiring quick access to whatever input data are required. Under such conditions it is quite likely that duplication of remotely sensed data analysis and land use mapping activities would take place in the environmental impact statement preparation process.

COMPATIBILITY WITH GEOLOGICAL CONDITIONS

Under cooperative arrangement with the Geologic Division, USGS, two separate CARETS project activities were undertaken to provide surficial geological information for use by those interested in land use planning

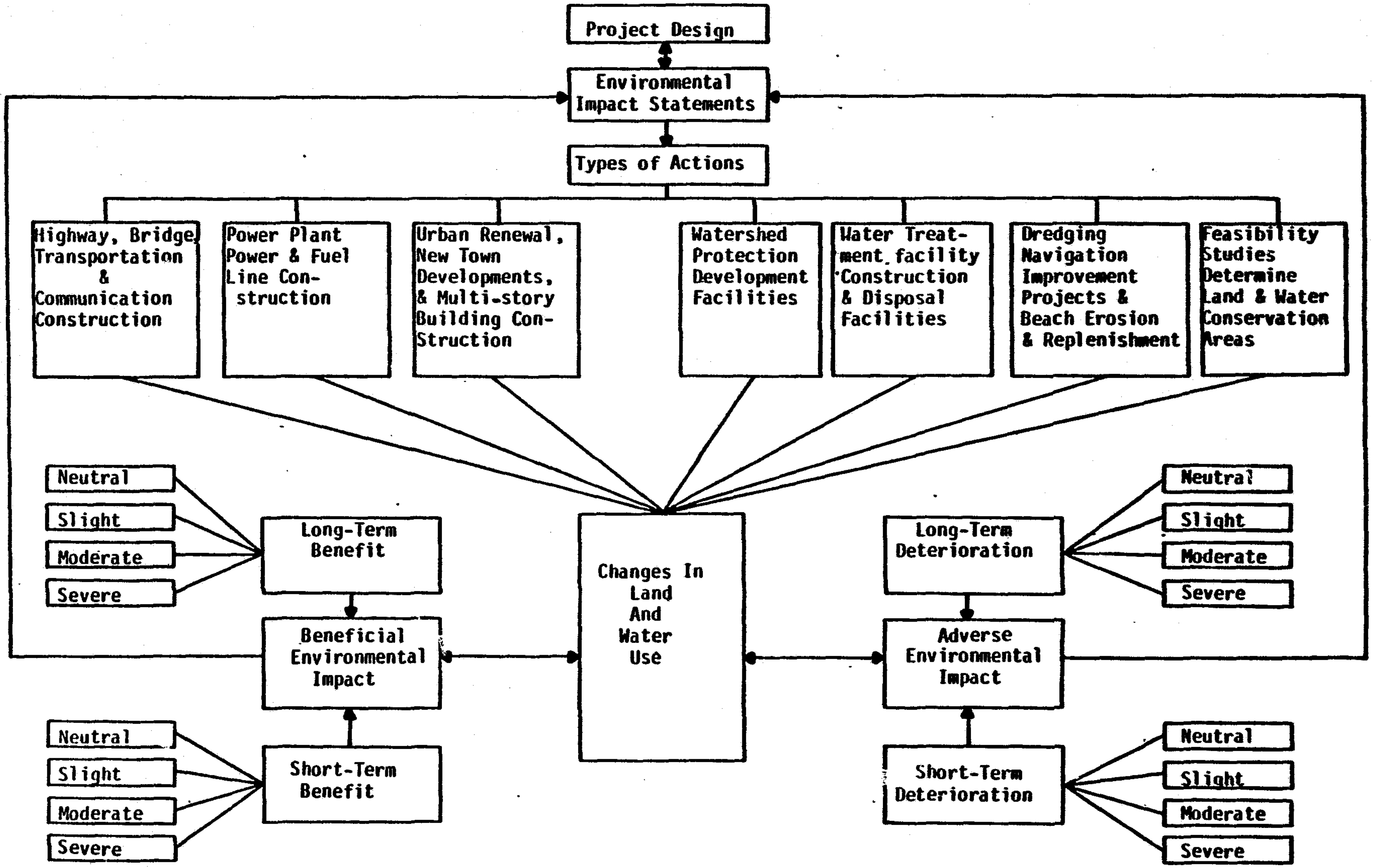


Figure 5.1--An approach to environmental impact assessment using land use and water data as central inputs.

Source: Buzzanell, 1975, p. 67

applications, in correlation with the land use and other data supplied by the CARETS project. The first of these was a detailed study in the Norfolk-Portsmouth SMSA in which a "map of Earth materials" was produced, at a scale of 1:100,000, based upon compilations of existing data (with sources other than remote sensing). Each unit of this map was described in terms of the materials (for example, sand, clay, peat, etc.) and their distribution at or near the surface. Each map unit was further described in terms of its topographic expression and present vegetation types as well as features affecting agricultural and engineering work such as the following: drainage characteristics, soil types and agricultural adaptability, adaptability to Earth work in wet periods, feasibility for use as topsoil, feasibility as source of construction materials, and feasibility for foundation material. It was expected that such a map would be a guide to regional planners for selecting most suitable sites for new development. The evaluation by the planners in the Norfolk-Portsmouth SMSA indicated that the information was valuable to them as they did not possess a single source of such information for use in comparison with their land use maps and other planning tools. This map was also accompanied by a matrix which enabled interpretation of each type in terms of most suitable land uses.

The second activity was a more general and widely applicable mapping system devised by William E. Davies of the USGS. The system uses a six-digit numerical representation of surface and near-surface characteristics--the numerals directly assignable to computer codes. The first two digits represent landforms: for example "zero" in the first digit stands for no slope, no relief, "1" in the first digit stands for little slope, small relief, etc. The second digit is for a more detailed breakdown of each first-digit category, e.g., 11 indicates undissected flats, 12 indicates dissected flats, 13 indicates flood plains, etc.

The third and fourth digits indicate lithology of bedrock more than 9 feet below the surface. For example, a third digit of "1" indicates igneous rocks; 11 indicates granite, 12 gabbro, and 13 basalt. Fifth and sixth digits are optional, and can be used for special descriptors. In CARETS maps 01 in fifth and sixth places indicates high water table and 11 indicates shallow soil, bedrock less than 9 feet below the surface.

Data for the landforms and surface materials maps were mostly obtained from existing maps--topographic maps for landforms data, and surficial geologic or soil maps for the lithology and other information. Complete coverage and digitization of these "landform and surface materials" maps were obtained for the two primary study SMSA's, Washington, D.C. and Norfolk-Portsmouth. A complete list of map categories is presented in table B.4. A reduced specimen of one of the maps is shown in figure B.14.

COASTAL ZONE MANAGEMENT

As stated in the beginning of this chapter, one of the original goals of the CARETS project was to provide information for integrated environmental assessments, taking account of the two-way interaction of land use and environmental factors. Our involvement with the physical task of preparing the basic data precluded carrying out all the analytical tasks that we had desired. We did, however, conduct some examples of studies showing one of the major CARETS environments, that of the coastal zone, and how the availability of the land use information, along with correlative environmental information could assist in the decisionmaking process for planning and managing new uses of these lands. A microcosm of problems existing in the CARETS coastal zone can be seen in the city of Virginia Beach where a somewhat more intensive study of these problems was carried out under the auspices of the CARETS program. These are discussed in more detail in Alexander and others (1975) and Buzzanell and McGinty (1975). The coastal and wetlands ecosystems here are undergoing great stress from increasing population pressure and associated land use change. Land use changes, especially those involving urbanization occurring in these ecosystems or on their periphery, result in modified runoff, siltation, and adverse changes in water quality. These ramifications of urbanization in turn affect the overall quality of the coastal zone resource, its commercial fishing, wildlife habitat, and local and regional recreational value. Concomitant with the land use changes, planners in the region are escalating their attempts to cope with a number of associated environmental problems. One is the stabilization of the barrier beach and its effect on the water quality in Back Bay, the lagoon behind this beach which extends south of the test site into North Carolina. Another is the problem of disposition of sewage, much of which goes into septic tanks dug into the city's wetlands and poorly-drained areas.

Much of the land use change, such as construction of housing or building of roads, into natural areas of Virginia Beach has been motivated by the recreational opportunities of the area. Paradoxically, the new development could destroy the amenities that attracted their location. The interrelations of land use decisions and natural environmental processes are exemplified by the situation where increased public use of the barrier island, forming the southeastern extension of Virginia Beach, is causing increasing stress on the natural ecosystem.

Planners and natural resource managers are now beginning to realize that natural disruptive change is often essential to the maintenance of ecosystem structure and function. This trend is indicated by the National Park Service policy for a topographically similar area to the south in the Cape Hatteras National Seashore. There the Park Service policy of fighting the sea on the outer banks and barrier islands is changed, according to an article in the Washington Post, September 24, 1973: "Instead of continuing to spend millions of taxpayer's dollars each year to tame the ocean, the Park Service intends to let nature work her will on seashores." In other words, natural forces would be allowed to shape the coastal landscape here rather than counting on artificial structures to maintain groins, buildings, roads, etc. Authorities have stressed that the islands are not being washed away, but rather are moving back by processes that are fundamental to their origin (Dolan and others, 1975). In the face of this philosophy of planning with nature, not against nature, pressures of urban growth remain severe and recreational demands are hard for the planners and managers to resist. To make the plans viable requires a substantial information base as well as a broad philosophical planning base. The CARETS land resource data base provides one set of techniques to develop that data base that will facilitate land use planning decisions and allow monitoring of change that may require future planning adjustments. These techniques applied to the socioeconomic and environmental situation of Virginia Beach would provide the means to cope with the pressures of population growth while maintaining the vitality of coastal and wetland ecosystems.

CHAPTER 6

USER INTERACTION AND EVALUATION

This chapter describes and summarizes the efforts to involve the information users in the operation of the CARETS project, both for purposes of receiving input on their information requirements and for receiving their evaluations of the experimental products. We established and maintained contact with representatives of other Federal agencies, State agencies, regional agencies, local governments and members of the university and nongovernment user community. The effort began with a one-day conference at the start of the CARETS project. A user information center was set up in the CARETS project office as part of the experiment and was operated throughout most of the lifetime of the project. Preliminary informal interaction with selected users enabled us to get some understanding of their problems and data requirements. Finally, a formal evaluation of 65 user agencies was conducted involving workshops, follow-up interviews, and the assembly of the results into one of the final report volumes. Most users having environmental planning or management functions in this metropolitan region required larger-scale maps and more detailed data than provided by Landsat. High-altitude color-infrared aerial photography was the single most useful CARETS product.

INITIAL CONFERENCE FOR POTENTIAL USERS

In June 1971, as the CARETS project was just beginning to get underway, the USGS conducted a conference of potential users of land use data products derivable from remote sensing. The conference was held at the National Academy of Sciences in Washington, D.C., under the auspices of the geography panel of the National Academy of Sciences - National Research Council (NAS-NRC) Committee on Space Programs for Earth Observations. This conference introduced the CARETS project to the user community, helped establish contacts with users, and provided insights into the land use data needs of agencies having responsibilities in land resources activities. User responses at this conference, combined with results of prior technical evaluation, led to the decision to establish the CARETS regional mapping scale at 1:100,000.

The format of the conference, attended by 198 people, was in the style maintained throughout the CARETS project, namely one fostering a two-way communication between the data producer community and the data user community. In the forenoon a number of technical presentations outlined the potential of the sensing projects and the specific objectives and goals of the CARETS project. The afternoon session was devoted to a panel discussion focusing on questions directed by the user agency representatives and exchanges aimed at providing the CARETS project staff with a better idea of the user requirements for remote sensing and land use information. A profile of conference attendees may be obtained by reference to table 6.1, containing summaries of questionnaire responses.

CARETS INFORMATION CENTER

An essential feature of the CARETS design was the establishment and maintanence of the CARETS Information Center. The information center was located in the CARETS project office, first in downtown Washington and later at the Geography Program office in USGS headquarters, National

Table 6.1--Responses to Data Requirements Questionnaire from invitees to the CARETS Initial User Conference

Question	Number of positive responses
Function of agency represented	
Administratation	34
Regulation	5
Research	60
Planning	44
Other	17
Type of data required	
Urban	44
Transportation	38
Agriculture, soils, forest	43
Water quality	51
Mining and quarries	20
Recreation	35
Air quality	30
Other	32
Data resources (source of)	
We collect	66
Provided by State government	36
Provided by Federal government	57
Other	13
Data formats used	
Maps	57
Air photos	48
Census data	33
Traffic surveys	20
Building permits	16
Climatological data	42
Hydrological data	44
Other	20
Total Number of responders	93
Responders attending conference	75
Total conference attendees	198

Source: McGinty, 1975, p. 13

Center, Reston, Virginia. The CARETS Information Center was a focal point for the visits by representatives of the user community. It helped us establish contacts with the users and provided insight into the land use data needs of agencies who have responsibilities in land resource planning and management. At the CARETS Information Center visitors had access to remote sensor data and the products that were being prepared from those data, for example, land use maps. Often they could obtain copies for loan or for reproduction for use in their own facilities. We also maintained a small library of reference materials consisting of aerial photographs, census data, soils maps, geological maps, water resource information, and other information that might aid in using CARETS data.

All of the NASA-supplied imagery from aircraft and Landsat were made available for inspection at the information center. Light tables and small screen viewer-projectors were available to assist in the use of this material. We also had a color-additive viewer for viewing Landsat and other multispectral imagery in a variety of color or false-color presentations.

After the completion of the basic set of maps derived from aircraft and Landsat data, part of the function of the CARETS Information Center was taken over by the USGS Public Inquiries Office. The maps were placed on "open file," a distribution system long-used by the USGS for material thought to be useful prior to publication, or material which may not be suitable for publication at all, such as some maps and field notes, but which nevertheless has value to the public. The CARETS maps, as in the case of all other materials placed on open file, were first announced to the public through regular news releases. At the Public Inquiries

Office users could obtain on short-term loan copies of stable-base (film) maps suitable for reproduction. We were not able to reproduce and distribute large numbers of copies of these materials.

PRELIMINARY INTERACTION WITH SELECTED USER AGENCIES

In addition to the user contacts established through the CARETS Information Center, interaction with users was carried on by means of direct visits to the offices of selected agencies, and by meetings of staff personnel of both the CARETS team and the planning agencies. There was too large a number of user agencies for detailed contact with all of them. The formal user interaction based on questionnaire interviews, described in the following section, was designed to obtain broader user agency representation. However, in the areas that were selected for earliest land use mapping coverage we developed more thorough contacts with principal user agencies to give us a more detailed understanding of their problems and how those problems were translated into needs for information of the type that might be supplied by the CARETS project. These three user groups were the Southeastern Virginia Planning District Commission (SEVPCO), the district which includes the Norfolk-Portsmouth SMSA where the first CARETS system tests took place, the Maryland State Planning Department, and Metropolitan Washington Council of Governments (MWCOG).

The Southeastern Virginia Planning District Commission has headquarters in Norfolk, Virginia, and serves as the officially designated "A-95" coordinating agency for Federal projects in the Norfolk-Portsmouth SMSA. CARETS project staff members had a number of exchange visits, both in the SEVPCO offices and in the CARETS offices. The director of planning from SEVPCO served as a member of the evaluation panel to give us a formal critique of the products resulting from the CARETS project. Our work with the SEVPCO personnel enabled us to get a good feeling for the kinds of data needs that they had. For example, when we were conducting the experiment for determining land use change using aircraft and satellite sensor data, we were aided by SEVPCO explanations of their needs for land use change information according to a requirement of the U.S. Department of Transportation, involving the update of land use data files to aid in planning of future transportation facilities. We were able to determine that if our data had been available a year earlier a saving of a few thousand dollars in their operation would have been possible.

Our contacts with the Maryland Department of State Planning also began early in the CARETS investigation. That office also served as an investigator under one of the NASA Landsat research efforts. Their objectives were to evaluate the Landsat system as an input to the data required for the use of Maryland State agencies involved in various aspects of land use planning. The CARETS project gave the Department of State Planning early copies of the Level II maps produced from the high-altitude aircraft data. The Department was also able to use, with minor modifications, the land use classification system that was being developed in CARETS and later modified into the USGS operational system.

The State of Maryland contracted to complete coverage of the western part of the State (not covered in the CARETS project) based on the same system of mapping that was used in CARETS. Because of their more detailed requirements, they added Level III categories. The maps were colored and presented in segments to county area users for further evaluation and coordination of land use data needs throughout Maryland.

The Metropolitan Washington Council of Governments is the officially designated "A-95" agency for coordination in the region which consists of the Washington, D.C. SMSA (Charles County, Maryland, which was later added to the SMSA, was excluded from our study). With funding provided by the EROS Program of the USGS, MWCOG conducted a contractual study for the CARETS project. The study had three objectives: (1) conduct an inventory of land use decisions in the MWCOG area for the purpose of assessing which decisions might have been aided by the use of remotely sensed land use data; (2) conduct and coordinate an evaluation of CARETS products by MWCOG and representatives of the member local governments (counties and cities in the Washington, D.C. metropolitan area); and (3) compare CARETS land use data with land use data maintained in the MWCOG parcel files derived from a different process.

The land use decision inventory involved review of the minutes from local planning and zoning authorities in order to extract issue areas related to land use. The issues of the representative government agencies have a different focus in different parts of the SMSA. Those representing the more concentrated urbanized areas within the region (District of Columbia, Alexandria, and Rockville, for example) are engaged largely in redevelopment of land already assigned to urban uses. The developing suburban counties (Montgomery, Prince Georges, and Fairfax) are generally addressing the impact of new development in relation to transportation, environmental quality, and site acquisition. The jurisdictions on the urban fringe of the metropolitan area (Prince William and Loudoun Counties) are primarily involved in comprehensive planning and the issue of growth. Most of the decisions inventoried had in common the concern with two types of actions: rezoning and site plan reviews. The details obtained in the inventory are presented in a summary report (MWCOG, 1974). In almost all cases the land use element which would be a required part of the staff analysis supportive of the land use decisions involved information much more detailed than that available in the Level II CARETS land use maps.

Details of the user evaluation results are presented in McGinty (1975), and details of the comparison of CARETS land use data with MWCOG land use files is contained in Metropolitan Washington Council of Governments (1976). Summarizing the results of this experience with the MWCOG, we found the conclusions generally the same as those cited above, namely for most uses in this metropolitan region the requirements for remotely sensed data and land use information were extremely detailed. High-altitude aerial photographs, such as those provided by the NASA program, are extremely useful.

FORMAL USER EVALUATION

The formal user evaluation effort began when most of the CARETS map and data products were completed or were in a sufficiently advanced stage so that they could be displayed to, and evaluated by the cooperating user groups. We selected a list of cooperating users from our initial contacts that developed later in the course of the project. A special form was prepared to identify user groups who would be willing to take part in the formal evaluation (fig. 6.2). While awaiting those responses we prepared lists of selected data products organized essentially in order of the amount of "processing" that had been added to the original data. Five general categories were used: (1) raw data products, those which were presented for evaluation essentially in the same form received from NASA, e.g., aircraft photography; (2) processed graphics derived from raw data by USGS, e.g., photomosaics and land use maps; (3) computer plots of land use; (4) data listings and summaries derived from area measurements; and (5) analytical reports.

User agency representatives were selected to attend one-day workshops at USGS headquarters. Three of such workshops were conducted, one each for representatives of the Metropolitan Washington Council of Governments agencies, State agencies, and Federal agencies. Attendance of these workshops was limited to about 30 individuals each, a number that we felt we could reasonably interact with. Again, the format was chosen to facilitate two-way communication. CARETS technical and scientific staff made short presentations on the nature of the products being evaluated. Then the group formed into smaller working groups with a CARETS staff member assigned to each group to make sure that data products were fully understood by the users, and to obtain information about the agencies and their functions. At the end of the day's workshop each attendee was given a packet of representative samples of the imagery, maps, etc.

CARETS USER INDICATION OF INTEREST

MEMORANDUM Date: ______________________

To: Robert H. Alexander Mail Stop 710
U.S. Geological Survey
Reston, Virginia 22092

From: Name: ______________________

Agency or Organization: ______________________

Mailing Address: ______________________

____

Phone: ______________________

I am interested in problems of land use and related environmental impact in the Central Atlantic Region. Pursuant to those interests, I wish to inquire about the suitability of land use data and related information being made available through the NASA-USGS Central Atlantic Regional Ecological Test Site (CARETS). In exchange for any information I receive, I agree to supply information on its utility for my purposes.

Types of CARETS products of interest to me:
( ) "raw" remote sensing data products (e.g. ERTS imagery, aerial photos)
( ) processed graphics (e.g. orthophotomaps, land use maps)
( ) data listings and statistical summaries (e.g. amount of land in certain uses)
( ) interpretive reports (e.g. analysis of regional land use trends and their environmental implications)

Geographical area(s) of my principal interest:
( ) Virginia ( ) Maryland ( ) District of Columbia
( ) Delaware ( ) Pennsylvania ( ) New Jersey
( ) Other (specify) ______________________

I would intend to use the information for
( ) recommendation to land use decision-making authority
( ) general background information on my region of interest
( ) education/public relations purposes
( ) research
( ) delivery to another person or agency (specify) ______________________
____
( ) Other (specify) ______________________

____
Signature

Figure 6.1.--CARETS user indication of interest

Approximately two months after each workshop CARETS investigators conducted evaluation interviews with representatives of the organizations who had attended the workshops. Questionnaire forms to be used were distributed earlier; agencies had an opportunity to prepare their answers. These interviews in most cases took place in the offices of the user agency.

The evaluation revealed that most of the 65 user agencies interviewed at all governmental levels require at least some of their data in a more detailed form than those provided by the CARETS project. This conclusion is demonstrated in table 6.2, which presents agencies (by major function) reporting an interest in Level I, Level II, and Level III land use information. The Level II data, the most detailed level available for most CARETS products, though reported useful in support of agency functions by a majority of users interviewed and considered of high value by some user agencies, were generally considered of secondary utility by most of these metropolitan area users. Organizations with larger-area responsibilities were able to make use of the Level II land use maps in support of their functions. Such agencies include the Maryland Department of State Planning, the Virginia Division of State Planning and Community Affairs, the New Jersey Department of Natural Resources and Environmental Control, the Baltimore District of the Army Corps of Engineers, and several county, regional and private organizations. Even with these groups the greatest use for such data has been for display purposes or for providing a generalized view of land use, rather than providing the detailed data needs for support of specific land use decisions or for use in planning models.

Table 6.2.--CARETS user agency survey: levels of detail required in land use information

MAJOR AGENCY FUNCTIONS	Number of Agencies: Level I			Level II			Level III		
	Primary Utility	Secondary Utility	Tertiary Utility	Primary Utility	Secondary Utility	Tertiary Utility	Primary Utility	Secondary Utility	Tertiary Utility
Land Use Planning (20)	0	1	4	3	12	0	18	0	0
Transportation Planning (5)	0	0	0	0	2	0	4	0	0
Environmental Protection (5)	0	0	0	1	4	0	4	0	0
Mineral/Energy Survey (3)	0	0	0	0	1	0	3	0	0
Disaster Warning Assessment(2)	0	0	0	0	0	0	2	0	0
Water Resource Planning (2)	1	0	0	0	2	0	2	0	0
Fish & Wildlife Management (2)	0	0	0	0	2	0	2	0	0
Agricultural Management (2)	0	0	0	1	1	0	2	0	0
Socio-Economic Data Collection (1)	0	0	1	0	1	0	7	0	0
Utility Planning (1)	0	0	0	0	1	0	1	0	0
Economic & Community Development (2)	0	0	0	1	1	0	2	0	0
Multi-Purpose Resource Management (2)	1	0	0	0	1	0	1	0	0
Total (47)	2	1	5	6	28	0	43	0	0

*Excludes organizations primarily engaged in research and agencies not having an actual need for such data.

Numbers in parentheses indicate number of agencies participating.

Another aspect of the evaluation concerned the variety of products potentially available from a CARETS-type information system. We presented, for example, aerial photographs, Landsat imagery, various maps and overlays provided by the CARETS project, and other products such as USGS orthophotoquads. We presented this array of products to assist in defining the broader range of users' needs. Responses to this evaluation are summarized in table 6.3, showing the highly positive response to the NASA-flown high-altitude aircraft photographs. Level II land use maps and the USGS 7 1/2-minute orthophotoquads were in a next-most-useful grouping. Few agencies found utility in Level I Landsat-derived land use maps.

Recommendations resulting from the evaluation by users are to establish a flexible and reliable system for providing more detailed raw and processed land resource information as well as the need to improve the methods of making such information available to users. A further recommendation was that USGS or other Federal agencies devote more effort toward technology transfer to State and local governments and toward educating potential users in the use of new data products derived from the advanced remote sensor systems.

Table 6.3.--Products reported useful in support of agency functions

	Number of Agencies Finding Products Useful														
	High-Altitude Photographs	Skylab Photography	ERTS Imagery	Photomosaic	Level II Land Use Map, 1:100,000	1970-72 Land Use Change, 1:100,000	Census Tract & Political Boundary Overlay	Cultural & Locational Features Overlay	Level I Land Use, ERTS-Derived, 1:250,000	Landforms & Surface Material Map	USGS Orthophotoquad	Orthophotoquad Land Use Overlay	ERTS Gridded Image	Computer Plots of Land Use	Computer Data Listings
Washington Area Local Planning Agencies (11)	11	*	1	17	10	10	3	3	1	9	11	*	*	9	9
Regional Planning Agencies (5)	5	0	4	3	4	4	3	3	4	4	2	1	1	1	3
State Agencies (22)	12	7	9	11	14	12	8	6	4	8	11	10	6	10	10
Federal Agencies (21)	17	7	6	7	12	12	5	4	2	7	13	4	1	4	11
Research and University Community (6)	5	3	3	2	2	3	1	1	0	2	2	2	0	1	2
Total	50	17	22	23	32	31	17	14	10	21	28	17	8	16	27

* Products not evaluated by local planners.

Numbers in parentheses indicates number of agencies participating.

CHAPTER 7

CARETS-TYPE SYSTEM APPLIED TO REGIONAL ANALYSIS

This chapter is primarily a look into the future at the kinds of benefits that might be expected to accrue from application of CARETS project results, in particular from establishment of an operational CARETS-type system to satisfy certain needs for improved regional environmental information. If the CARETS project could come back to life briefly after 10 years to assess its impact, we would hope that this section of the report could be called "How we Helped to Improve the Environment in the Central Atlantic Region." At present we have the more modest achievement of delivering packages of land use and related data to a variety of users.

The idealized system of the future, built out of experience gained from CARETS and other similar demonstration efforts, is diagrammed in figure 7.1. The process depicted in figure 7.1 is based upon the blending of data from remotely sensed sources, including land use information derived therefrom, with a whole sequence of other stages and activities necessary to bring about the desired beneficial environmental results. A companion stage, the use of data from conventional sources, joins the remotely sensed data in leading to the preparation of an objective "regional description." Also leading to the "regional description" activity is a flow of stimuli deriving from the existence of certain environmental problems requiring mitigation, and the construction of models for proceeding toward mitigation, the problems themselves being verifiable by suitable supporting documentation.

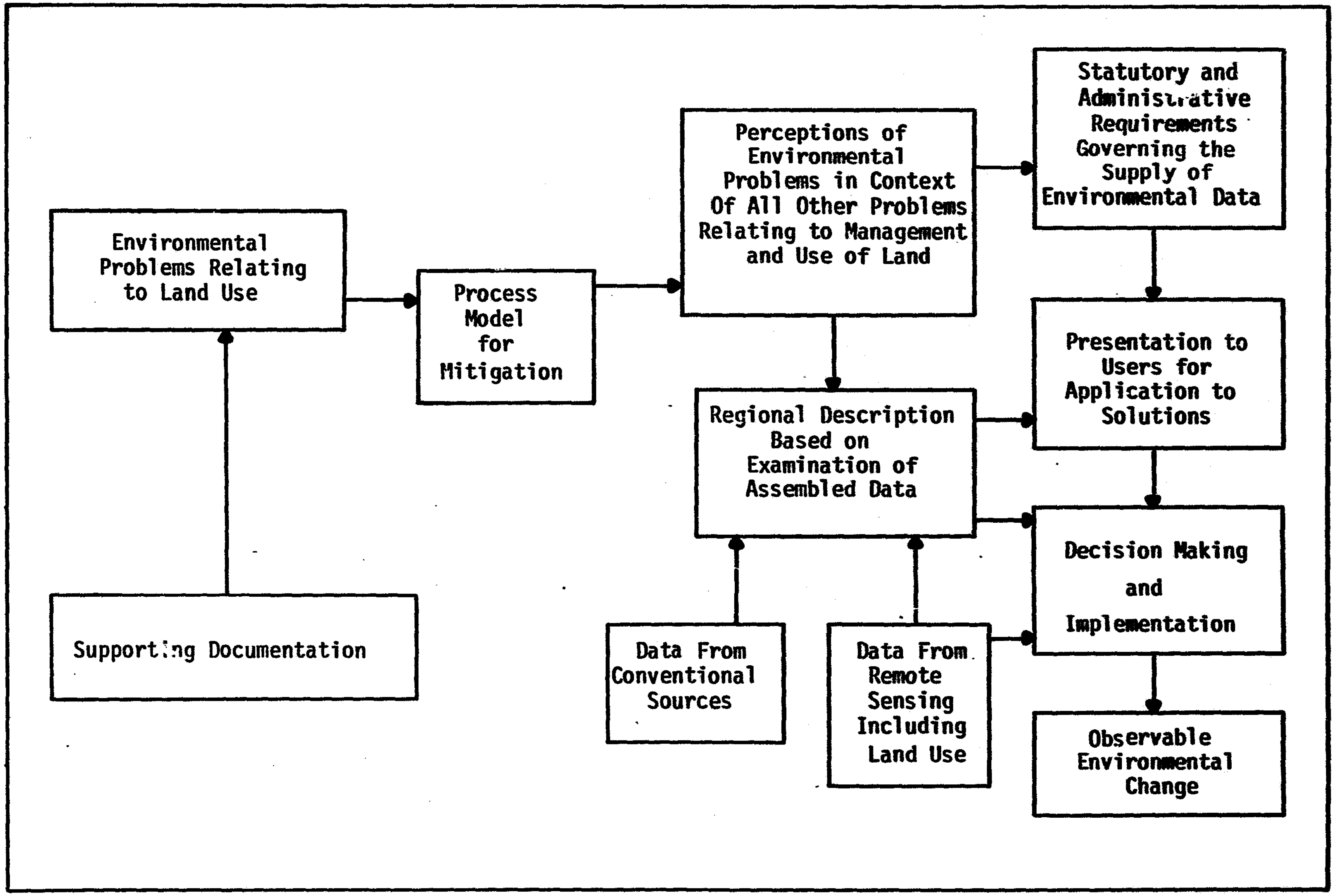


Figure 7.1.--Idealized information flow for environmental problem solving

We hope that the use of the model will enable the individuals who are concerned with these environmental problems to perceive them in the context of the other problems and situations that are impacted. These perceptions can then feed into a process which takes account of the statutory and administrative requirements, for example, Federal and State laws which govern the supply of environmental data or which require certain kinds of data to be used in a process such as the development of an environmental impact statement. The statutory requirements input then joins the regional description input in the flow of information to the users, in this case the agencies who are putting the whole package together for presentation to the decisionmakers and for implementation by the appropriate agency with responsibility for environmental management. After a while the process should lead to some observable environmental change as indicated by the lower right-hand box of figure 7.1, and the system would have run its course from the existence and definition of the problems to the solution or mitigation in the form of system change.

In the remainder of this chapter the concepts just described will be made more specific by citing some of the major issues in environmental management in the central Atlantic region, existing approaches to their solution including sources of information, additional information available from the CARETS project, the proposed approach based on an operational CARETS-type environmental information system, and finally, examples of how it should all fit together to help the people living in the region make a more appropriate adjustment to the environmental realities which combine with the developmental activities to produce the problems in the first place.

STAGES IN THE REGIONAL ANALYSIS PROCESS

We imply that methods for mitigating regional environmental problems go through stages as increased awareness and new technology for problem-solving are brought in.

Major Issues in Environmental Management

An early stage is characterization of the region with respect to major issues in environmental management. In order to place the applications of the CARETS information system in its proper context it will be necessary to obtain an assessment of the highest priority environmental problems as perceived by the people living in the region. Typically these problems will be made known to the political leaders or to the managers of institutions responsible for environmental decisionmaking. Examples of such environmental problems that are important in the central Atlantic region are the following:

(1) Increase in population and urbanization

(2) Fragility of coastal and estuarine environments

(3) Susceptibility to flooding and erosion

(4) Declining quality of air and water resources

(5) Increasing energy costs

(6) Preservation of open space and balance among competing demands for land

(7) Impact of transportation systems

These and other major issues in environmental management will become the basis for demands for information to solve the problems.

Existing Approaches and Sources of Information

In most cases the present system for dealing with problems such as those listed above is to refer them to one or more agencies already set up to deal with portions of the total environmental complex, but almost never to deal with all the significant interrelations among environmental phenomena and processes. The agency to which the problem is referred will draw upon whatever sources of information are available. Generally this information may be divided into two large classes: biophysical data and socioeconomic data.

Examples of biophysical data are:

- Topographic maps
- Geologic maps
- Soils maps
- Hydrological records
- Agricultural statistics
- Forest and vegetation statistics
- Water quality monitoring records
- Air quality monitoring records
- Fish and wildlife surveys
- Mineral and energy resource estimates
- Mineral and energy production statistics
- Electricity generating capacity and statistics
- Weather and climate data
- Materials input and output from industrial and agricultural processes
- Land use statistics

Examples of socioeconomic data are:

- Census of population
- Employment statistics
- Education statistics
- Income statistics
- Manufacturing statistics
- Housing statistics
- Commerce and trade statistics
- Transportation statistics
- Financial transaction records
- Land valuation and transaction records
- Public health and safety information
- Economic indicators
- Governmental expenditure budgets

For the most part these kinds of information are being collected by a large number of agencies for a variety of different purposes. The system of data collection by traditional agencies lacks a grand design. With the present diverse sources of information, one of the most difficult tasks facing the analyst is to assemble the data in spatially and temporally coherent formats, or in complementary packages suitable for application to a given region or subregion, or for synthesis in any given geographic area.

Additional Information Available From CARETS

It has been the purpose of the CARETS project to develop a regional land use information system incorporating, where necessary, appropriate data sets from the types listed above, but adding remotely sensed measurements on land use as a new data set calibrated in terms of its most probable impact on the environment. The CARETS project was designed to integrate new information with information from traditional sources in a spatial and temporal framework. The new information would thus be more amenable to appropriate synthesis and quantitative analysis, as would be necessary to meet the requirements of existing environmental legislation, and in support of better environmental decisions. Although the CARETS project cannot be described as an operational information system, it functioned with many of the characteristics of an operational system. A variety of data products were made available to typical users and decisionmakers within the region. These products are discussed in detail in chapter 4 and are summarized in the following list:

(1) **Remote sensing data archives, including high-altitude aircraft photographs and Landsat imagery**

(2) **A photomosaic at a scale of 1:100,000 which serves as a uniform mapping base for geographic referencing for the entire region**

(3) Land use maps at a scale of 1:100,000, Level II classification detail, both in graphic and digital form

(4) Land use change at 1:100,000 for the 2-year period 1970-72

(5) Land use maps at 1:250,000 scale, Level I classification detail, derived from Landsat, stored in maps and digital tape format

(6) Capability to retrieve land use data by census district and drainage areas

(7) Interpretation and area measurements of the land use data sets

Proposed Approach Based on CARETS-Type System

The operational system that is recommended here based upon the experience gained in the CARETS investigation would use a systematic approach to the gathering and utilization of land resource data to aid in the attack on the above listed environmental issues. A series of steps roughly in the order listed in the following section would be employed for problem-solving, incorporating data from a follow-on CARETS-type information system.

(1) Coordinate environmental and land use analysis activities within the region. Under this step all appropriate agencies would be contacted and informed of the proposed problem-solving effort, perhaps by some identified lead agency. Information exchange would take place between agencies with logical jurisdictions within the appropriate agency functions.

(2) Provide for a systematic flow of information to the appropriate user agencies to assist in environmental problem-solving (fig. 7.1).

(3) Select the appropriate process models to guide the problem-solving effort.

(4) Perceive, describe and analyze significant environmental issues or problems in the context of all other problems relating to management and use of land and water resources. This step is necessary so that priorities can be established and agreed upon for the order in which the solutions to the various problems will be addressed.

(5) Respond to statutory and administrative requirements governing the supply of environmental data. This section refers to the laws currently on record which dictate requirements for information on land and water, or air resources.

(6) Carry out regional descriptions and forecasts based upon a combination of data from conventional sources and remotely sensed land use data.

(7) Present results to appropriate user agency.

(8) Monitor decisionmaking, implementation, and resulting environmental adjustments.

(9) Facilitate feedback to data sources so that future data products can be improved.

APPLICATION EXAMPLE: POPULATION INCREASE AND URBAN GROWTH

In this section an issue in environmental management is discussed in a suggested scenario for problem-solving by making use of a CARETS-type information system. This particular environmental problem is fundamental to many of the others. Growing populations are often looked upon as a boon to the economy. Their problem-causing potential may therefore be overlooked at first. However, they produce the demands for housing, transportation, jobs, recreation, etc., which translate into increased requirements for land, increased pressure on the quantity and quality of the other resources available and increased opportunities for conflicts with already existing components of the regional population.

At the level of the individual or household the problem of increasing population and urbanization is expressed many times over throughout the country by a familiar set of circumstances. A household unit or family who is part of the increase in population has perhaps already been assured of employment in the region and is now seeking a place to live. The familiar screening of want-ads, real estate listings, and other sources of information on the location of suitable housing takes place. Most of this family's dealings are with respresentatives of the private sector of the economy, sellers or renters, and the family simply seeks to maximize its total satisfaction with the type of housing, location with respect to job, schools, shopping, recreation, and other amenities that they may desire. If the particular family is looking in the inner-city and seeking housing already available from the existing stock, their particular action does not have any direct consequence for a change in land use as regards the location of the residence itself. However, if they are choosing a house in a new subdivision, their actions directly contribute to the change from a former land use (usually agricultural or forest land) to a residential land use with all of the attendant environmental consequences.

Behind the scenes, and not always known or visible to the family seeking its new location, are a large number of organizations that have to make plans for this family plus all of the other families contributing to the increase in population and urbanization in the region. Generally a land developer has assessed the population growth potential for the region and translated it into plans for building a subdivision, bringing him into contact with local officials for the required permits for building, zoning changes, etc. The agency which must act on such requests from developers may or may not have much concern about environmental consequences of its decisions. At some stage in the development of local governments which have to deal with growth, a planning function will come into existence to try to fit the growth into a coherent structure for the region under their jurisdiction. In a large metropolitan area with a good tax base, such as Fairfax County, Virginia, one of the counties belonging to the Metropolitan Washington Council of Governments, the governmental body in charge of making the development decisions is likely to have a staff of professionals to obtain the necessary information. Often these groups are sophisticated and have the ability to deal with rather advanced computer modeling and regional planning techniques.

One task common to all such analyses is to assemble the required socioeconomic and environmental data sets to support the plans. To obtain help in this often large task, planners have learned to rely upon a variety of sources at the State and Federal governmental levels, for example, topographic maps and census data. Only in very special circumstances do local jurisdictions undertake direct base mapping or population counting activities on their own.

Although planners have no legal responsibility outside of their own jurisdiction, the advantages of forming associations with other nearby jurisdictions have nevertheless become apparent in recent years. One such advantage is that cooperation permits compliance with Federal laws which require coordination by a single designated agency of all programs receiving Federal funds under programs such as the Housing and Urban Development "701" programs, the Environmental Protection Agency "208" programs, Department of Transportation Highway Planning programs, and others (see chapter 9 of this report).

In the case of Fairfax County the planners would turn to their associates in the Metropolitan Washington Council of Governments. The MWCOG has no direct governmental authority over its region, but it exerts a certain influence through its coordination responsibilities. One of the responsibilities is to examine data needs common to all member jurisdictions. Looking over the aggregated effects of all the families, such as the one described above, who are seeking housing within the region, the MWCOG has become involved in projections and forecasting of future populations. Projecting population is vital to the planning process because the responsible governmental bodies must anticipate population changes well in advance so that the necessary services (schools, roads, sewers, etc.) can be ready when needed.

Existing methods of forecasting population and land use apply complex models based on projected demand for jobs, housing, and institutional activities with inputs to the models comprising social, demographic, and environmental data sets. An example of a model that has been in use in the MWCOG area is the "EMPIRIC" activity allocation model (Peat, Marwick, Mitchell, and Co., 1972). This model, one of a family of regional planning models, is designed to perform three major functions: (1) to allocate regionwide projections of future population, employment, and land use growth among a set of smaller subregions or districts; (2) to estimate the probable impact of alternative planning policy decisions on the future distribution of regional growth; and (3) to provide an analytical foundation for the evaluation and coordination of planning-policy decisions in a vareity of different functional areas. To accomplish these functions the model is broken down into four major components. The first component is a set of simultaneous equations which develops population and employment projections. The outputs of these equations are typically expressed as estimates of future numbers of households within each subregion broken down by income level and type, together with equivalent estimates of future employment by place of work broken down by industry type or land use classification.

The second component is a "land consumption" module which receives the population and employment projections from the first component and translates them into equivalent changes in land use for each subregion. A third component, operating in parallel with the land consumption module, breaks down the population and employment projections into more detailed categories so that they can be assigned to different segments in the regional economy. These three components are calibrated in parallel using subregional activity and land use data collected for two different times, usually approximately 10 years apart, together with parallel data on the planning policies implemented during the same time period (Peat, Marwick, Mitchell, and Co., 1972, p. 8-9). Policy inputs may be incorporated within the calibration process such as regional transportation and utility system improvements, zoning, environmental and conservation standards, and regional housing and employment location policies.

After calibration these three components are linked together with a fourth "forecast-monitoring" module into a single forecasting chain designed to yield recursive estimates of the future subregional distribution of activity and land use for points 10, 20, 30, etc. years into the future. Each forecast is designed to be conditional both upon a presumed "regional total" of population and employment for the region as a whole, and upon the pursuit of a particular mix of future regional planning policies over the forecast interval.

Data on land use and its environmental consequences have relevance to the activity allocation model involving both model input and model output. An example of this is contained in the following quote from Peat, Marwick, Mitchell, and Co., 1972, p. 25, concerning the structure of the land consumption module:

> "The estimated changes in district-level population and employment generated as output from the simultaneous-equation module are translated into equivalent changes in land use characteristics by means of a simple 'land-consumption' module. This is essentially an accounting mechanism for keeping track of changes in land use acreages by type within each district as the region grows. It accepts as input the projected changes in activity generated by the simultaneous-equation module, together with data on the existing distribution of land uses, and the availability of vacant land within each district and the projected densities at which different forms of development may occur. It generates as output a revised accounting of land use acreages by type within each district, based upon the amount of land either consumed by new activities or released from development by declining activities over the growth period."

Both for the initial description of the region (inventory) at the time when the operation of the model is to be started, and for the monitoring of changes that take place during the operation of the model, inputs of land use information from some type of measurement are required. The existing system using the EMPIRIC allocation model in the MWCOG area involves the input of land use data from a cumbersome land parcel file containing 700,000 parcels which itself has been very expensive to maintain at an acceptable level of accuracy (MWCOG, 1976). A regional environmental information system, serving collectively the information needs of users such as the MWCOG and its member governments, could provide a major part of the necessary land use information input into this or other planning allocation models. Such inputs would not necessarily be exactly in the same form as the CARETS Level II land use maps. Correct use in the allocation models would require close coordination between the users, in this case the MWCOG, and the producers of the information, in this case the operational regional information system which is hypothesized as following on the CARETS experimental effort.

The modeling and forecasting process is a complex and expensive one. Much of the cost is borne by grants to the regional agencies for development, calibration, testing and application of such models as the EMPIRIC model discussed here. Other models are also available and may be used in conjunction with, or instead of, the EMPIRIC activity allocation model. The ability to add environmental factors such as expected water and air quality changes resulting from land use changes would be particularly important. This description is meant to be an example of the kind of problem where an existing method could be supplemented by the proposed new environmental information system. Other examples that could be presented for each of the other categories of problems mentioned on page 230 are left to the readers to pursue according to their own interests, or are left as suggestions for further research and demonstration of the useful applications of the techniques described herein.

CHAPTER 8

CARETS PROJECT CRITIQUE

This chapter presents critical assessments of the CARETS project, both by reviewers and by the principal investigator. This critique is presented in the hopes that benefits from both the project's successes and its failures may assist in the design or implementation of similar projects elsewhere.

EVALUATION BY EXTERNAL REVIEW PANEL

A public evaluation of the CARETS project was conducted at the annual meeting of the Association of American Geographers in Milwaukee, April 21, 1975. The purposes of the evaluation were to provide USGS with advice covering the following points: (1) integrity of the project design, (2) a critique of what we actually accomplished, (3) advice on publication and/or dissemination of the results, and (4) guidance for follow-on research or operational applications.

The evaluation was by a panel of reviewers under the chairmanship of Duane F. Marble, State University of New York at Buffalo. The evaluators were chosen because of their expertise in land use information systems, remote sensing, and the involvement of users in information programs aimed at improving land use planning and management applications. Also, at the same evaluation the land use climatology part of the CARETS project (funded by the Skylab program) was evaluated. Other members serving on the CARETS/Landsat evaluation panel were Hugh Calkins of the University of Washington and John E. Estes of the University of California at

Santa Barbara. Evaluators for the climatology portion of the project were John N. Rayner and John Arnfield, Ohio State University.

One month prior to the Milwaukee evaluation the panel met at the CARETS office, USGS headquarters. There they were given a detailed presentation of the status of the CARETS project and were shown copies of all of the data products which had been prepared up to that date. Draft copies of portions of the final report were also made available. At this preliminary meeting one representative of a user agency, Arthur Collins of the Southeastern Virginia Planning District Commission, also attended to share with the panel his involvement with the CARETS project and the reactions of his agency to the potential of the new remote sensing data and the proposed land use information derived therefrom.

The evaluation panel members were presented with selected copies of reports to study further during the month prior to the Milwaukee meeting. At that meeting a presentation of the technical results was given by CARETS staff members to an audience of about 100. Following the technical presentation by CARETS staff, the evaluation panel responded both to the material as presented in the oral session and to the material that they had reviewed during the preceding month.

The evaluators felt that the overall design connecting land use with environmental impact, in an information systems framework, was a valid one. They felt that the project was aimed at a recognized need for land and environmental information. The project was probably too large, however, for the level of effort available.

The evaluators felt that the products produced were useful and needed. However, the application of available technology was uneven. For example, a tremendous amount of money had already been spent on gathering the remote sensing data, e.g., expenses for satellites, aircraft, cameras, etc. In the CARETS project, however, very little money was spent on technology to assist in the photo and image interpretation process. CARETS interpreters in general were using already available techniques. On the other hand, the CARETS investigators got into very large data processing problems in the digitizing and data manipulation part of the information systems task. They were perhaps pushing for the availability of that technology beyond the point where it was ready to respond. Involvement with users was an ambitious part of the project. There seemed to be some danger of leaving the user groups tantalized but stranded after the completion of the CARETS project if USGS or some other agency was not ready to continue the functions that were performed by the CARETS project. There was not enough time available to see the project through to the adoption of the new technology by users. A minimum period of 10 to 15 years is generally given for the introduction and adoption of a new technology such as this.

The panel recommended that more automation be used in the interpretation process, and better equipment be obtained to support interpreters who are deriving land use information from remotely sensed data. The computer techniques for handling Landsat data are in the developmental stage and should be evaluated by future projects of this nature. More attention might be paid to geographic theory, for example, in attempting to understand and measure the process of land use change. If the project had paid attention to a possible role for geographical theory, different data collection procedures might have been found to be more appropriate. Also, it was thought that in the future it would be useful to separate most research and development functions from prototype production functions of a mapping nature. Both were combined in the CARETS project and the resulting complexity made scheduling and management chores very difficult and contributed to bureaucratic delays in completing some of the component parts. More attention should be paid to the question of the accuracy in land use data. The linkages between data producers and data users should be strengthened in determining the accuracy question. The CARETS project took a conservative approach on the issue of accuracy, i.e., the project attempted to obtain high accuracy on the assumption that information could later be discarded if not needed. A compromise at the data input stage might have resulted in less problems with handling the tremendous amounts of information that were required given the initial accuracy requirements as stated in the information system specifications.

EVALUATION BY PRINCIPAL INVESTIGATOR

At this point in the report I give my own evaluation of what we did and what we failed to do. I will do this first by simply using a checklist of original objectives followed by brief comments concerning status of that objective at the end of the project (table 8.1). Following that listing I will make some general summary comments.

In summary, some of the desired objectives were accomplished and others were not. Much more effort had to go into the preparation of input to the information system in relation to the effort required to deal with the output of the system than was envisioned at the beginning of the project. This meant that the data analysis activities were slighted at the expense of the data input and data processing activities. While this is unfortunate for the results of the CARETS project package, CARETS did leave a legacy of environmental information for the central Atlantic

Table 8.1.--Checklist of original objectives and status at end of project

Original Objectives	Status at End of Project
1. Test hypothesis that Landsat can become an operational input to the regional environmental information system in the CARETS test area.	Landsat data and manually-interpreted land use maps drawn therefrom became part of the experimental information system, but fell far short of meeting the needs of the present region's users. We were able to demonstrate some improvement in stream flow estimates, but not as much improvement as was obtained from the use of aircraft data.
2. Compare aircraft- and Landsat-derived data to ascertain validity of Landsat interpretation and to provide measures of accuracy of Landsat-derived land use data.	Satisfactorily achieved, with measures of accuracy of Landsat-derived land use data according to the different Level I categories.
3. Establish a land use data base in graphic (map) form for the central Atlantic region, and monitor land use change.	Successfully completed with aircraft data at 1:100,000 scale and Landsat data at 1:250,000 scale. Change monitoring for entire region produced with aircraft data at 1:100,000 scale. Sample studies of other change monitoring capabilities with both aircraft and Landsat data were demonstrated but not put into operation.
4. Establish a regional environmental data base in digital, machine-readable format, with both numerical and graphic output capability.	Partially successful; digitization and machine processing of entire region complete for Landsat data; partial coverage of region with digitized land use data from aircraft sources and correlative overlay maps; numerical and graphic output capability demonstrated.
5. Study environmental processes as they affect land use choices and as they affect the environmental impact of land use changes.	Successfully demonstrated in air quality, stream flow characteristics, coastal barrier beach stabilization and surface energy exchange (the latter with funding from Skylab experiment).

Table 8.1.--Continued

Original Objectives	Status at End of Project
6. Employ an integrated ecological approach, including environmental process studies and modeling of alternative futures for the central Atlantic region.	Not accomplished.
7. Establish an experimental land use and environmental information service for users.	Successfully demonstrated through the CARETS regional information center, and through other information services provided as a result of earlier user contacts.
8. Cooperate with user agencies in supplying needed data and in seeking evaluation of experimental data products.	Successfully carried out through conferences, workshops, regional information center, and detailed user evaluation study. More study needed on how data get from "user agency" to "decision-maker."
9. Reach the regional land use decision-makers with accurate and timely land use information derived from the remote sensor sources and incorporated with appropriate information from other sources.	Objective largely unrealized; we reached agency representatives or technical staff personnel, but few decision-makers were reached with the CARETS data and no new land use decisions were known to result from the application of CARETS data.
10. Improve environmental quality and mitigate environmental problems through the improved decisions that result from availability of timely remote sensing data.	No evidence of any environmental improvement resulting from application of our data.

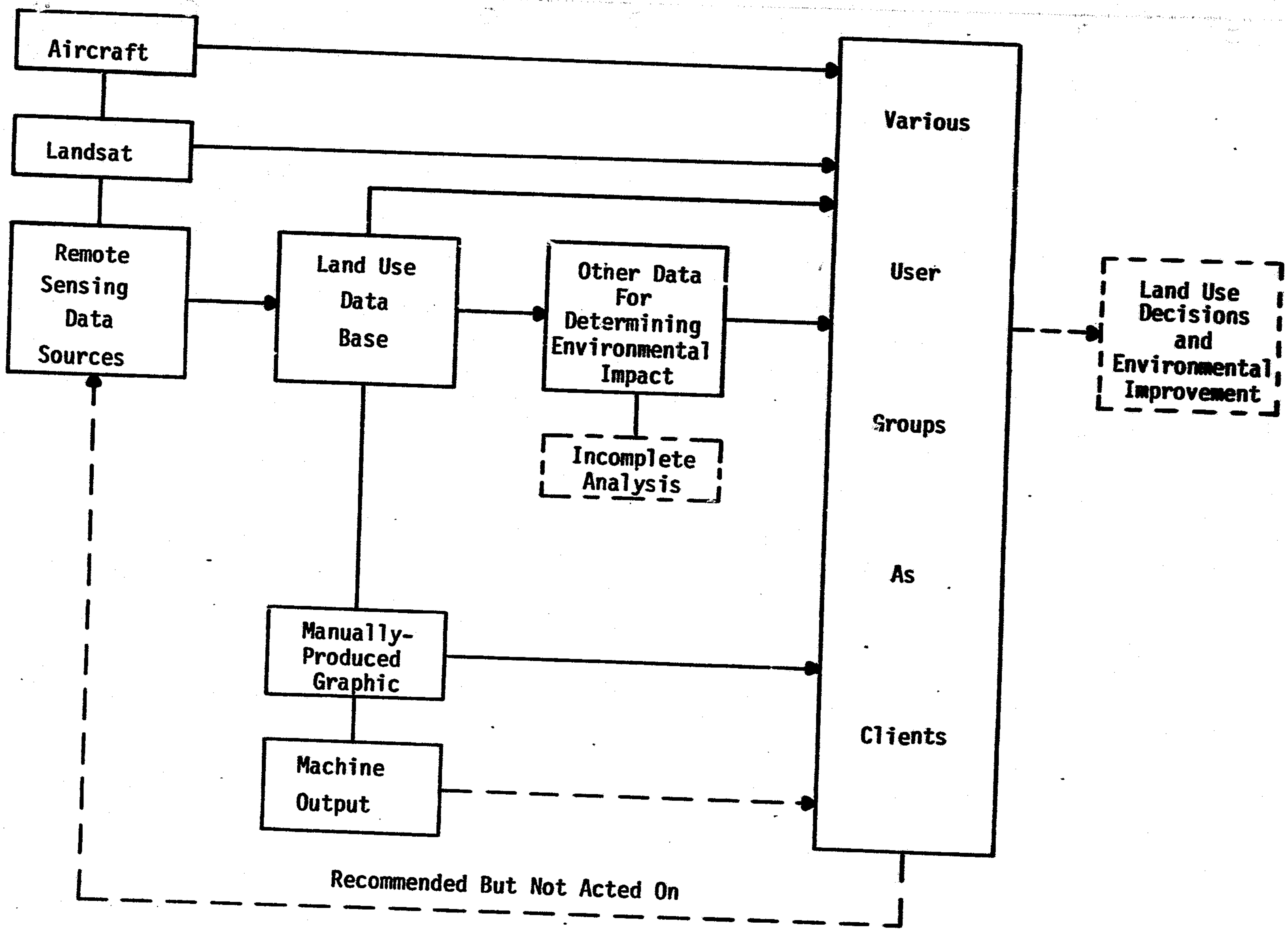
Table 8.1.--Continued

Original Objectives	Status at End of Project
11. Build the CARETS experimental information system as a prototype of a new USGS operational program.	The USGS-LUDA (Land Use Data and Analysis) program was funded for nationwide land use mapping at a scale of 1:250,000, with some maps being produced at a scale of 1:100,000. CARETS project personnel participated in reorganization of USGS Geography Program during period of operation of CARETS project. Many of the procedures developed in CARETS for land use mapping and geographic information systems were incorporated into the LUDA program. Also, USGS reorganization creating the Office of Land Information and Analysis took place during the same time period, with some input from the results of the CARETS investigation. Other aspects of the CARETS model, for example, the incorporation of the regional environmental systems outlook, were not adopted in an operational system. The "prototype" objective, therefore, was only partially realized.
12. Incorporate the CARETS system into a regional operational remote sensing-based information system, with appropriate linkages among agencies at Federal, State, and local levels of government.	Recommendation made, but not carried out.

region which can serve future investigators who are interested in carrying the analytical work further than we were able to do. The results discussed above, and tabulated in table 8.1, are further summarized in a revision of the CARETS concept diagram originally presented in figure 2.2. The revised diagram, with dashed lines shown where project objectives were not accomplished, is contained in figure 8.1.

As noted by the advisory panel, the project was too large in scope for the available program resources. Management was complicated by the operation of the project alongside of a changing situation in the USGS where new program foci were channeling resources elsewhere that had formerly been assigned to CARETS. In a way these developments were a vindication of a part of the CARETS project model even though the substantive results of the reorganization efforts appear elsewhere. The project did indeed take a more conservative approach to land use mapping than might have been possible; the conservative approach taken did assure deliverability of final products. It might be useful to experiment with a larger component of risk in a project of this nature, to permit exploration of promising new avenues of image interpretation and computer map data handling.

A great deal of effort went into the quasi-operational aspects of the program dealing with the preparation and handling of the land use maps and other maps. There is something inexorable about a mapping production operation that tends to swamp other activities. Perhaps this inexorability derives from the very large amount of drafting detail that goes into the preparation of even a single map sheet, the complexity of the many steps in the process of map production, and the necessity for



-----not accomplished

Figure 8.1.--CARETS information system diagram showing those portions not accomplished (based on figure 2.2)

considerable advance planning and scheduling to produce large numbers of maps. In any event, it was much more difficult to allow for feedback of user response than we had originally hoped.

The information systems framework theoretically would have allowed for quicker access by the users to the data bank. However, delays in developing and applying the digitizing and data-handling technology precluded much interaction of that nature. In the future a manager of a regional or national information system based on land use data and involving computerized operations is cautioned to be quite sure of the availability of sufficient data-handling technology before committing program resources which require products at the end of a year as proof of the wisdom of the expenditure of the funds. An information system of the CARETS type needs probably 5 years of development; it would facilitate the process of information system development if the sponsor could wait for results and not require intermediate presentations or intermediate operational demonstrations of the use of the data. However, no known sponsor in the experience of the CARETS investigator can wait that long to justify continuation of a program without the presentation of intermediate product results. The CARETS project was thus caught in a dilemma of having to prepare and deliver intermediate products to users before the capability to produce those products according to the original design was fully developed. We were always behind the level of the technology that we had expected to have ready to apply at any given stage of the project. Just at the end of the project, as we had opportunities to experiment with the digitized data from the Canada Geographic Information System, we were beginning to understand the use of the technology that we needed much earlier in the project's schedule.

CHAPTER 9

CONCLUSIONS AND RECOMMENDATIONS

The CARETS project has examined a range of remote sensor systems and produced a range of land use map types that can be derived from the sensor data. This examination has been conducted in the context of information needs of agencies having responsibility for environmental management and planning in the coastal metropolitan region of the mid-Atlantic seaboard. An archival collection of remotely sensed imagery, maps, data summaries, and technical reports has been assembled, constituting the raw material for a resource and environmental profile of this heavily populated region. This archive can serve as a data base for future research and for monitoring environmentally critical land use change over the next two decades.

CARETS functioned as an experimental information system that was able to provide linkages among several dozens of local, regional, State, and Federal agencies having certain environmental responsibilities and data needs in common. CARETS sponsors (NASA and USGS) were interested in ascertaining data needs that could be fulfilled by Landsat and by land use maps. We were able to identify some of those data needs, but in doing so we uncovered a more fundamental need relating to the supply of data to solve environmental problems.

This more fundamental need is for increased coordination and communication among all agents involved in the flow of land use and environmental information--information producers, information brokers, information consumers, and those who must make decisions based upon someone's analysis and recommendation drawn from such environmental information. Information producers at the Federal level have capabilities to produce needed information, but in many cases the information does not reach those who need it. On the other hand, local and regional planners and managers have information requirements which do not get translated into appropriate data-gathering activities by the information producing agencies. Meanwhile, much duplicative data-gathering and land use mapping is done by separate projects doing "208" water quality studies, "701" comprehensive planning maps, environmental impact statements, transportation planning studies, and coastal zone management, all funded with Federal dollars.

These conclusions lead to a set of recommendations, based on our experience in the central Atlantic experiment, but deemed applicable nationwide, particularly in the major metropolitan regions. The recommendations are in two parts. One part calls for immediate actions to address urgent needs of public agencies for current land use and related environmental impact information. The other part calls for long-range coordinated research and development aimed at adapting the expanding capabilities of remote sensor systems to evolving societal needs for environmental information.

The recommendation calling for immediate actions consists of three interrelated components: (1) the creation of an operational Federal-level remote sensing program; (2) the establishment of regional information centers for remote sensing, land use, and environmental data; and (3) implementation of data use at decisionmaking levels. Since each of these actions would be drawn from existing agency programs, leaving present organizational structures and personnel rosters intact, they could be accomplished without additional expenditures of public funds. Implementation of these actions would in fact be expected to result very quickly in cost reductions compared to present practices.

Federal-level research programs producing data from high-altitude aircraft and Landsat could be transformed into an operational program with immediate emphasis on providing high-altitude aircraft photography in accordance with a flying schedule based on priority needs for the data. An adjunct research program could work toward improving uses of Landsat through digital image processing, to the stage where Landsat and Landsat follow-on satellites, too, could become part of the operational system. Regional information centers somewhat like the one that was part of the CARETS experiment would coordinate data collection and use, identify the region's data priorities, and recommend the most efficient mix of local, State, and Federal-level data gathering and mapping activities. Finally, efforts could be directed at improving implementation of land use and environmental data programs at the decisionmaking level. These efforts would involve modest beginnings at present, but would merge with the efforts of the longer-range actions (see below) in working toward improved use of scientific (i.e., environmental) information in decisions affecting land use change and environmental quality.

The recommendation calling for longer-range research and development would address society's environmental information needs for adaptation and survival in the decades ahead. The CARETS experience suggests two main thrusts to such an effort: the one just mentioned above, concerning improved use of scientific and technical information, including remotely sensed data, in the decisionmaking process, and a thrust toward better understanding of relatively large-sized environmental process systems encompassing phenomena that lead to land use change. This latter thrust derives from the effort attempted but not fully implemented in the ecological or integrative "systems" approach of the CARETS project. In contrast to the first set of recommendations, these longer-range ones probably could not be implemented without additional expenditures of funds, but such expenditures are already programmed through the National Science Foundation and other public and private organizations supporting environmental research. Once part of operational planning and management programs, however, these research expenditures would be expected to "pay off" through more responsive and more responsible environmental management.

The remaining sections of this chapter present (a) major CARETS project conclusions in the context of both capabilities of the sensor systems and requirements of users, and (b) detailed discussion backing up the immediate and long-range recommendations.

PRESENT LAND USE AND LAND COVER DATA NEEDS PLACED IN CONTEXT

"Raw" and "Processed" Data

Two kinds of data are considered: (1) "raw" remotely sensed data in the form of photographs, images, or computer tapes, and (2) land use maps and other "processed" graphics and data sets derived from the remotely sensed data. Typically, a processed unit of such data consists of a classification of a block or parcel of the terrain surface, or a numerical designation representing a measure or count of some phenomenon, as determined from the remotely sensed data. Examples of such derived data are: residential land, single family; residential land, mobile homes; number of single-family dwelling units; land in open space or undeveloped; recently cleared or disturbed land; forest land; percent of land covered with impervious, manmade surfaces; and wetlands.

Characteristics of the Data Users

Typically, the user of such data is an institution already established with some responsibility for planning, managing, or zoning present or future uses of the land and water resources--local planning departments, agencies responsible for coordinating and drawing up regionwide land use plans (such as regional councils of government), State planning departments, State resource mangement or environmental departments, and numerous Federal agencies having roles ranging from direct planning and management on Federally-owned lands, to administration of programs through which funds are transferred to State or local agencies for implementation of various data gathering or planning functions. These user agencies vary greatly in budgets, skilled staff, data processing equipment, and sophistication in obtaining, handling, and making use of land use and related environmental data. However, the user institution typically has some kind of information system for dealing with data of the type described; some of these information systems are highly advanced, making use of modern spatial data handling equipment and procedures, including large digital computers linked to forecasting and other modeling capabilities.

Range of Types of Information Needed

In some cases the land use map or other form of graphic display, such as a color-coded printout from Landsat digital tapes, is treated by the user as a "final" product; for example, an attractive land use map which is displayed in the office of the county executive, or one used as a visual aid in making presentations to councils or other legislative bodies. Such uses can be very important in conveying significant land use distributional patterns, thus helping decisionmakers to see the "big picture" necessary for making wise decisions.

In most cases, however, the map or graphic display or derived measurement is not treated by the user as a final product. Instead, the remotely sensed data unit is used by scientific and technical staff as a measure or indicator of population, traffic generation, water quality, air quality, urban microclimate, soil condition, amount of infiltration and runoff that will result from a given rainfall, etc. A considerable interest has been aroused by the potential of such use of remotely sensed data as surrogates for other socioeconomic and environmental measures; this interest stems from a desire for knowledge of how the various environmental processes act to produce distinctive patterns of land use and land cover, as observed by the remote sensors; and it also stems from the conviction that in many cases remotely sensed data can be obtained far cheaper than surrogate data sets obtained by ground survey, or other costly methods of gathering data needed for planning and management decisions.

This variety of types of information needed has implications for the way or ways in which the remotely sensed data are to be classified for either map presentation or presentations of other forms of data aggregations or summaries. For comparisons of two or more maps, as for example when determining the extent of change between images obtained at two different dates, obviously the classification systems must be consistent with each other. On the other hand, when studying the relation of impervious surfaces to stream runoff, or the relation of land cover type to surface thermal properties, it is best to seek a variety of means of classifying the remotely sensed data, to best achieve the desired results. Research is needed to establish empirical relationships, which will enable "calibration" of remotely sensed data in terms of surrogate environmental or socioeconomic measures. Furthermore, classification derived primarily for use with manual interpretation of photo or image data is not necessarily best for use with data in pixel (digital) form, and so a variety of classification systems may be needed to satisfy a diversity of needs.

Range of Scales and Resolutions

In addition to the wide variety in the types of information needed, users have a wide range of scales and resolution requirements. These range from extremes with those needed to count people and vehicles on the one hand to those needed to observe gross regional distributions of land and water on the other. Between the extremes lie the arrays of data needs for information on landownership parcels, groupings of parcels with the same use category, generalized land use by cells of 1 acre, 1 ha, 1 km^2, 1 mi^2, one county, etc. A useful display of ranges of data uses as related to coarseness or fineness of the resolution of the required information is contained in table 9.1, prepared by Kenneth Dueker of the University of Iowa. Dueker assumes that the user has a computerized geographic information system capability, or is at least contemplating such a system. The array of applications is listed in table 9.1. They range from policy planning to land capability and regulation, each having somewhat different requirements in terms of coarseness or fineness of

Table 9.1.--Level of data aggregation, system requirements and modeling capabilities as a function of data use/application, and geocoding options

Data Use/ Application	Geocoding Options: External Index — Place Name	External Index — Place Code	Coordinate Index — Area Centroid Coordinate	Coarse — Grid	Coarse — Polygon	Coarse — Network	Fine — Grid	Fine — Polygon	Fine — Network
Policy Planning	S1,A0,M1	S1,A1,M2							
Program Planning			S1,A2,M3						
Land Inventory				A2,A4, A5,M4	S2,A7,M4				
Impact Assessment						S2,A7,M4 M5,M6			
Land Capability							S3,A7,M4		
Regulation								S3,A7,A8, M4,M6	

Key:

System Requirements

- S1 General purpose computer
  Card and tape files
  General data management software
  No specialized peripheral equipment
- S2 General purpose computer
  Digitizer, plotter
  Specialized software for data capture
- S3 Dedicated computer with digitizer, CRT, plotter
  Specialized software for data capture

Level of Aggregation

- A0 State
- A1 County
- A2 Minor Civil Division/Tract
- A3 Enumeration District/Block Group
- A4 Square mile/square kilometer
- A5 40 acre/9 hectare
- A6 One acre/one hectare
- A7 Natural areas
- A8 Ownership parcel

Modelling Capabilities

- M1 State demographic and economic model
- M2 Region/county demographic and economic model
- M3 Location and service area analysis (location/allocation algorithms)
- M4 Area measurement and overlay models
- M5 Diffusion models
- M6 Impact Models

Source: Kenneth J. Deucker, University of Iowa, Institute of Urban and Regional Research the required ground resolution and hence of the coordinate index of the geocoding system used to incorporate the raw data units into the information system.

Faced with this wide range of scales and levels of resolution required for the various applications in a metropolitan region, suppliers of data may consider a range of strategies, based upon the ability of remote sensing observation systems to acquire data at many different resolution levels. One strategy would be to collect data for the entire region in the smallest areal unit required for any of the applications, and then produce the more aggregated data by cartographic generalization, either manually or by machine. An alternative strategy would be to select some intermediate level of generalization, such as that which would be provided by the Landsat system, and let those users with more detailed data requirements go elsewhere for their data. Still another strategy would be to utilize a multiple-sensor array, calling upon each particular system for those portions of the data collecting task for which the system is most suited and most economical. For example, "uniform coverage" at any particular scale might not be called for, if a variety of scales should prove to produce a more useful array of data for the problem at hand.

Range of Possible Responses to Land Use/Land Cover Data Needs

The users of primary concern here have needs for extremely large quantities of data, with a variety of types of classifications and formats of presentation. Some may need immediate delivery of data.

Many have a longer-range perspective whereby they would like to have the benefit of research enabling them to have improved data systems in the future. Thus there is an immediate operational requirement for delivery of large amounts of information by present technology, and a longer-range research requirement for improved data systems and improved understanding of how data can be made more relevant to the problems and processes being addressed.

Range of Other Data Needs Also Faced By Users

In addition to remotely sensed data requirements, metropolitan area users also face other large data requirements such as on sub-surface conditions, water quality, air quality, climate, population numbers and characteristics, economic and production statistics, education, finance, and historical records of many types. The implication of these other data needs insofar as remotely sensed data are concerned, is that the data must be capable of being integrated with other information in the planning and analysis process. Also, it is very helpful for the person who is approaching an urban "user" with the idea of "selling" remote sensing systems or land use data derived from remote sensing to have in mind beforehand an idea of the immense range of other data problems that this particular user must cope with.

How Present Data Needs are Being Met (Or Falling Short of Being Met)

At present the users of urban area remotely sensed data obtain these data from a wide variety of sources. Heavy reliance is placed on standard sources of aerial photos, such as the U.S. Department of Agriculture photography, which is obtained for most areas approximately every 5 years. In addition, the USGS photography taken in support of topographic and orthophotoquad mapping programs is available on an operational basis for purchase by users. More recently, aerial photographs, space photographs, and multispectral scanner imagery from space have been available from the NASA Earth Observation Program's aircraft and satellites, data being distributed to users by the EROS Data Center of the Department of the Interior in Sioux Falls, South Dakota. Where coverage from these sources is not adequate, and where data needs are urgent, special arrangements for obtaining aerial photo or remotely sensed data coverage must be made. These generally involve services performed by private contractors, or in some cases government agencies who cooperate with user groups working on environmental and mapping projects in certain regions.

Attempts have been made to consolidate remotely sensed information so that all users could have easier access to the coverage for their particular areas of interest. A recent example of such coordination effort is the establishment in the USGS of the National Cartographic Information Center, which is providing essential information on maps and aerial photography nationwide. The Department of Agriculture also provides indexes to their aerial photo coverage. Of less widespread use are the indexes maintained by the Department of Defense for their unclassified photography. Other Federal agencies provide similar or related services.

The single most prominent characteristic of the present system for supplying remotely sensed data is its lack of coordination through the network of data producers and users. Workers who are familiar with various agency sources learn where and when certain regions are likely to be photographed. A potential user who is new to the field, however, has more difficulty locating photography. To serve such users a number of State and Federal agencies have attempted to provide summary information, but there is no uniformity in the availability of such information. Particularly conspicuous by its absence is continuing user agency input to the specifications and scheduling of the basic data collection at the Federal level.

SOME DATA REQUIREMENTS OF EXISTING FEDERAL PROGRAMS

Probably the largest numbers of users of remotely sensed data and land use data derived therefrom in metropolitan areas are at the local level. Their needs are diverse and not focused and in many cases are not coordinated with those of their neighboring cities or of other governmental institutions. Now, however, many State governments and many regional metropolitan councils of government are attempting to coordinate the applications and use of remotely sensed data within their jurisdictions. Even with this coordination these users are often not in close contact with the appropriate agencies at the Federal level where large amounts of data and sometimes even technical assistance are available on an ad hoc basis.

However, there is a class of users, again mostly local agencies, tied to Federal funding programs which have considerable implications for the collection of land use data. Since these programs carry Federal funding and are ongoing, I have examined some of them to determine whether existing coordination mechanisms are serving the public interest in economizing on data collection and other expensive tasks involving the handling of large amounts of environmental information. I have listed five acts, along with a brief statement of their implications for land use data.

Federal Housing Act of 1954, As Amended

Section 701 of this Act requires comprehensive regional plans for the recipients of HUD grants in support of housing improvement programs. Over a period of years the 701 program has been a major supporter of land use mapping and of the preparation of comprehensive plans in cities throughout the Nation. The 1975 amendment contains a stronger statement of the requirement for a comprehsensive land use plan which must be prepared for those recipients who receive Federal funds under this program. No guidelines or standards for data collection are given. However, a subsequent bilateral agreement between HUD and USGS may result in some useful standardization of data requirements at least as far as the national topographic mapping program is concerned.

Data for 701 plans are presently obtained through local jurisdications, often with the aid of consultants hired locally who may draw up the comprehensive land use plans and collect the necessary data according to whatever means they think best. The result is a great many individual studies none of which are necessarily coordinated with those of nearby areas, and few of which have standardized data items that could very easily by consolidated into data summaries at a more aggregated level for the use of other governmental agencies. The resolution requirement for many of the data items for this program is higher than available from present Landsat data, and probably higher than available even from the proposed Landsat follow-on thematic mapper. However, there is a very great need at once for coordination of the data collection efforts in support of this program, so that the return from expenditure of Federal funds is maximized.

National Environmental Policy Act, 1969

This Act requires environmental impact statements (EIS) on Federally-funded projects. One element of each EIS is an inventory of present land use. While there is no provision for monitoring to see whether the EIS predicts the future accurately, it would be useful to examine environmental impact statement sites to see what impacts have actually occurred over the years. Because of the diverse nature of the phenomena, and the site-specific aspect of most EIS's, resolution requirements are high, generally at least as high as that provided by the high-altitude aircraft, and in many cases as high as that provided by medium and low-altitude aircraft.

Clean Air Act, 1972, As Amended

This Act is for the purpose of air pollution prevention and control by encouraging and assisting the development and operation of regional air pollution control programs. It calls for the establishment of interstate air quality agencies or commissions "for the purpose of developing implementation plans for any interstate air quality control region."

As interpreted in a recent court ruling, the Clean Air Act requires assurance that an acceptable level of air quality will be maintained through time. In order to comply with that ruling, the Environmental Protection Agency is now setting up procedures for "growth tracking," i.e., monitoring growth areas, wherever they may occur, which would be expected to have substantial future impact on local or regional air quality. It is clear that land use data derived from remote sensing, and periodic monitoring of change, could be used for obtaining basic data on urban growth, as needed for Clean Air Act applications.

Coastal Zone Management Act of 1972

The primary thrust of this legislation is to establish a Federal granting program to assist the States in developing and operating management programs for their coastal land and water resources. While not mandatory, participation by States will be rewarded by the receipt of a planning grant to develop a management program. A first step is the determination and identification of the boundaries of a State's coastal zone. The management program is required to include "a definition of what shall constitute permissible land and water uses within the coastal zone which have a direct and significant impact on coastal waters." The implication, again, is that remotely sensed data can be helpful in supplying certain portions of the land use and land cover information as required to carry out the intentions of this Act. In addition, it is required that an inventory and designation of areas of particular concern be included in the management program. Many States have gone further and required detailed definition and mapping of their coastal and wetland critical areas.

Federal Water Pollution Control Act of 1972

Of particular importance in this Act is Section 208, the areawide waste treatment program, which funds regional planning and implementation programs for assuring proper controls on both point and area sources of water pollution. Draft guidelines set up under this Act state the need for land use data necessary to perform several tasks related to attainment of water quality standards. Land use data would be used as a base for land use regulation, as one method of control of point and nonpoint sources of pollution. Two 208 program scientists who were consulted indicated that the requirements for inventory of features significant to the identification of point and area sources of water pollution dictate relatively high-resolution data, at least as high as that of the NASA high-altitude aircraft data. Again, many millions of Federal dollars are spent on 208 programs throughout the Nation.

Other Laws

Other Federal laws have implications for the use of remote sensors and/or land use data derived therefrom, and examination of these laws may yield further examples justifying data coordination. Examples of such laws are the National Flood Insurance Act of 1968, the Federal Disaster Protection Act of 1973, and the Disaster Relief Act of 1974.

Implications of Federal Legislation Requirements for Data

The programs described above are present requirements impacting heavily on many or all of the metropolitan areas of the country. Since these acts are in force at the present time the need for supportive information is immediate. Experience in a metropolitan area test site indicates that imagery from Landsat-1, and better yet, data derivable directly from computer-compatible tapes from Landsat-1 and 2, are useful for providing some of the required information under these programs. In all cases, however, much of the information required is more detailed than that available from Landsat, and would therefore call for the use of aircraft data beginning immediately. Whether the private sector can provide this coverage in as orderly and cost-effective basis as can the principal Federal agencies is a question not answered by this report. It is clear, however, that whatever source is drawn upon to obtain the basic remotely sensed data, much greater coordination is needed. The need is now--users cannot wait for Landsat follow-on or Space Shuttle in the post-1980 period to plan for data delivery.

LANDSAT AND LANDSAT FOLLOW-ON SENSING CAPABILITIES COMPARED TO DATA NEEDS

As already stated, our conclusions from the CARETS experience are broadly applicable elsewhere. Briefly, the conclusions are these: Landsat data in image form, and 1:250,000-scale land use maps derived therefrom, are so coarse in resolution that they supply only a small fraction of the data needs for metropolitan area planning and management. Slight improvements in this situation might be possible by (a) conducting further research to determine relationships between such low-resolution image elements and surface environmental phenomena of interest to the users, and (b) improving the spatial resolution of the imagery by enhancement techniques. Whether the users would find these efforts worthwhile would depend on their willingness to forego higher-resolution sources already known to them.

Landsat data in computer-compatible tape format aroused the interest of many users; however, before such a system could become operational software and low-cost analysis techniques would have to be made readily available to the users, or alternatively, some central data processing facility would have to assume responsiblity for providing Landsat-derived data units that would be digestible by the user's information systems. Certainly the description and mapping of vegetated surfaces, many of which are diagnostic of particular land use and land cover types, would be welcome to many users.

NASA proposes a "Landsat follow-on" satellite program to extend the flow of orbital Earth observation data into the mid-1980's. The principal component of Landsat follow-on is an advanced multispectral scanner called the thematic mapper, which contains improvements over the multispectral scanner used in Landsats 1, 2, and 3. One such improvement, increased spatial resolution, is shown in figure 9.1 in comparison with that of sensor systems of the high-altitude aircraft, Landsats 1, 2, and 3, and Skylab.

The Landsat follow-on thematic mapper represents an improvement of considerable interest to users who require higher-resolution data. However, since delivery of such data is still many years in the future, and since research is needed to calibrate such data in terms of users' needs, this system cannot satisfy the urgent needs of today's metropolitan area land use planners and managers. A dilimma arises when

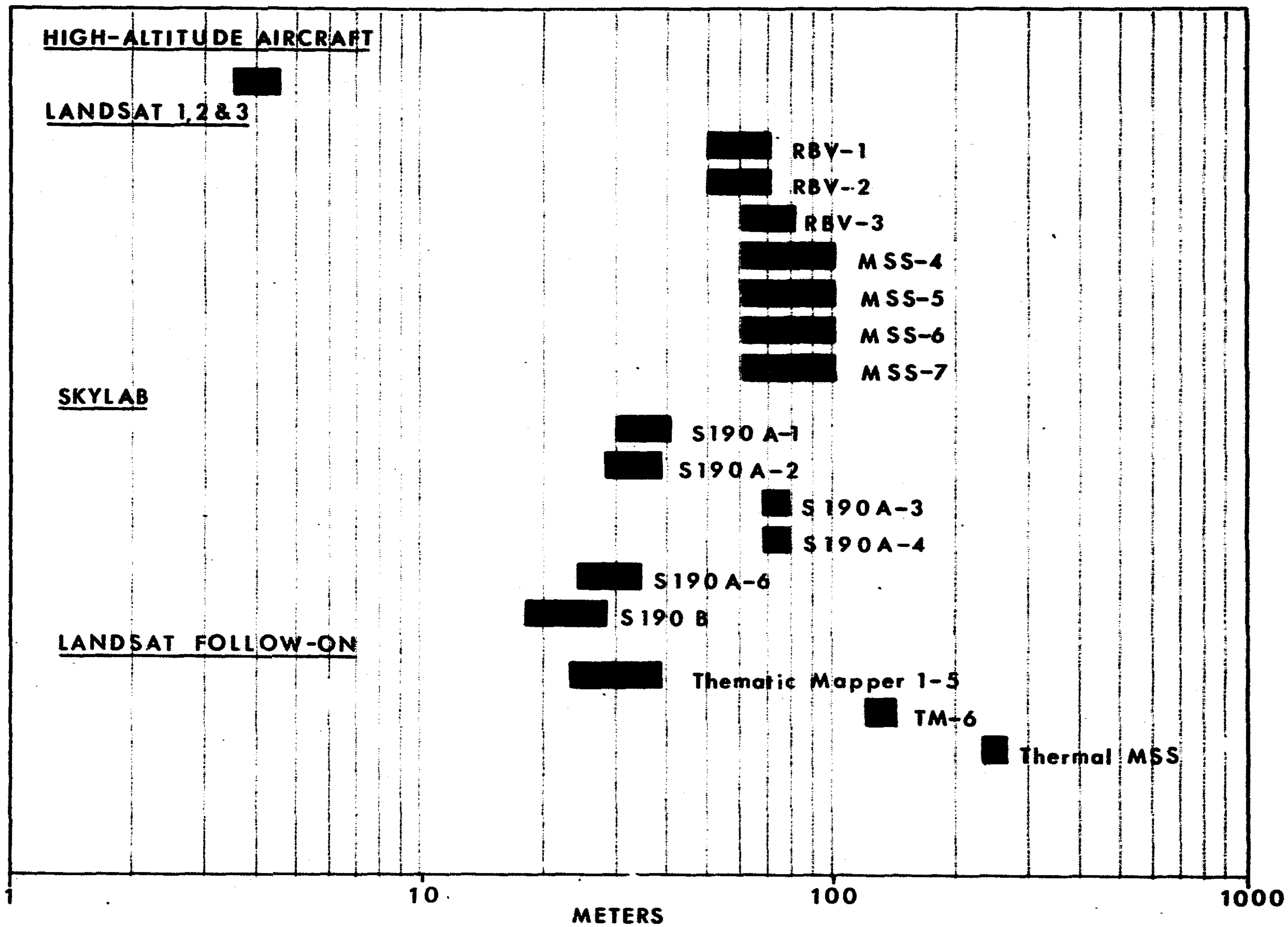


Figure 9.1--Approximate ground resolution of various sensor systems critical to users' identification of key land use features.

metropolitan area users are asked to support Landsat follow-up by listing the applications in their discipline which could be satisfied by Landsat follow-on. Should such users "play the game," supporting a nonoptimal system in hopes of getting a better system later when high-level acceptance of satellite observation systems is greater? Or should these unsatisfied users ask now for a federally-coordinated operational remote sensing system which will come closer to addressing their needs? Whatever strategy is chosen, a strong argument could be given for beginning now a much more meaningful coordination and cooperation among data producers and user institutions.

ALTERNATIVE WAYS OF RESPONDING TO INFORMATION NEEDS

The CARETS project investigated a complex environmental and decision-making system having many component parts, and dealing with the needs for remote sensing, land use, and related environmental information at all levels of government and also by users from the private sector. There are many possible ways of recommending responses to the information needs that were identified. These might be classified into the following general categories of possible responses by the individuals and organizations who will be evaluating the results obtained from CARETS and from other related research and demonstration efforts: (1) Continue the present system unchanged, (2) make piecemeal improvements in various components of the system, without regard to how the individual improvements may contribute to the workings of the overall system, and (3) adopt a combined immediate and long-range program which addresses the "systems" aspects of the problems at the appropriate levels of the Federal-State-local governmental hierarchy.

To continue the present "system" unchanged would continue program research elements which do not lead directly to information that can be regularly delivered to operational agencies. Further, the present system is not as well coordinated as it might be, and we discovered indications that duplication of remotely sensed data gathering and land use mapping was adding to total costs. Not addressing this need to coordinate would mean an abdication by the Federal Government of its own logical role as implied by the large number of Federal laws and regulations which set in motion (sometimes overlapping) requirements for remotely sensed data.

Piecemeal improvements in various components of the system; for example, the building of a uniform and nationwide land use and land cover information program by the Geological Survey, seem to be taking place in some of the agencies which have been brought into contact with the Federal-level remote sensing research efforts. These kinds of improvements are often seen to be attractive to forward-looking administrators, who recognize the potential for enhancing the agencies' abilities to fulfill their missions, and who can define new programs at manageable levels, adding them to budget proposals. However, the single-agency approach, without the proper coordination by data management professionals who recognize common data elements in otherwise diverse proposals, almost certainly leads to expanded agency functions and increased total costs. At present, information is not available on whether those increased costs are justified by corresponding benefits.

The third type of response, to adopt a combined short and long-range strategy which addresses the "systems" aspects of the problems at the appropriate governmental levels, is the one recommended in this report based upon the lessons learned in the CARETS project. More detailed discussion of this "systems" approach is presented in the remaining portions of this chapter.

The choice among the three alternative ways of responding to information needs carries with it an implication as to the target audience of resulting recommendations. If we recommend continuing the present system unchanged the main target is local government where most land use decisions are made, and the message from the Federal Government is essentially, "We cannot give you additional help in obtaining information to support land use decisions; you are welcome to try to find it if you know where to look among existing Federal agency programs."

If we recommend piecemeal agency improvements the target audience consists of heads of agencies with environmental data production responsibilities, such as Cabinet-level officers in the Federal Government and various corresponding officers in State government. The message is, essentially, "We have discovered some uses of the new space technology which may help you in your agency's mission. You might want to make a benefit-cost study and/or build your own computer capability so you can receive the new remotely sensed data in the formats now available from the Federal agency sources."

The recommendations for a combined strategy emphasizing a "systems" view of the problems, as advocated in this report, aims at a target audience including local government, State government, and all appropriate Federal agencies. Because of its implications for multi-agency coordination and direction, the message must also be communicated to appropriate functions within the Executive Office of the President. The message being transmitted to users in this case is "We are offering you an avenue through which you may communicate your data needs to the appropriate data producing agencies, to be considered along with those of other users like yourselves. Priorities will be determined and data will be delivered according to an open process of deliberation and communication through this network of data producers and data users."

NEEDED COORDINATION AMONG DATA PRODUCERS AND USER INSTITUTIONS

In the face of the diversity of data needs which cannot satisfactorily by met by the Landsat follow-on system, the data producers and the data users need to find some common meeting ground so that the right priorities can be established. One approach would be to select a single system, say Landsat follow-on, and ask all potential users to join in the attempt to define useful applications. As alluded to in the previous section, such an approach might not be attractive to the metropolitan area users, especially if they should get the impression that opting for a major system like Landsat might preempt Federal expenditures in support of other more urgently needed remote sensor data systems.

Another approach might be to have the Federal Government withdraw entirely from involvement in remote sensor systems having high-resolution components, on the grounds that such systems should be left to private industry, as determined by local agencies and their own priorities. As shown above, however, even the local agency users have ties to federally-funded programs which have many implications for land use and land cover data. Thus it seems likely that while the actual aircraft missions might be done by either government agencies or private firms, or a combination, the setting of standards and the utilization of large-scale technology might best be a Federal-level activity. Since the Federal Government is already deeply involved in environmental programs which determine many of the data requirements, it can hardly abdicate all responsibility for seeing that the needed data are collected in the most effective and efficient way.

Still another approach might be to make use of classified (military) data sources, which could be analyzed and "sanitized" by cleared personnel; the resulting products in the form of land use maps could then be declassified and released. This approach, however, would be directly contrary to one of the prominent results of the CARETS project user survey, namely that the basic photography or imagery itself is the most highly-valued data product presented to 65 user agencies. Furthermore, for metropolitan area users and those others affected by the Federal legislation cited above, much of the actual data analysis is done at the local level or by contractors. The Federal role in such cases might be limited to the setting of standards, quality control, and coordination. A user must also be able to verify mapped data, where necessary. Therefore, the use of classified source material is not recommended for the users addressed in this report.

Recommended Land Use Information Program and Coordination Mechanism

A conservative approach to coordination of Federal land use information programs is to build first on the known requirements of existing metropolitan area user institutions. This approach calls for a coordination mechanism involving both data producers and data users. The tasks to be coordinated include the remote sensing data collection phases and the transformation of remotely sensed data into the maps or other storage media so that the basic units of terrain information can be input into user-accessible information systems. There are many advantages in having the remote sensing and information processing phases closely linked.

Such a coordination activity would bring together producers' capabilities along with users' requirements in a common framework for comparison. For example, sensor performance charts, such as the one in figure 9.1, should be compared with users' requirements so that the appropriate match between sensor system and data gathering task could be made. We found three levels of detail needed by metropolitan area users, representing the three levels of aggregation (or generalization) required to prepare land use data at parcel or block level, census tract level, and metropolitan region level, respectively. By identifying diagnostic features characterizing each level, and then determining the range of image resolution requirements for identifying those features, we prepared the chart displayed in figure 9.2, which should be compared with figure 9.1. Such comparison reveals that Landsat, Skylab, and

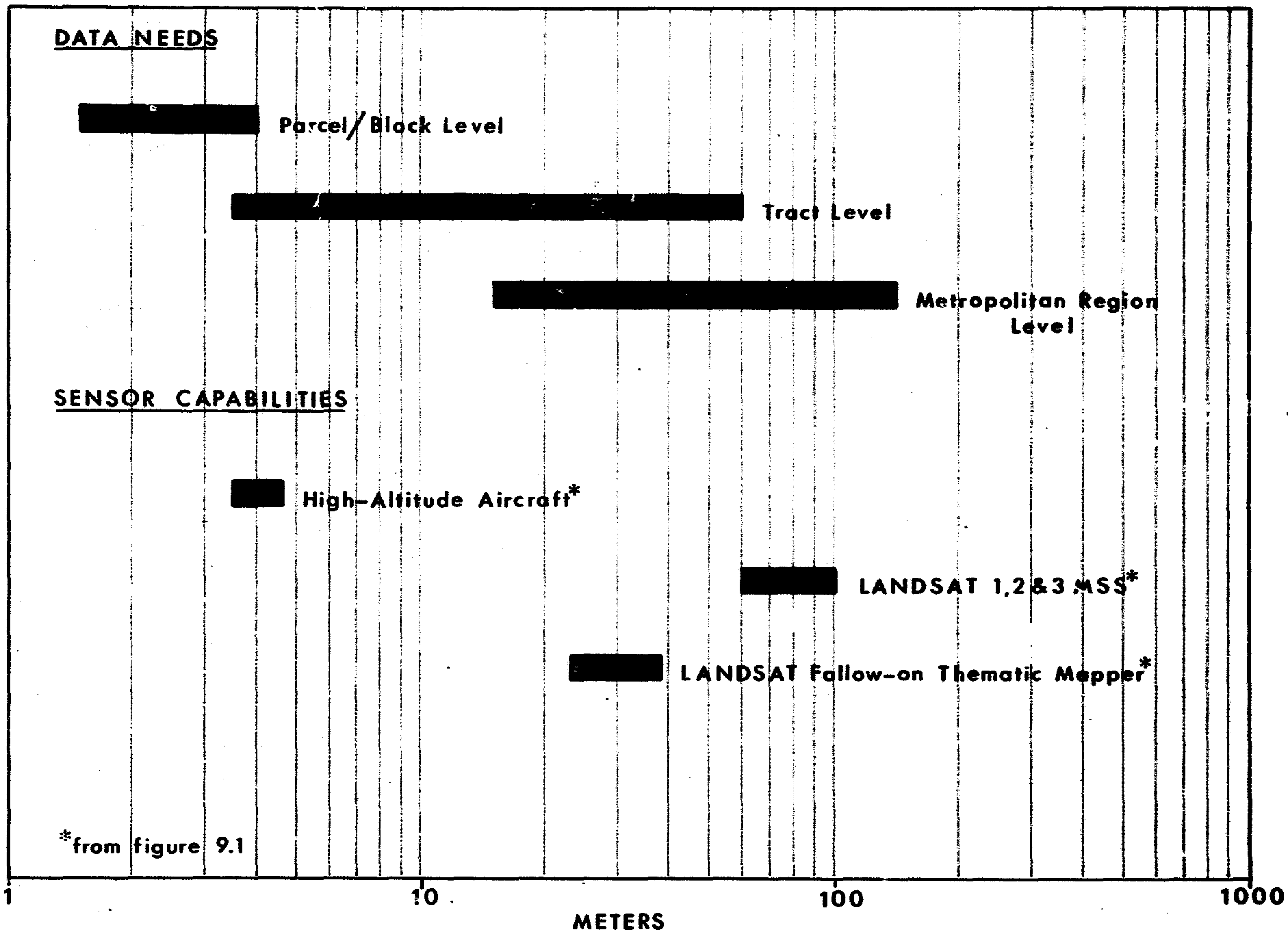


Figure 9.2--Approximate ground resolution required for identification of key land use features for three levels of the geographic hierarchy of needs for metropolitan area remote sensing data; compared with high-altitude aircraft, Landsat, and Landsat follow-on resolution capabilities.

Landsat follow-on sensors are all suitable for some degree of data gathering at the metropolitan region level. The Skylab photographic sensors reach well into the resolution required for tract level data; Landsats 1, 2, and 3 do not. The Landsat follow-on thematic mapper (TM 1-5) seems capable of providing data at the tract level. Only the high-altitude aircraft photographs, however, begin to reach the resolution requirements at the parcel/block level. Through data aggregation each sensor system that meets one resolution level requirement is also capable of supplying needs at less detailed levels of resolution.

Regional Land Use Information Coordination Centers

As part of the CARETS investigation we operated an experimental regional information center. Some of the experience gained in operating this center may be applicable to the problem of bringing Landsat and other remote sensing systems to bear on the problems to be solved. For an operational data delivery system, I recommend that the coordination functions go farther than was the case in CARETS. Nonetheless, the CARETS project proved to be an effective method of performing several useful functions: keeping in touch with the particular land resource planning and management problems which were of most concern to users; consolidating information on Federal and State remote sensing and mapping programs, and making that information readily available to users; performing certain land use mapping and research tasks; conducting workshops and informal demonstrations of products, techniques, and capabilities; communicating the results of the project to users, and obtaining their feedback. One important value of such an information center is that through working in close cooperation with user groups, the project staff obtains a "feel" for the priorities of the region, in terms of the class of problems for which the land use and land cover information can be useful. Knowledge of these priorities should be communicated throughout the entire community of data producing agencies.

I propose that a network of regional land use information coordination centers be set up, with the primary purpose of reducing the gap between data needs and data production. The information centers should begin operations immediately and extend through the Landsat follow-on period, until user groups are well adjusted to data supply activities. Landsat applications would thus be considered alongside applications of other systems, as determined by the driving force of the user's demand, transmitted through the regional centers. A concomitant objective would be to foster efficient regional distribution of information about Federal environmental programs, and to foster better cooperation and coordination among Federal, State, and local land use related activities. A carefully structured coordination program should result in improved efficiency in environmental management programs, and at the same time improve the efficiency of Federal data programs for supplying information crucial to that management process.

A search for a milieu under which such coordination could be established leads to an examination of the existing institutional structure. On the one hand we might look to the 50 State governments, each of which to varying degrees has entered the field of environmental data management in its own area, and many of which have gone quite far toward establishing remote sensing, land use, and environmental information agencies.

Such organizations can surely be an important part in the coordination mechanism as described; however, the direction to date has been toward building separate entities within the States, as they quite properly respond to the laws and internal requirements of the State administrative and political leaders. This process has not resulted in interstate, regional, and river basin level cooperation.

Another obvious place to look are the officially designated coordinating agencies in the metropolitan regions, as established by the Intergovernmental Coordination Act and Office of Management and Budget Circular A-95. These agencies might be particularly appropriate for the distribution of data having to do with urban and metropolitan planning and management. A-95 agencies are usually existing regional planning bodies which have a large variety of other responsibilites and which in many cases could provide facilities and staff support for a small information clearinghouse of the type envisaged. The number, however, of such agencies nationwide is probably too large for efficient direct data distribution from the Federal Government. Looking toward larger groupings of States or metropolitan regions, one comes to such entities as the Federal Regional Commissions authorized under Title V of the Public Works and Economic Development Act of 1965, as amended. Two of these Federal regional commissions, the Ozarks and Pacific Northwest, have already taken an active role in coordinating remote sensing and land use mapping programs within their respective regions, in cooperation with NASA, USGS, and State agencies. The Federal regional commissions (fig. 9.3) do not, however, cover the entire country, and so could not be the basis of a complete nationwide coordination effort of the type described here.

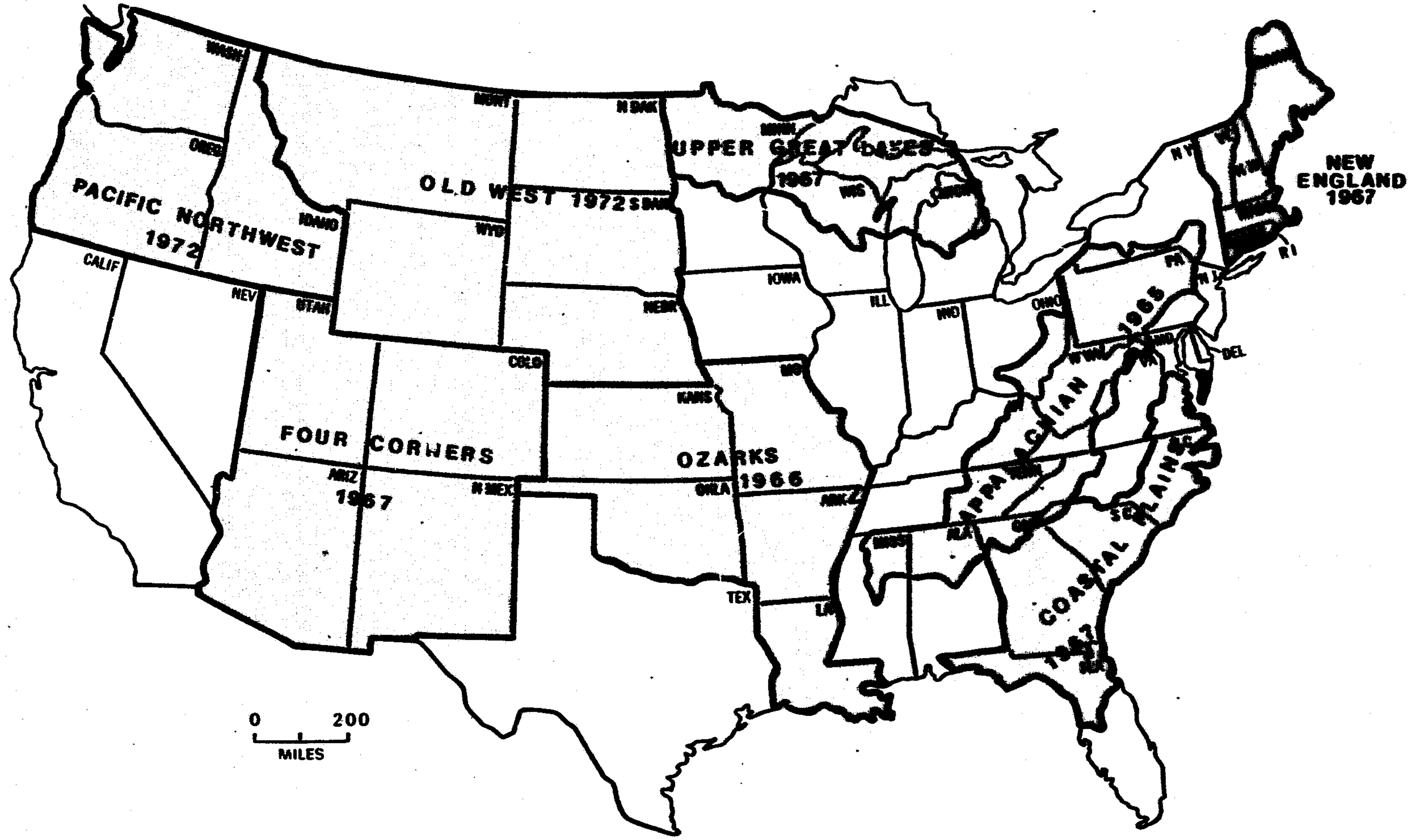


Figure 9.3.--Economic development regions and dates of establishment of federal regional commissions, dates represent when Commissions were organized, U.S. Department of Commerce, January 5, 1976.

The more recently established Federal regional council structure does cover the entire country, dividing it into 10 officially designated standard Federal regions (fig. 9.4), with several prescribed functions aimed mainly at coordinating Federal impact programs in the regions concerned. These standard Federal regions are made up of entire States, and so would be a natural intermediary coordination mechanism between the Federal Government and the States. None of them, however, are sufficiently organized at present to take on additional functions and provide support (four or five professionals, plus some equipment) for the type of information center that is envisioned here.

Based on the experience with the CARETS experimental information center, the number and size of standard Federal regions seem about right for accomplishing the regional coordination functions for land use information programs. Whether that structure could serve better than a regionalization based on different boundaries or a different organization could be determined as a subsequent step.

Establishment of the Regional Land Use Information Coordination Centers could be done immediately and without setting up any new mapping or remote sensing data gathering agency. Technical staff could be contributed by agencies now participating in remote sensing and Earth observation programs and in environmental planning and management. Examples of such agencies at the Federal level are listed in table 9.2. Many such personnel are already functioning in similar roles unofficially in the course of doing their regularly assigned duties. No additional tax dollars should be needed.

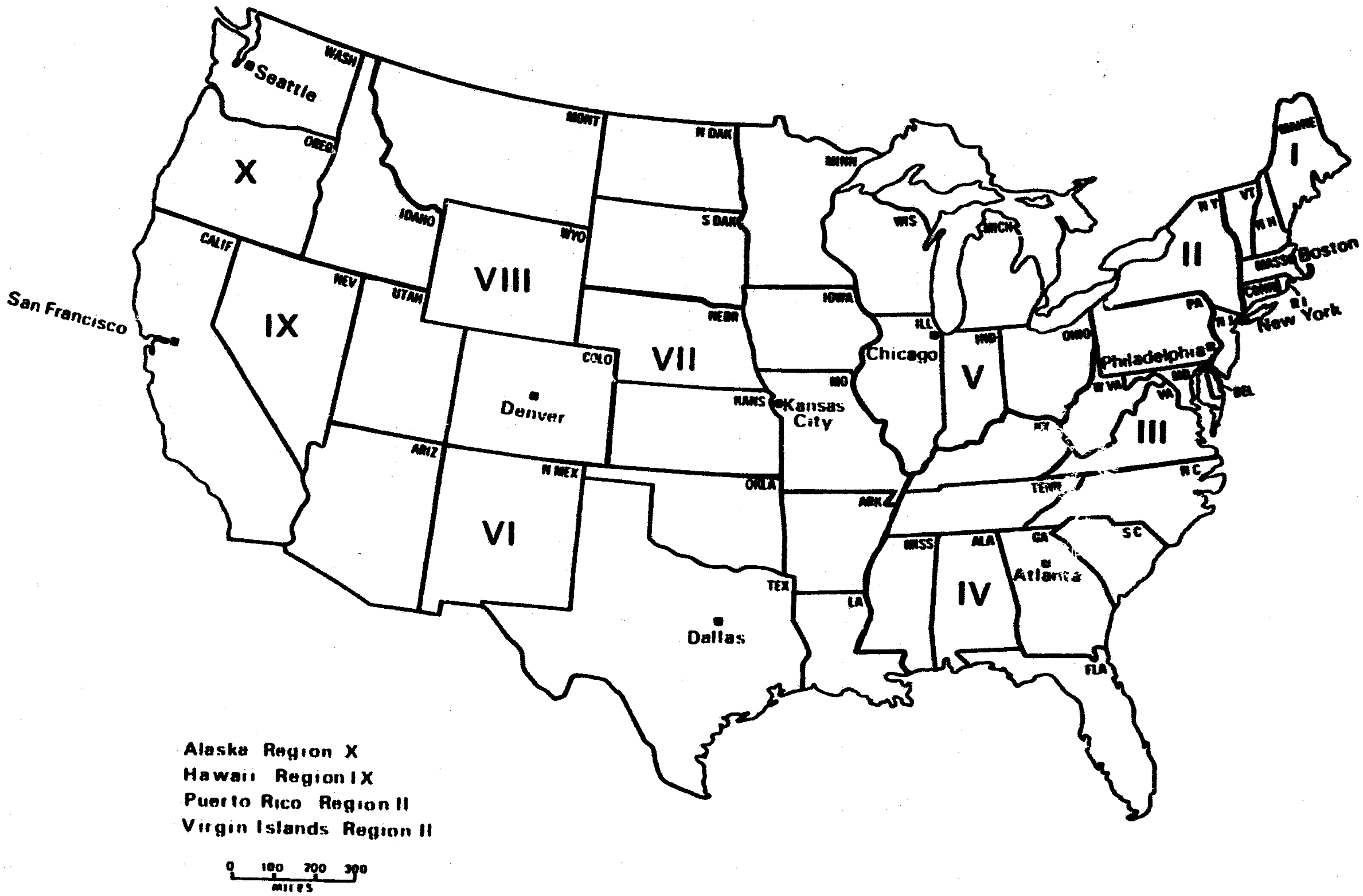


Figure 9.4--Standard federal regions.

Table 9.2.--Federal agencies involved in remote sensing, land information systems, and/or environmental planning and management

Department of Agriculture
- Agricultural Stabilization and Conservation Service
- Foreign Agricultural Service
- Forest Service
- Soil Conservation Service

Department of Commerce
- Economic Development Administration
- National Oceanic and Atmospheric Administration
- Bureau of the Census
- Office of Telecommunications

Department of Defense
- Defense Intelligence Agency
- Defense Mapping Agency
- Research and Development Agencies
- Army Corps of Engineers

Department of Energy

Department of Housing and Urban Development
- Community Planning and Development
- Federal Disaster Assistance Administration
- Federal Insurance Administration

Department of the Interior
- Fish and Wildlife Service
- National Park Service
- Geological Survey
- Bureau of Indian Affairs
- Bureau of Land Management
- Bureau of Outdoor Recreation
- Bureau of Reclamation

Department of State
- Agency for International Development

Department of Transportation
- Federal Highway Administration

Other Agencies
- Appalachian Regional Commission
- Environmental Protection Agency
- General Services Administration
- National Aeronautics and Space Administration
- National Science Foundation
- Pacific Northwest Regional Commission
- Tennessee Valley Authority

The regional Information Coordination Centers should be staffed with about five professionals to perform such tasks as the following: (1) Inventory ongoing federally-funded programs within the region, which have some requirement for remotely sensed data or land use information derived therefrom. These would include the EPA 208 programs, the coastal zone management program, the HUD 701 programs, and any DOT program requiring update of land use information; (2) inventory problems of an environmental or land use nature already identified by Federal, State, or local agencies as critical, or otherwise worthy of attention; (3) inventory all federally-funded aerial photography or remote sensing data gathering programs affecting the region, including the provision for using data from Landsat, the provision for obtaining USGS photographs within the regular mapping program, the provision for obtaining USDA aerial photographs as part of the regular operation; (4) translate the requirements for remote sensing and land use information into specific descriptions of the data gathering, mapping, data processing, and delivery systems that would be necessary to fulfill all bona fide user requirements; and (5) in consultation with specifically designated agencies within the region, draw up a priority schedule for allocating available Federal, State, and local resources to the obtaining of the necessary remotely sensed data, and for deriving of the necessary land use and land cover maps.

Federal Data Producer Agency Scheduling Panel

A central coordinating and scheduling panel made up of representatives of the principal Federal data producing agencies could be established as part of the recommendations of this report. These would include the mapping and remote sensing agencies of the Department of the Interior, Department of Commerce, Department of Agriculture, National Aeronautics and Space Administration, Army Corps of Engineers, and the Environmental Protection Agency, with possible additional representation from the Departments of Transportation, and Housing and Urban Development.

The Data Producer Agency Scheduling Panel could be required and empowered to assign data collection and mapping priorities to the member agencies, and distribute related mission and task assignments, in accordance with the recommendations and initial priority designations submitted by the regional land use coordination centers. These mission and task assignments would then be published and reviewed both at the level of the regional user institutions and information centers, and at the higher level of an Executive Board on Land Information Programs (see below).

After a reasonable time for receiving comments on the assignment of data collection and mapping priorities, the Federal Data Producer Agency Scheduling Panel would transmit assignments to the member agencies which would then implement them.

One immediate effect of this proposed arrangement would be to create a government-wide operational remote sensing and land use information program, responding to the needs of the existing users throughout the Nation. It would be authorized by executive order of the President, as direction of such a program could not function at any lower level of the government without much greater cooperation among agencies than has been evident to date. Many of the data programs presently labeled by NASA and the other data producing agencies as "research" or "demonstration projects" should more appropriately be assigned to the proposed "operational" program, although no functions or personnel need be moved from their present agency designations (except those few which might be rotated into assignments in the regional Land Use Information Coordination Centers).

There is, of course, continuing need for a vigorous research function supported by the various agencies with direct concerns either as data producers or as supporters of data producers. The research function should look to future environmental information needs, and improvement of systems to provide the information. The new coordination mechanism, however, should also be used to coordinate and strengthen the research program.

Executive Board on Land Information Programs

Overseeing the entire operation would be a blue-ribbon panel representing data producers, data users, and the public. This Executive Board on Land Information Programs would transmit the instructions of the President, reconcile conflicts in data collection priorities that might arise in the system, monitor the progress of the coordination system, and make recommendations for improvement. A possible organizational arrangement for the entire coordination structure is indicated in figure 9.5. Admittedly, the functions outlined here are sketchy and

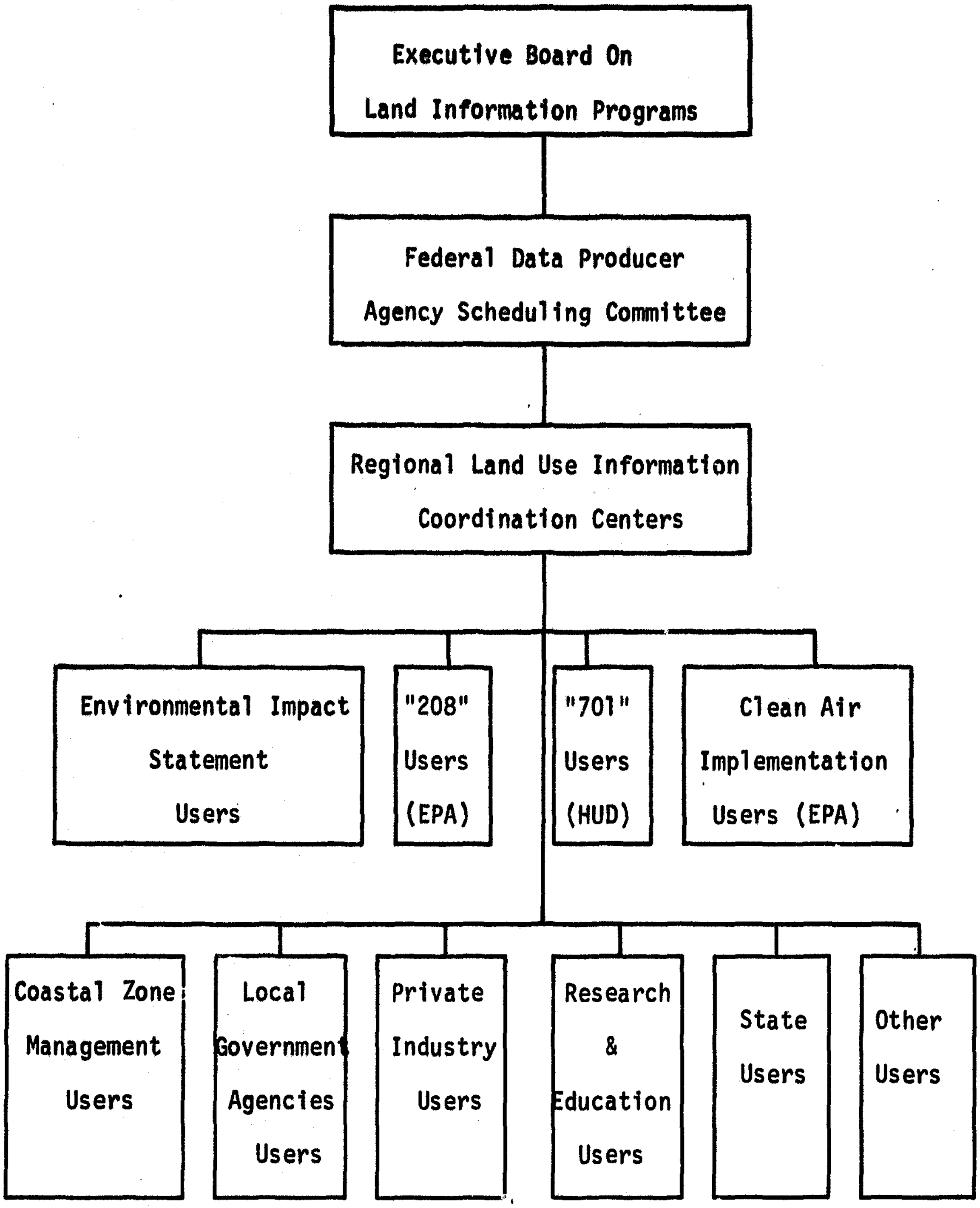


Figure 9.5.--Proposed organization of land use information coordination structure

need further development. But the proposals set forth here might result in considerable savings in programs that involve very large expenditures of Federal funds, and would lend a broader base of support to the programs that would emerge from the coordination process, including quite possibly the Landsat and Landsat follow-on systems.

Information Flow as Viewed by Secretary of the Interior

From the viewpoint of one Cabinet officer, the Secretary of the Interior, the flow of information under the proposed coordination system might look something like that diagrammed in figure 9.6. The Secretary could draw directly upon this network of information when faced with major policy issues involving land use, such as setting aside additional wilderness areas, leasing for coal mining on Federal lands, and approval of a new dam. Much of the information to be supplied under the headings of "inventory" and "change" in figure 9.6 may be the responsibility of bureaus within the Department of the Interior, including the Geological Survey. However, other information products produced elsewhere would also be accessible to the Secretary through the proposed coordination mechanism.

"Remotely sensed data," though not listed as a separate entity in the information flow depicted by figure 9.6, may be contributory to any or all of the categories of information listed under "inventory" and "change" (geologic and mineral resources, water resources, etc.). Introduction of remote sensing data in this manner facilitates later analysis by appropriate discipline specialists and stresses the role of

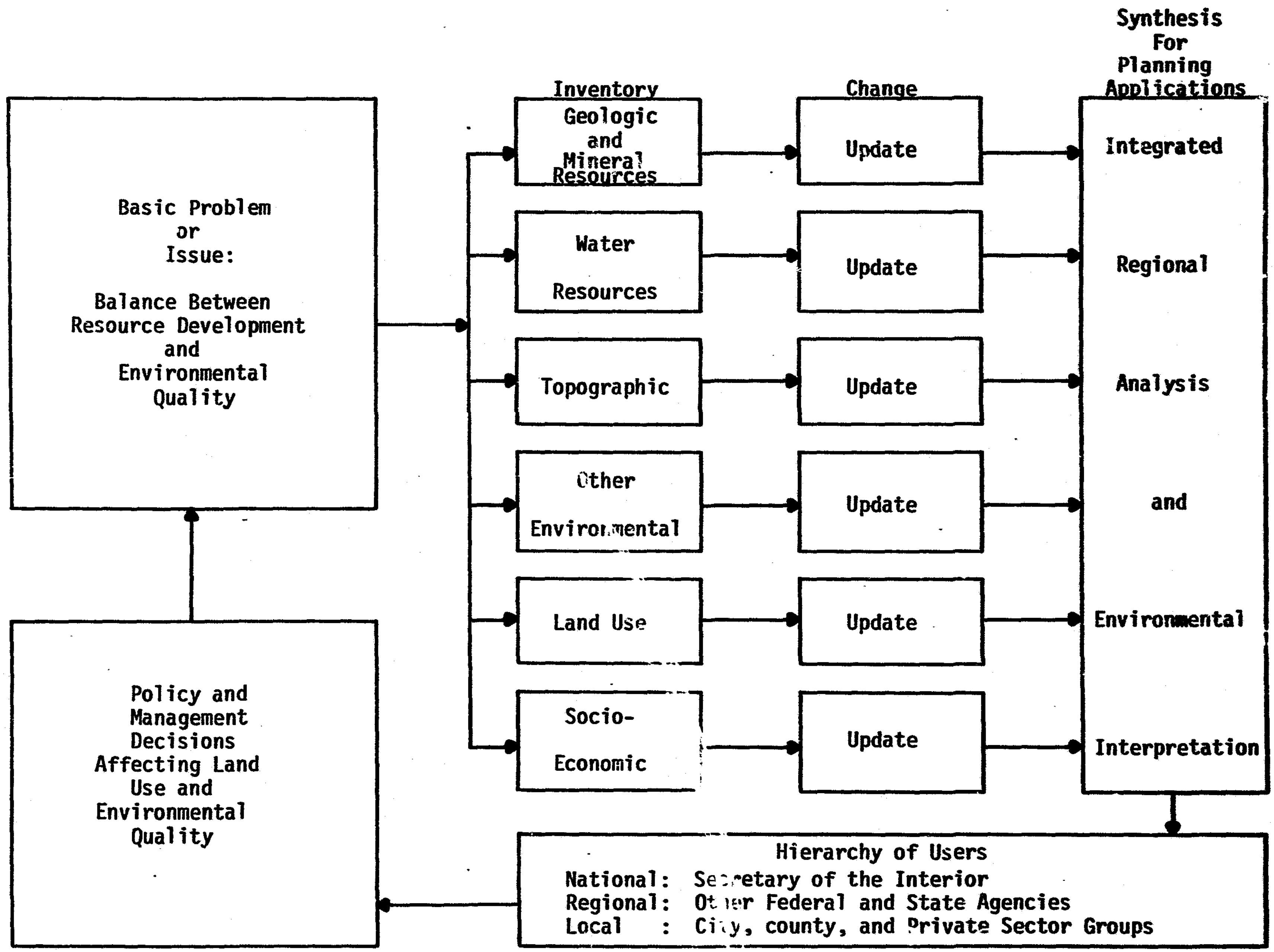


Figure 9.6.--Department of the Interior information flow under proposed coordination system

remote sensing as supportive of the environmental problem-solving function. Action is directed toward effective problem analysis rather than toward promotion and encouragement of data use.

The procedure outlined in figure 9.6 should strengthen and make more relevant the roles of the information producing agencies, by enabling their activities to be more directly linked to the policy, management, and planning functions. Procedures similar to those of figure 9.6 could be used by other Federal agencies and departments, and by user institutions at other levels of government.

Data Utilization for Decisionmaking

This report also recommends improvements in the utilization of remotely sensed data in the decisionmaking process. While some of these improvements must await longer term changes and further research results, useful steps could be taken immediately within existing agency programs merely by shifting emphasis slightly in directions indicated by lessons learned in CARETS and other projects examining society's use of scientific and technical information.*

Whether scientific information actually gets used to support environmental decisions may depend on many complexities and subtleties of the communication process, including an array of factors governing acceptance and use of such information by a nonscientist decisionmaker. Expanding and consolidating contacts between data producers and decisionmaking

* A relevant experience involving earthquake hazard mitigation information is described by Buck (1978).

groups should have beneficial results when accompanied by conditions and attitudes that foster genuine two-way communication. For example, barriers to communication might result from users' lacking the expertise or technical apparatus to make proper use of the data. In such cases data producers might make special efforts to assist in technology transfer through seminars, workshops, or other kinds of small-group demonstrations (McGinty, 1975).

Data supportive of local land and environmental management decisions are more likely to be accepted if related to requirements of existing laws, and to local economic issues that translate into dollars and cents in somebody's bank account (Pendleton, 1978). Where it is possible to point out probable economic benefits derived from having better data, the beneficiary will be more likely to accept and use the data; however, in the absence of growth in the economy, one person's benefit will be another's cost, and those who perceive additional costs for themselves may be among the opponents of adoption of new data programs to support decisions. Failure of an analysis to take account of such situations could result in non-use of data.

Increased awareness of the importance of environmental processes may be expected to improve the demand for, and use of, environmental information in land use decisionmaking. Federal agencies having established channels of communication to State and local governments--for example, regular coordination meetings, local and regional offices, public information programs--might attempt more systematically to employ such channels for transmitting suitable educational materials, and to make scientists available for speaking on environmental issues within their areas of expertise. In these activities the issues themselves should be stressed, not the agency's programs. Given the resource limitations of the Federal environmental agencies, when compared to the detail and quantity of information needed to support sound environmental decisionmaking throughout the Nation, Federal efforts to build local environmental expertise and awareness (through education, training, technology transfer, the setting of standards and guidelines) may in the long run prove to be of greater significance than merely producing, publishing, and distributing environmental data and maps.

UNDERSTANDING FUNDAMENTAL PROCESSES: LONG-RANGE ACTIONS NEEDED

The dividing line between the two categories of recommendations given here--meeting immediate needs and taking long-range actions--is not a sharp one. Building local environmental awareness, as just discussed, can be started in a modest way immediately. But doing so leads into needs for longer-range actions to strengthen education and research activities, bases for a continuing effort to improve the payoffs realized from investment of public funds to increase our understanding of Earth environments. Two categories of such long-range recommendations are to increase our understanding of the fundamental decisionmaking processes that govern how people plan and manage their land, water, and air resources; and to increase our understanding of regional-scale biogeophysical processes, including their linkages with man's social, economic, and political systems as they operate over time. The resulting increased understanding and knowledge should then be fed back into the environmental management process for continual update and adaptation of management systems to environmental reality.

The CARETS user survey monitored users' reactions to the various data products produced by the project, and also to samples of products potentially available from an operational CARETS-type system. Additional studies are needed of how remotely sensed data, and land use data derived therefrom, are put to use in the land decisionmaking process. The CARETS effort was unable to pursue the data to the decision point. Further, land use decisionmakers may include such diverse entities as a major governmental agency on the one hand and a small householder or farmer on the other. More work is needed to identify the network of decisionmakers at all levels of the societal hierarchy, and the communication channels that are used to transmit environmental information. The CARETS project monitored for a few months the land use decisions made by a local planning body during the course of their regular deliberations. Such efforts should be extended to include representatives of the variety of decisionmakers to be encountered. In many cases it is difficult to sort out the role that remote sensing or other environmental data may have, but such attempts should be made. Finally, research is needed to determine what factors influence the decisionmaking process in hopes of generalizing from one region to another and/or from one time to another. Such factors range from how the individual decisionmaker perceives the environmental situation or problem, how he perceives the range of possible alternative solutions, what the various special interest groups want, what the political factors are, to the balance of benefits versus costs. A considerable body of research has been done on how people act in the face of information on natural hazards, some of which may be relevant to the study of land use decisions in general (Slovic and others, 1974).

Even though not fully realized in the operation of the CARETS demonstration project, the other category of long-range recommendations--to increase our understanding of regional-scale environmental processes-grew out of the CARETS project "systems" philosophy. We need to know and understand more about the way the natural and man-modified systems work. In the CARETS region, for example, there are ecosystem complexes where the balance between maintaining quality acceptable to human use is precarious, and where the line between a healthy environment and the onset of environmental pathology or degradation is a thin one. Examples of these fragile ecosystem complexes are the coasts, the floodplains, the metropolitan airsheds, the interconnected water resources of the region, and the areas called "open space" by the planners. Information to help manage these environments must be based on knowledge of regional impacts of increasing populations and their technology, which should in turn be based on fundamental knowledge of the regional geophysical, biological, and social dynamics. In addition to supplying new information from the remote sensing systems, the scientists representing the proposed regional information service should interpret the regional environmental systems concept and explain the relationships of the various environmental processes, problems, and diverse data sets.

A key task of the regional information service should be the monitoring of important land use and environmental changes that are taking place within the region, and the communicating of information about changes to the appropriate user institutions. Even though the change, as observable from satellites and other remote sensors, is only one of many significant kinds of change taking place in the region, nevertheless the monitoring of such change can help to dramatize the extent and rates of other changes that are going on, and can help people gain an appreciation of the essential unity of the planet's ecosystems. The regional information service could also be useful in developing and improving regional applications of remote sensing. Detailed baseline data sets could be used to determine the amount and rate of change. It would be important to monitor both those relatively "natural" or seemingly undisturbed portions of the region (which exist even in the close vicinity of large metropolitan areas) as well as the portions of the region which have been subjected to rather intensive industrial, agricultural, and urban development.

Recognizing that different users will require information summaries for different portions of the region or subregions (e.g., counties and other administrative areas) the data derived from the remote sensing systems would be organized for retrieval by such regions and also by regional airsheds, watersheds, transportation districts, and other natural or administrative subdivisions for which information summaries are required. Combined with some method for enabling such flexibility of information retrieval, there are many advantages of incorporating into a regional information service data from satellites and aircraft sensors. Among these advantages are uniformity of the land description and change monitoring which is possible, rapidity with which surveys can be made, objectivity possible from measures of physical environmental phenomena, and comparability of data from one subregion to another and with other regions.

The same regionally focused environmental information service can be useful to both the scientific community and to enlightened lay citizen groups. The latter, in fact, could be supplied with information which is often unduly expensive for them to obtain, but which is useful in obtaining factual representations of complex environmental issues and enabling those issues to be discussed knowledgeably in the public arena.

The underlying assumption of the approach advocated here is that while there is a finite limit to the number of people who can be accommodated in any given region without causing irreversible change in either the environmental or the supporting social systems, the regional land, water, and air resources could be intelligently managed. Proper coordination among agencies could improve the availability of environmental data to support management and planning decisions. Present populations could be more comfortably accommodated and in some cases population growth can be planned for in such a way that the additional people will face the prospect of a better environment than they would have faced without the existence of such planning.

Taken together, the recommendations arising from the CARETS project are aimed at completing the missing link in the rationale for the large expenditures for remote sensing and land use information programs. This missing link is the assumption that better information will lead to better decisions which will in turn lead to a better environment--one that is cleaner, safer, healthier, and in general more satisfying for humans and other creatures sharing with us the surface environments of the Planet Earth.

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APPENDIX A

REPORTS AND PUBLICATIONS RESULTING FROM THE CARETS PROJECT

This report is volume 1 of a thirteen-volume set constituting the official final report of the CARETS project. Abstracts of the other twelve volumes are presented in the first part of this appendix.

In addition to the official final report volumes, several other project reports and publications were issued during the course of the investigation, deriving their sponsorship from CARETS. These latter reports and publications are listed in the second part of this appendix.

ABSTRACTS OF CARETS FINAL REPORT VOLUMES 2 THROUGH 13

Reports produced under Interagency Memorandum of Understanding No. S-70243-AG; Earth Resources Technology Satellite, Investigation SR-125 (IN-002), "Central Atlantic Regional Ecological Test Site: A Prototype Regional Environmental Information System."

Volume 2

Alexander, R.H., Buzzanell, P.J., Fitzpatrick, K.A., Lins Jr., H.F., and McGinty III, H.K., 1975, Central Atlantic Regional Ecological Test Site (CARETS) project, v. 2, parts A and B, Norfolk and environs: a land use perspective: NASA Goddard Space Flight Center, 353 p.

The Norfolk-Portsmouth Standard Metropolitan Statistical Area (SMSA) in southeastern Virginia was the site of intensive testing of a number of land resources assessment methods, built around the availability of remotely sensed data from the Earth Resources Technology Satellite (ERTS-1), later renamed Landsat 1. The Norfolk tests were part of a larger experiment known as the Central Atlantic Regional Ecological Test Site (CARETS), designed to test the extent to which Landsat and associated high-altitude aircraft data could be used as cost-effective inputs to a regional land use information system.

The Norfolk SMSA contains a variety of land uses typical of the urbanized eastern seaboard, along with typical associated problems: rapid urbanization; heavy recreational, commercial and residential demands on fragile beaches and coastal marsh environments; industrial, transportation, and governmental land and water uses impacting on residential and agricultural areas; drainage and land stability difficulties affecting construction and other uses; and increasing difficulties in maintaining satisfactory air and water quality.

Land use and land cover data at three levels of detail (Level I, most aggregated; Level III, most detailed) were derived by manual image interpretation from both aircraft and satellite sources and used to characterize the 1,766 km^2 (682 mi^2) SMSA from the perspective of its various resource-related activities and problems. Measurements at Level I from 1:100,000 scale maps revealed 42 percent of the test area (excluding bays and estuaries) to be forest, 28 percent agriculture, 23 percent urban and built-up, 4 percent nonforested wetlands, and 2 percent water. At the same scale and level of detail, 10 percent of the SMSA underwent change from one land use category to another in the period 1959-1970, 62 percent of which involved the relatively irreversible change from forest or agriculture to urban uses. Digitization and machine processing of line data from land use maps facilitated these and other area measurements and comparisons.

CARETS research found the traditional concepts of map accuracy to be not exactly applicable to assessments and comparisons of land use maps derived from aircraft and Landsat remote sensor data. The investigation included field observations and a variety of photo and image sampling methods for accuracy assessments. With the exception of urban-rural fringe areas where complex intermixtures occur, most Level I land use categories can be accurately interpreted using Landsat imagery.

The aircraft data used in this study (color infrared photography at a scale of 1:120,000) provided more detailed land use information than Landsat data (in the form of color composite enlargements to scales of 1:100,000 and 1:250,000). The greater detail, however, is obtained at increased costs. Aircraft data interpretation and editing costs (exclusive of field checking, digitizing and publication costs) for producing Level II land use coverage of the SMSA at a scale of 1:100,000 amounted to $1,824 (1973 dollars), or $0.92 per km^2 ($2.38 per mi^2). Similar costs for Level I coverage for Landsat, at a scale of 1:250,000 amounted to $150, or $0.08 per km^2 ($0.20 per mi^2).

The CARETS project demonstrated applications of the land use information in regional problem-solving in examples of air quality planning, transportation planning, land use planning, and coastal zone management. The project also produced a new Earth materials map, depicting surficial geologic conditions as they affect land capability and suitability. These maps in turn serve as complementary data to aid in interpretation of land use prospects. CARETS investigators conducted this study in cooperation with the staff of the Southeastern Virginia Planning District Commission, who evaluated the data and results as applied to regional planning activities in the SMSA. In addition, several Federal, State, and local user agencies assisted in evaluating the study results.

Volume 3

Ackerman, E.A. and Alexander, R.H., 1975, Central Atlantic Regional Ecological Test Site (CARETS) project, v. 3, Toward a national land use information system: NASA Goddard Space Flight Center, Type III Final Rept., 68 p.

It is recommended that a national land use information system be established by an agency of the Federal Government. This recommendation comes at a time of increasing demand for scientific information in support of environmentally relevant land use planning and management at all levels of government. It is also a time when new airborne and spaceborne remote sensors, tested in cooperation with the National Aeronautics and Space Administration (NASA) and the Earth Resources Observation Systems (EROS) Program of the Department of the Interior, make possible the gathering of land use information rapidly and on an unprecedented scale. Furthermore, information-handling technology is developing toward a capability to receive, store, and disseminate the huge quantities of data that would be involved.

The recommendation for the national land use information system is based upon careful analysis of the results of remote sensing experiments funded by NASA, EROS, and the Geography Program of the Geological Survey, with specific examples drawn from the demonstration project known as the Central Atlantic Regional Ecological Test Site (CARETS). CARETS is cast in the framework of a regional land use information system, channeling the flow of information generated in response to users' declaration of their needs, through stages dealing with remote sensing data gathering systems, data processing and land mensuration, calibration in terms of environment impact, and evaluation with feedback from users.

The proposed system would develop and implement a unified approach to the description and interpretation of the changing uses of the nation's land resources, building upon the base of interagency and intergovernmental cooperation already achieved in the experimental work to date. The land use data base that is being derived from high-altitude aerial color infrared photography would be the initial component of the recommended system. High-altitude photographic coverage would immediately be extended to as much of the nation as possible as technological developments and economic considerations permit. The system would later expand to include multiple-sensor, multiple-platform data sources. Six system characteristics are recommended: (1) high capacity storage of data available for quick retrieval, inexpensive processing, and update; (2) provision of accuracy appropriate to the scale of survey or to the level of detail dictated by different types of management and decision requirements; (3) permanent, publicly accessible sensor records for historical interpretation; (4) compatibility of the recording, storage, and retrieval system with all types of inputs, from ground observer to satellite; (5) products of diverse formats and scales, responsive to user feedback; and (6) standardization of formats, scales, and storage inputs to permit nationwide comparability.

Volume 4

Mitchell, W.B., Fegeas, R.B., Fitzpatrick, K.A., and Hallam, C.A., 1977, Central Atlantic Regional Ecological Test Site (CARETS) Project, v. 4, Geographic information system development in the CARETS project: NASA Goddard Space Flight Center, Final Rept., 68 p.

Experience in the development of a geographic information system to support the CARETS Project has confirmed the considerable advantages that may accrue by paralleling the system development with a rational and balanced system production effort which permits the integration of the education and training of users with interim deliverable products to them. Those advantages include support for a long-term staff plan that recognizes substantial staff changes through system development and implementation, a fiscal plan that provides continuity in resources necessary for total system development, and a feedback system which allows the user to communicate his experiences in using the system. Thus far, balance between system development and system production has not been achieved because of continuing large-scale spatial data processing requirements coupled with strong and insistent demands from users for deliverable products from the system. That imbalance has refocused staffing and fiscal plans from long-range system development to short- and near-term production requirements, continuously extends total system development time, and increases the possibility that later system development may alter the usefulness of current interim products.

Volume 5

Alexander, R.H., De Forth, P.W., Fitzpatrick, K.A., Lins Jr., H.F., and McGinty III, H.K., 1975, Central Atlantic Regional Ecological Test Site (CARETS) Project, v. 5, Interpretation, compilation and field verification procedures in the CARETS project: NASA Goddard Space Flight Center, 107 p.

The production of the CARETS map data base involved the development of a series of procedures for interpreting, compiling, and verifying data obtained from remote sensor sources. Level II land use mapping from high-altitude aircraft photography at a scale of 1:100,000 required production of a photomosaic mapping base for each of the forty-eight 50 x 50 km sheets, and the interpretation and coding of land use polygons on drafting film overlays. CARETS researchers also produced a series of 1970 to 1972 land use change overlays, using the 1970 land use maps and 1972 high-altitude aircraft photography. To enhance the value of the land use sheets, researchers compiled series of overlays showing cultural features, county boundaries and census tracts, surface geology, and drainage basins.

In producing Level I land use maps from Landsat imagery, at a scale of 1:250,000, interpreters overlaid drafting film directly on Landsat color composite transparencies and interpreted on the film. They found that such interpretation involves pattern and spectral signature recognition. In studies using Landsat imagery, interpreters identified numerous areas of change but also identified extensive areas of "false change," where Landsat spectral signatures but not land use had changed.

CARETS investigators conducted extensive field verification exercises to determine and improve map accuracy. They also used field checking to test the USGS land use classification scheme.

From the CARETS interpretation and compilation experience, investigators conclude that the high-altitude aircraft photography is easier to interpret and provides greater detail and more accurate data than does Landsat imagery. Landsat imagery, on the other hand, allows interpreters to produce a very generalized land use map of a large area, quickly and inexpensively.

Volume 6

Fitzpatrick, K.A., 1975, Central Atlantic Regional Ecological Test Site (CARETS) Project, v. 6, Cost, accuracy, and consistency comparisons of land use maps made from high-altitude aircraft photography and ERTS imagery: NASA Goddard Space Flight Center, 57 p.

Accuracy analyses for land use maps of the 74,712 km^2 Central Atlantic Regional Ecological Test Site were performed for a one percent sample of the area. Researchers compared Level II land use maps produced at three scales, 1:24,000, 1:100,000, and 1:250,000 from high-altitude photography, with each other and with point data obtained in the field. They employed the same procedures to determine the accuracy of the Level I land use maps produced at 1:250,000 from high-altitude photography and color-composite ERTS imagery.

The accuracy of the Level II maps was 84.9 percent at 1:24,000, 77.4 percent at 1:100,000, and 73.0 percent at 1:250,000. Between 1:23,000 and 1:100,000 the generalization due to the smaller scale was measured as 4.6 percent, and between 1:100,000 and 1:250,000 the generalization was 4.1 percent. The accuracy of Level I 1:250,000 maps produced from high-altitude aircraft photography was 76.5 percent and for those produced from ERTS imagery was 69.5 percent. The difference in measured land use areas between the aircraft and ERTS maps, resulting from the coarser resolution of ERTS imagery, was 4.6 percent.

Accuracy estimates were compared to the costs of producing the maps. The cost of Level II land use mapping at 1:24,000 was found to be high ($11.93 per km^2) and was not offset by the slight increase in accuracy. The cost of mapping at 1:100,000 ($1.75) was about two times as expensive as mapping at 1:250,000 ($ .88), whereas the accuracy increased by only 4.4 percent. Level I land use maps at 1:250,000, when mapped from high-altitude photography, were about four times as expensive as the maps produced from ERTS imagery, although the accuracy is 7.0 percent greater. The Level I land use category that is least accurately mapped from ERTS imagery is urban and built-up land in the nonurban areas; in the urbanized areas built-up land is more reliably mapped.

Volume 7

Reed, W.E. and Lewis, J.E., 1975, Central Atlantic Regional Ecological Test Site (CARETS) Project, v. 7, Land use information and air quality planning: NASA Goddard Space Flight Center, 91 p.

The pilot national land use information system developed by the U.S. Geological Survey in the Central Atlantic Regional Ecological Test Site project has provided an improved technique for estimating emmissions, diffusion, and impact patterns of sulfur dioxide (SO_2) and particulate matter.

Implementation of plans to control air quality requires land use information, which, until this time, has been inadequate. The pilot system, however, provided data for updating information on the sources of point and area emissions of SO_2 and particulate matter affecting the Norfolk-Portsmouth area of Virginia for the 1971-72 winter (Dec.-Jan.-Feb.) and the annual 1972 period, and for a future annual period--1985. This emmission information is used as input to the Air Quality Display Model of the Environmental Protection Agency to obtain diffusion and impact patterns for the three periods previously mentioned. The results are: (1) During the 1971-72 winter, estimated SO_2 amounts over an area with a SW-NE axis in the central section of Norfolk exceeded both primary and secondary levels; (2) future annual levels of SO_2, estimated by anticipated residential development and point-source changes, are not expected to cause serious deterioration of the region's present air quality; and (3) for the 1971-72 winter and annual 1972 period the diffusion results showed that both primary and secondary standards for particulate matter are regularly exceeded in central Norfolk and Portsmouth. In addition, on the basis of current control programs, the 1985 levels of particulate matter are expected to exceed the presently established secondary air quality standards through central Norfolk and Portsmouth and in certain areas of Virginia Beach.

The land use information can be used to estimate emmissions for inputs to diffusion models and to interpret the implications of diffusion patterns for: (1) Implementing various control strategies, (2) selecting sites of air sampling stations, and (3) predicting the effects that proposed changes in land use might have on emission patterns and air quality.

Volume 8

Pluhowski, E.J., 1977, Central Atlantic Regional Ecological Test Site (CARETS) Project, v. 8, Remotely sensed land use information applied to improved estimates of streamflow characteristics: NASA Goddard Space Flight Center, Final Rept., 80 p.

Land use data derived from high-altitude photography and satellite imagery is presented for 49 basins in Delaware, and eastern Maryland and Virginia. Based on 1:100,000 scale maps from high-altitude photography basin land cover was extracted at the generalized Level I and the more detailed Level II classification categories. Level I land use data summaries were prepared for 46 of the basins using the 1:250,000 scale maps derived from Landsat imagery. Land cover in the basins ranged from 93.9 percent urban at Little Falls Branch near Bethesda, Maryland, to 96.2 agricultural at Morgan Creek near Kennedyville, Maryland.

Applying multiple regression techniques to a network of gaging stations monitoring runoff from 39 of the basins, it was demonstrated that land use data from high-altitude photography provides an effective means of significantly improving estimates of streamflow. By comparing 40 stream characteristic equations incorporating remotely sensed land use information with a control set of equations using map derived land cover, significant improvement was detected in six equations where Level I data was added and in five equations where Level II information was utilized. Only four equations were improved significantly using land use data derived from Landsat imagery. Significant accuracy losses due to the use of remotely sensed land use information were detected only in estimates of flood peaks.

Volume 9

Dolan, R., Hayden, B.P., Vincent, C.L., 1975, Central Atlantic Regional Ecological Test Site (CARETS) Project, v. 9, Shore zone land use and land cover: NASA Goddard Space Flight Center, 52 p.

Anderson's 1972 United States Geological Survey classification in modified form was applied to the barrier-island coastline within the CARETS region. High-altitude, color-infrared photography of December 1972, and January, 1973, served as the primary data base in this study. The CARETS shore zone study was divided into six distinct geographical regions; area percentages for each class in the modified Anderson classification are presented. Similarities and differences between regions are discussed within the framework of man's modification of these landscapes. The results of this study are presented as a series of 19 maps of land use categories. Recommendations are made for a remote sensing system for monitoring the CARETS shore zone within the context of the dynamics of the landscapes studied.

Volume 10

Buzzanell, P.J. and McGinty III, H.K., 1975, Central Atlantic Regional Ecological Test Site (CARETS) Project, v. 10, Environmental problems in the coastal and wetlands ecosystems of Virginia Beach, Virginia: NASA Goddard Space Flight Center, 14 p.

Many of the city of Virginia Beach's beach stabilization and sewage disposal problems are the result of an inadequate understanding of the physical and biological systems. Influenced by population and economic pressures, natural systems were artifically stabilized by engineering projects that had to be constantly maintained. These same pressures continue to prevail today in spite of a new environmental awareness; changes are occurring very slowly.

Furthermore, the lack of adequate sewage disposal facilities and the continued urbanization of inappropriate areas are threatening Virginia Beach's attractiveness as a resort area.

Volume 11

Buzzanell, P.J., 1975, Central Atlantic Regional Ecological Test Site (CARETS) Project, v. 11, Potential usefulness of CARETS data for environmental impact assessment: NASA Goddard Space Flight Center, 72 p.

The National Environmental Protection Act of 1969 requires that Federal agencies prepare environmental impact statements (EIS) for all proposed actions that significantly affect the quality of the environment. The EIS builds a predictive model of beneficial or adverse changes resulting from an action. Environmental impact statement preparation requires identification of environmental, social, and economic conditions likely to change and also requires prediction of intensity and spatial dimensions of changes. The Central Atlantic Regional Ecological Test Site (CARETS) project has produced land use data that can be of value for such assessment.

To ascertain the types of proposed actions requiring EIS's, all EIS's prepared for proposed actions in the test site between January 1970 and June 1974 were reviewed. The actions were divided into seven categories: (1) construction of transportation and communication facilities; (2) construction of power plant, powerline, and fuel line facilities; (3) urban renewal, new town development projects, and multistory building construction; (4) construction of facilities for watershed protection and development; (5) construction of waste treatment and disposal facilities; (6) maintenance dredging, navigation improvements, and beach erosion control and replenishment projects; and (7) establishing or enhancing land and water conservation areas. Examples of actions from each category were selected for more detailed study.

In view of the types of projects being proposed, an approach to environmental impact assessment using land use and water data as central inputs was recommended. The viability of such an approach as well as other approaches depends upon the availability of quantitative data such as those produced by the CARETS project.

Volume 12

McGinty III, H.K., 1975, Central Atlantic Regional Ecological Test Site (CARETS) Project, v. 12, User evaluation of experimental land use maps and related projects from the central Atlantic test site: NASA Goddard Space Flight Center, 170 p.

The user interaction and evaluation phase of the USGS/NASA Central Atlantic Regional Ecological Test Site was designed to obtain the input of local, regional, State, and Federal agency users of land resource information into the development of a regional information system; to provide users with assistance and data resulting from CARETS research; and to have user organizations evaluate to what extent the CARETS products meet their needs.

The evaluation of CARETS land use and related products revealed that most user agencies interviewed, at all governmental levels, require more detailed data than that provided by the CARETS project. Few agencies found utility in the generalized ERTS Level I land use maps. Level II data, though reported valuable by several users, was generally considered of secondary utility by most users. The products considered most useful by users at all levels were the high-altitude color-infrared photographs and the USGS orthophotoquads.

Recommendations resulting from the evaluation reflect the need to establish a flexible and reliable system for providing more detailed raw and processed land resource information as well as the need to improve the methods of making information available to users.

Volume 13

Bendelow, S.W., and Goodyear, F.F., 1975, Central Atlantic Regional Ecological Test Site (CARETS) Project, v. 13, Utility of CARETS products to local planners: an evaluation: NASA Goddard Space Flight Center, 46 p.

The Metropolitan Washington Council of Governments (MWCOG) in cooperation with and under contract to the U.S. Geological Survey, conducted an evaluation of the utility of remote sensor derived land

use data produced by the USGS Central Atlantic Regional Ecological Test Site (CARETS) project. Investigators invited representatives of Washington, D.C. metropolitan area planning agencies to a workshop, introduced them to the CARETS products, and asked them to evaluate the products. In follow-up interviews, planners from 12 participating agencies reported general support for the full spectrum of CARETS products but gave more positive responses towards products with which they had some familiarity. Planners considered some products of limited utility because of (1) insufficient detail, (2) too small a scale, or (3) lack of technical capability to incorporate the information and products into the current planning process. Some planners expressed doubt about the application of CARETS products in most day-to-day planning activities, which involve specific rezoning requests of site development plans requiring highly localized data. The greatest potential of the CARETS products was in the identification of broad development patterns at the county or regional level. An appendix documents the results of an inventory of local government decisions relating to land use change.

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Fitzpatrick, K. A. and Lins Jr., H. F., 1972, A preliminary evaluation of land use mapping and change detection capabilities using an ERTS image covering a portion of the CARETS region: U.S. Geol. Surv. Progress Rept. prepared in support of NASA/ERTS Expt. No. 125, Task 32 (434-641-14-07-60).

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McGinty, H. K., and Fitzpatrick, K. A., 1975, An evaluation of land use maps compiled from Landsat imagery using nonautomated techniques: Paper presented at 72nd Ann. Meeting, Assoc. Am. Geographers, New York, N.Y., 10p.

Alexander, R. H., Fitzpatrick, K. A., Letke, K. S., Lins Jr., H. F., and McGinty III, H. K., 1976, Land use and land cover Central Atlantic Regional Ecological Test Site (CARETS), 1972: MF-798, U.S. Geol. Survey.

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APPENDIX B

CARETS DATA PRODUCTS: LISTS AND EXAMPLES

Appendix B contains lists, index maps, and examples of data products that were produced by the CARETS project, including products in graphic and digital form. The actual products are available through inquiry to the Chief, Geography Program, U.S. Geological Survey, 710 National Center, Reston, Virginia 22092.

Table B.1.--Information products handled by CARETS project: imagery, graphics and maps

INFORMATION PRODUCTS	AVAILABLE FOR ENTIRE TEST REGION	AVAILABLE FOR NORFOLK-PORTSMOUTH SMSA	AVAILABLE FOR WASHINGTON SMSA	NUMBER OF "PIECES" HANDLED
REMOTE SENSING IMAGERY				
"Raw" Landsat imagery, 1:3,300,000	x			2220
Landsat false-color composites, 1:1,000,000	x			8
Landsat false-color composites, 1:250,000	x			24
Landsat false-color composites, 1:100,000		x		4
Landsat black-and-white prints, 1:1,000,000	x			64
Landsat black-and-white prints, 1:250,000		x	x	80
Aircraft photography, 1970	x			954
Aircraft photography, 1971-1973				2092
Aircraft photography, 1959		x		60
Low-altitude aircraft and ground photos		x	x	460
MAPS DERIVED FROM REMOTE SENSING				
Land use from Landsat data, 1:250,000; 1:500,000; 1:1,000,000; and 1:2,000,000	x			230
Gridded photomosaic, 1:100,000	x			290
Land use from aircraft data, 1:100,000	x			398
Land use change from aircraft data, 1:100,000	x			378
Land use change, 1959-1970, 1:100,000		x		2
Level III land use, 1:100,000		x		2
OTHER MAPS				
County boundaries, 1:250,000	x			72
County boundaries and census tracts, 1:100,000	x			398
Drainage basins, 1:100,000	x			398
Culture and place names, 1:100,000	x			398
Surficial geology, 1:100,000		x	x	212
Air quality data and simulation		x		16

Table B.2.--List of CARETS maps at 1:100,000 scale[1]

Map Sheet Name	Map Sheet Number[3]	Geology Coverage[2]
Accomac	38	
Annapolis	18	x
Atlantic City	13	
Baltimore	10	
Belmont	28	
Berlin	33	
Bridgeton	12	
Burlington	6	
Cambridge	26	
Cape Charles	44	
Cape Mary	21	
Charles City	42	
Chesapeake Beach	25	x
Chestertown	19	
Chincoteague	39	
Coatesville	4	
Colonial Beach	30	
Darvils	40	
Dover	20	
Elkton	11	
Emporia	45	
Franklin	46	
Frederick	8	x
Goochland	34	
Indian Head	24	x
Leesburg	16	x
Lexington Park	31	
Little Egg Harbor	14	
Newton	3	
Norfolk	47	x
Orlean	22	
Petersburg	41	
Philadelphia	5	
Pottstown	1	
Quakertown	2	
Rehoboth Beach	27	
Richmond	35	
Salisbury	32	
Saluda	37	
Spotsylvania	29	
Toms River	7	
Upperville	15	x
Virginia Beach	48	x
Warrenton	23	x
Washington	17	x
Westminster	9	x
West Point	36	
Yorktown	43	

[1] Each sheet available in the following coverages: Photomosaic, Land Use 1970, Land Use Change 1970-72, Drainage Basins, County Boundaries and Census Tracts, Cultural Features

[2] Land forms and surface materials map available in whole or part

[3] Position number on index map, numbering from left to right in each row, and from top to bottom rows; thus Pottstown is No. 1, Virginia Beach No. 48

Table B.3.--Land use categories in the Central Atlantic Regional Ecological Test Site data base

Level I Categories and Map Notation Used	Level II Categories and Map Notation Used	Level III Categories and Map Notation Used
1-URBAN & BUILT UP	11-Residential	111-Single-family residential
	12-Commercial and services	
	13-Industrial	
	14-Extractive	
	15-Transportation, communications, and utilities	151-Highways and other auto transportation facilities
		152-Railroads and associated facilities
		153-Airports
	16-Institutional	
	17-Strip and clustered settlement	
	18-Mixed	
	19-Open and other	
2-AGRICULTURAL	21-Cropland and pasture	
	22-Orchards, groves, bush fruits, vineyards, and horticultural areas,	
	23-Feeding operations	
	24-Other	
4-FORESTLAND	41-Heavy crown cover (over 40%)	
	42-Light crown cover (10% to 40%)	
5-WATER	51-Streams and waterways	
	52-Lakes	
	53-Reservoirs	
	54-Bays and estuaries	
	55-Other	
6-NON-FORESTED WETLAND	61-Vegetated	
	62-Bare	
7-BARREN LAND	72-Sand other than beaches	
	73-Bare	
	74-Beaches	
	75-Other	

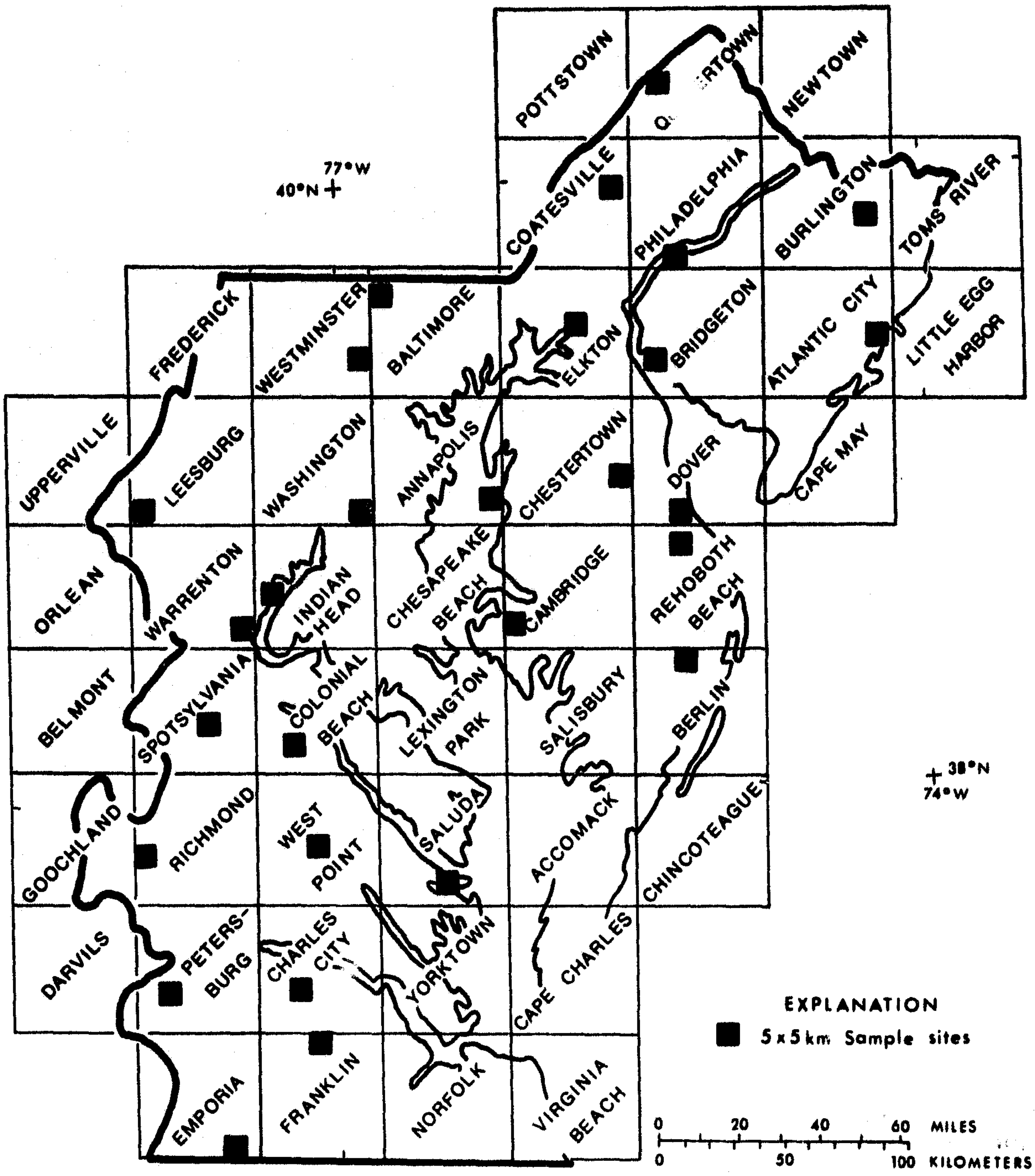


Figure B.1--Index to 48 sheets of CARETS 1:100,000 scale data base.

ORIGINAL PAGE IS OF POOR QUALITY

CONTROLLED PHOTOMOSAIC, 1970, OF THE WASHINGTON SHEET, D.C., MD., VA.
1973

Figure B.2--CONTROLLED PHOTOMOSAIC: REDUCED SPECIMEN SHEET, ORIGINAL SHEET 50 x 50 cm AT SCALE 1:100,000. INSERT IS FULL-SCALE COVERAGE SHOWN IN FIGURES B.3 THROUGH B.10

Figure B.3--High-altitude aircraft photo; scale 1:100,000, NASA Mission 144, October 1970 (area outlined on figures B.2 and B.11). EDC-010139

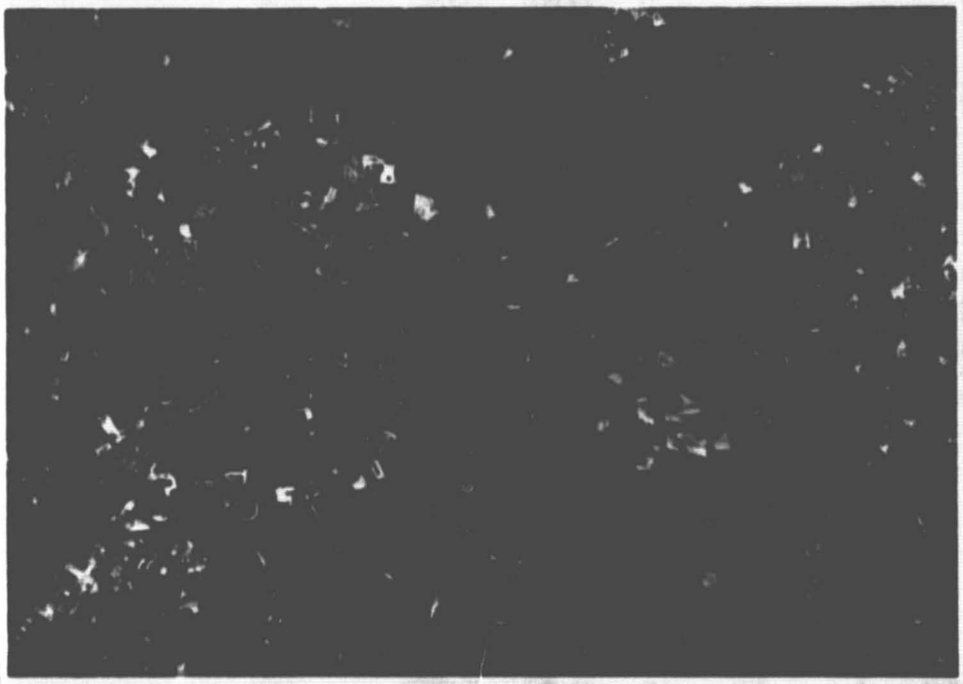


Figure B.4--Landsat color composite image, bands 4, 5, and 7; scale 1:100,000, E 1080-15192, October 11, 1972 (area outlined on figures B.2 and B.11). EDC-010140

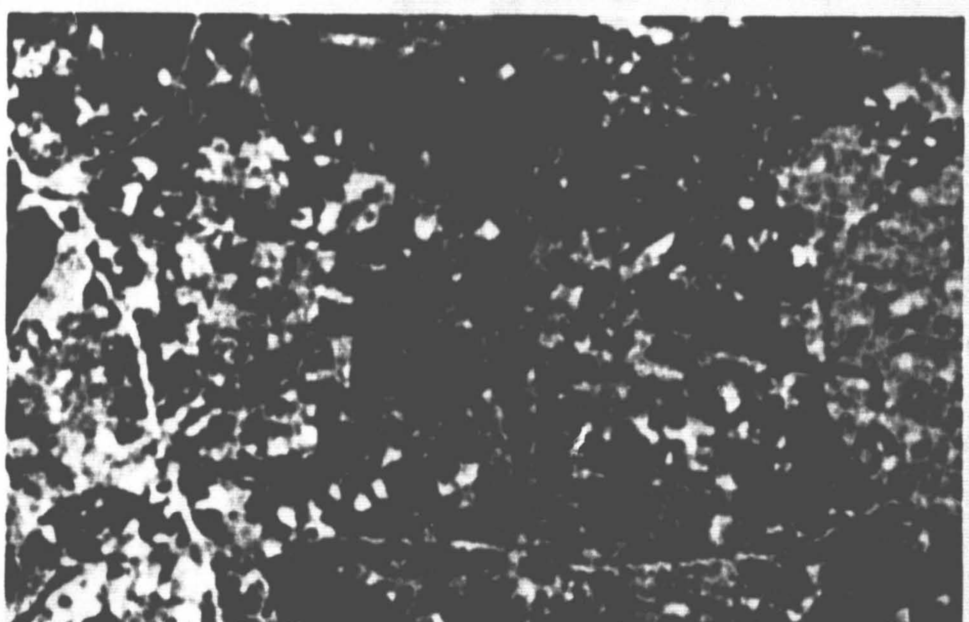


Figure B.5--LAND USE MAP FROM AIRCRAFT PHOTOGRAPHY, 1970, SCALE 1:100,000, LEGEND IN TABLE B.3 (area outlined on figures B.2 and B.11)

Figure B.6--LAND USE MAP FROM LANDSAT IMAGERY, 1972, SCALE 1:100,000 (original map at 1:250,000), LEGEND IN TABLE B.3 (area outlined on figures B.2 and B.11)

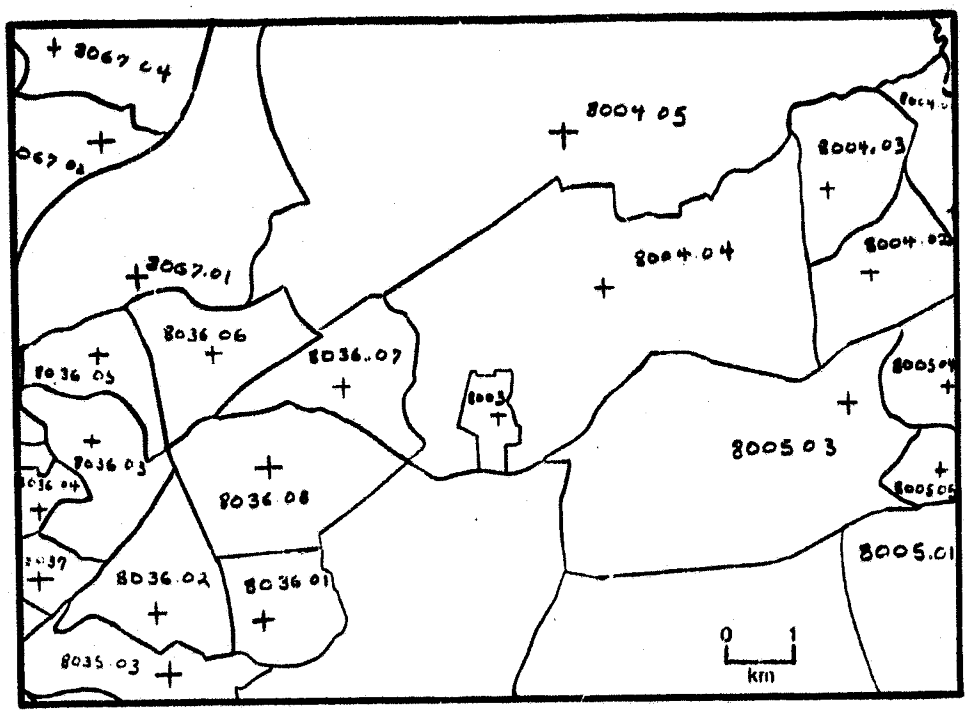


Figure B.7--CENSUS TRACT AND COUNTY BOUNDARY MAP, SCALE 1:100,000, CENSUS TRACT DESIGNATIONS (area outlined on figures B.2 and B.11)

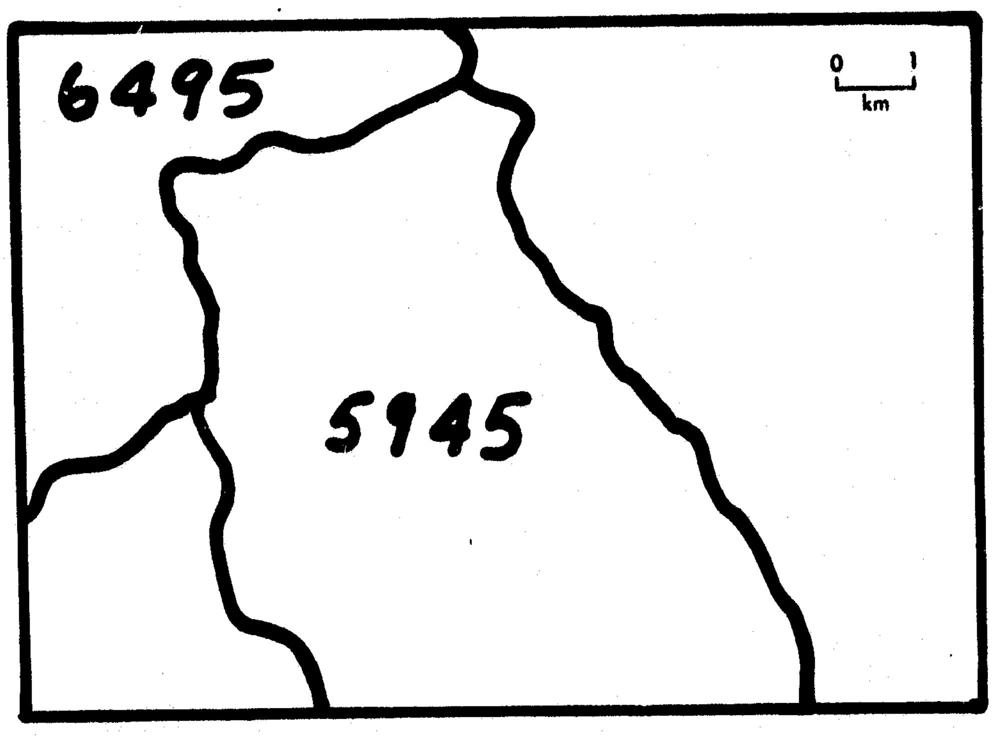


Figure B.8--SMALL DRAINAGE BASINS, USED IN STUDY OF EFFECTS OF LAND USE ON STREAM RUNOFF CHARACTERISTICS; BASIN DESIGNATIONS BY USGS WATER RESOURCES DIVISION (area outlined on figures B.2 and B.11)

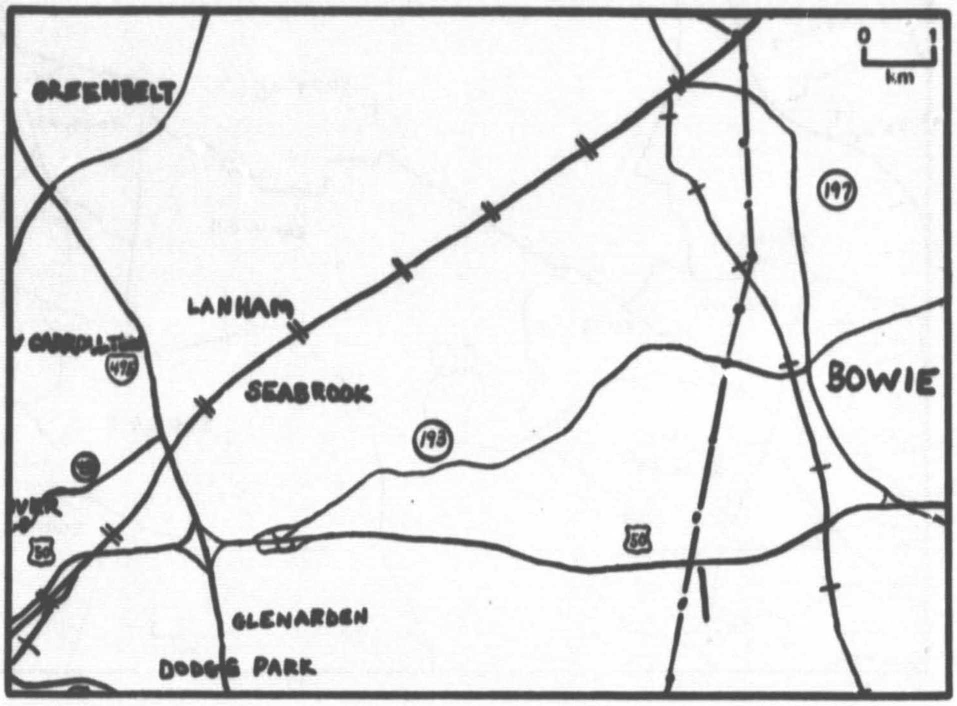


Figure B.9--CULTURAL FEATURES MAP AT SCALE 1:100,000 (area outlined on figures B.2 and B.11)

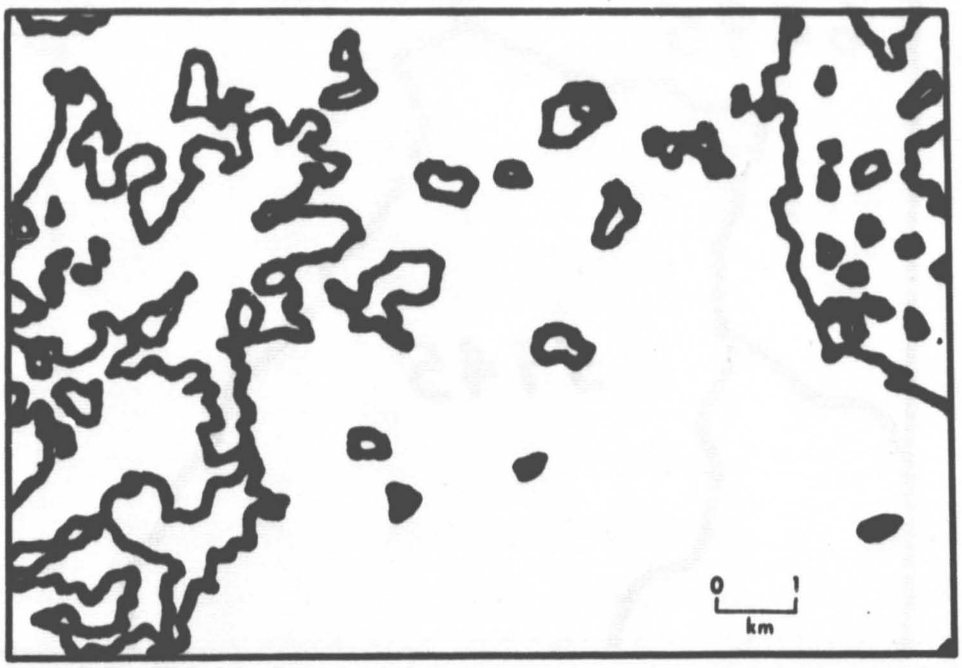
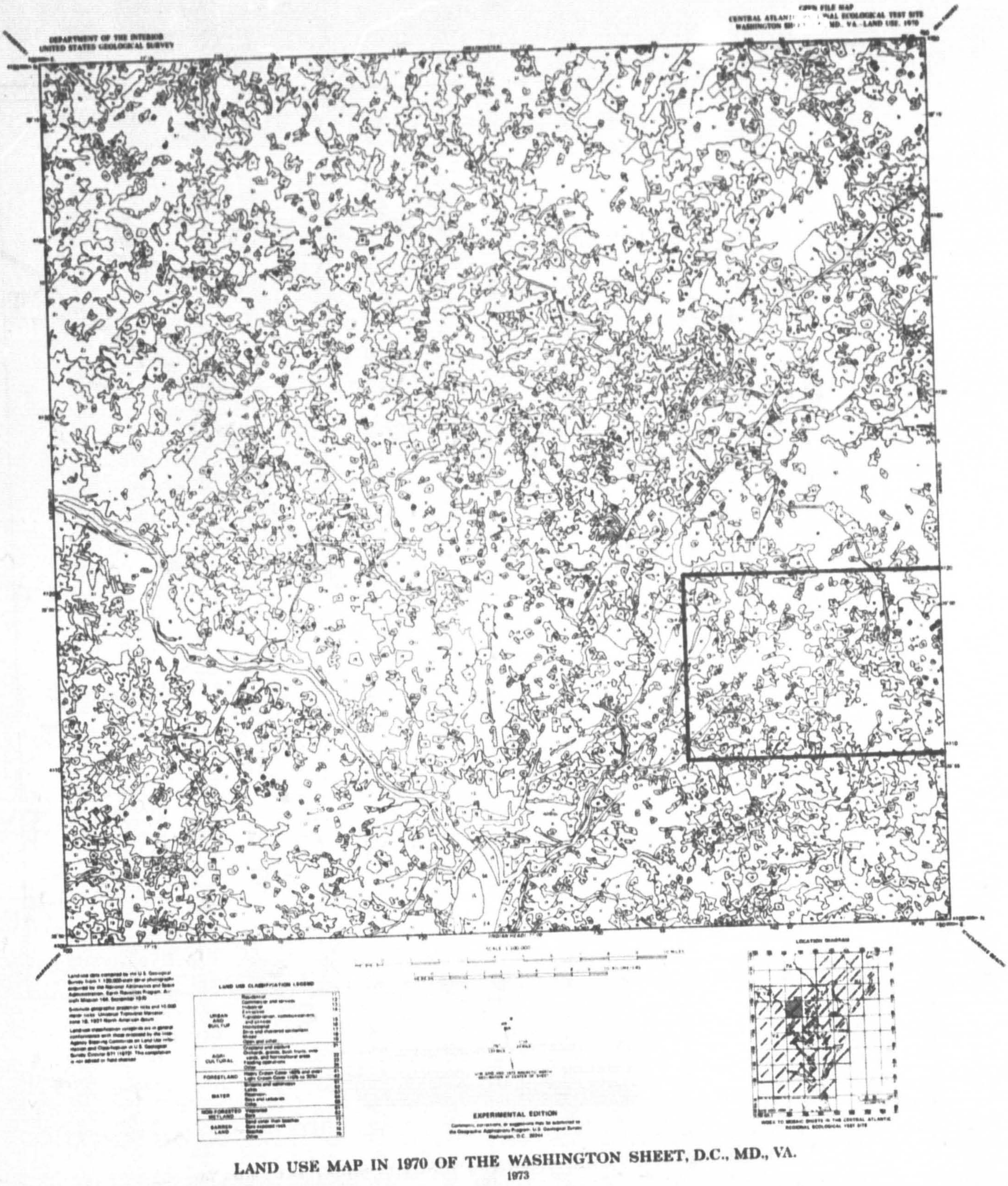


Figure B.10--EXPERIMENTAL DISPLAY OF DIGITIZED LAND USE MAP, URBAN RESIDENTIAL (CATEGORY 11) ONLY; HARD COPY FROM COMPUTER GRAPHICS TERMINAL LINKED BY LONG-DISTANCE LINE TO CANADA GEOGRAPHIC INFORMATION SYSTEM, OTTAWA (area outlined on figures B.2 and B.11)



LAND USE MAP IN 1970 OF THE WASHINGTON SHEET, D.C., MD., VA.
1973

Figure B.11--Land use map 1970: reduced specimen sheet, original sheet 50 x 50 cm at scale 1:100,000 (detailed coverage of figures B.3 through B.10 from area outlined).

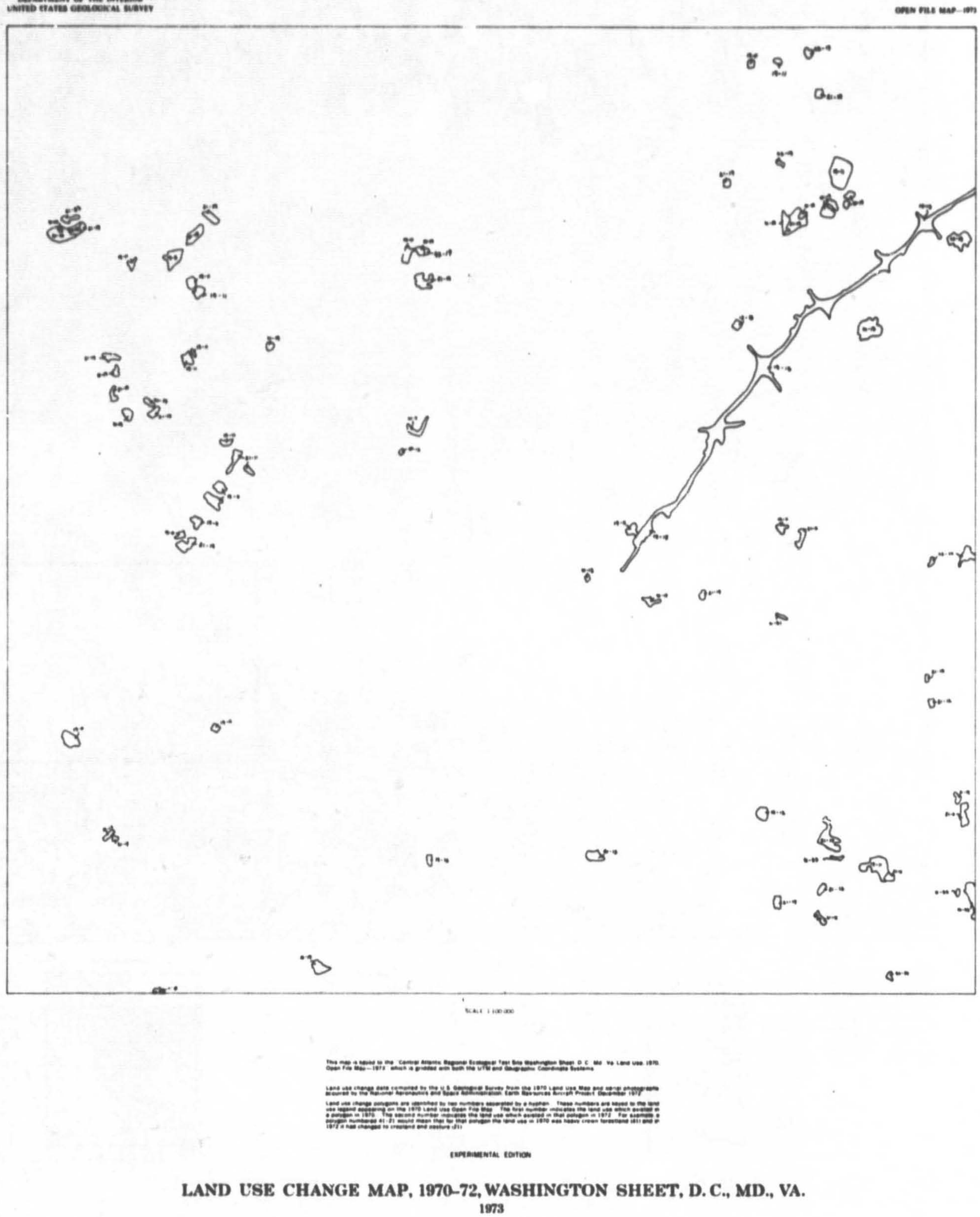
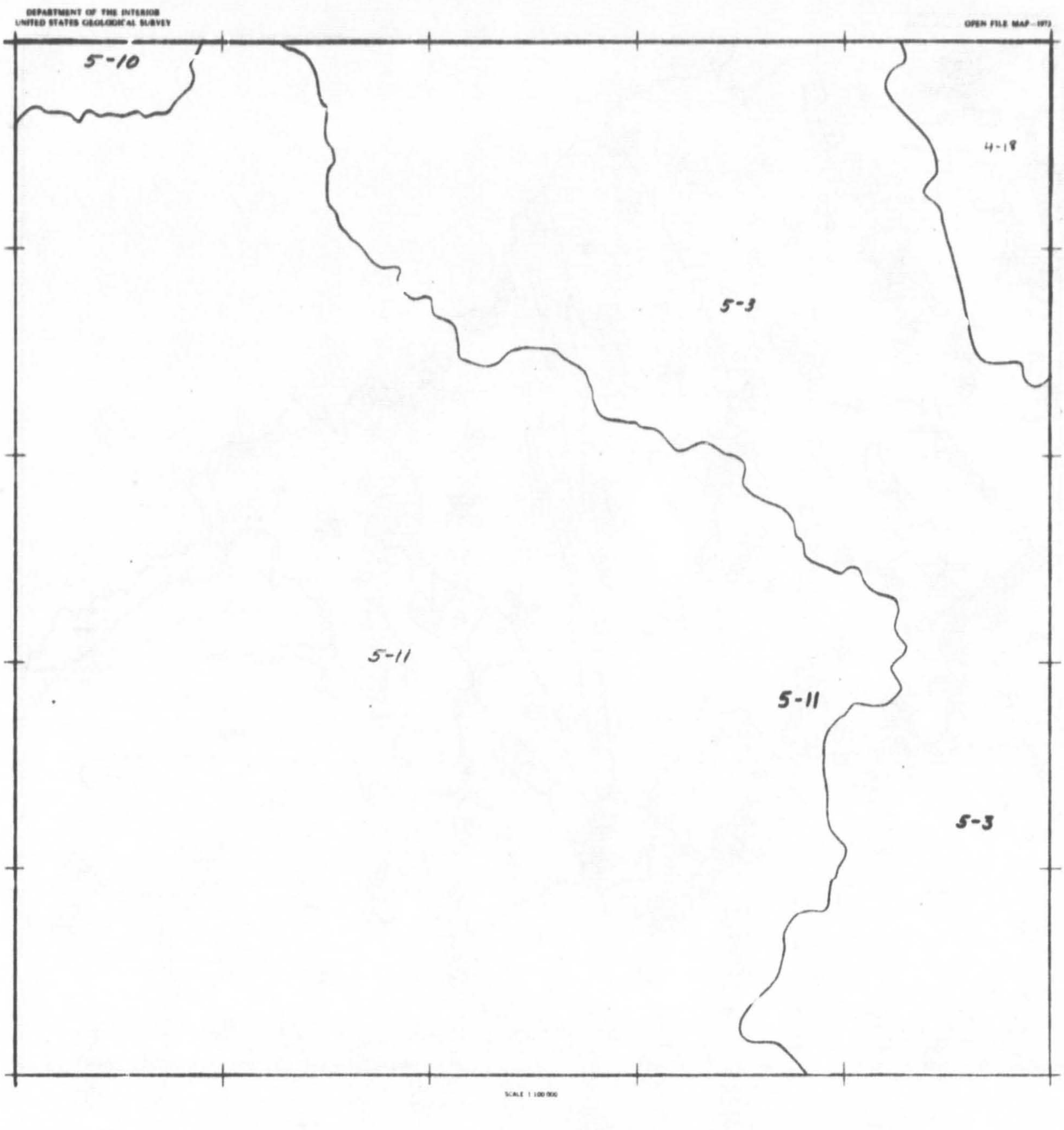


Figure B.12--Land use change map, 1970-1972: Reduced specimen sheet, original sheet 50 x 50 cm at scale 1:100,000.



EXPERIMENTAL EDITION

DRAINAGE BASIN MAP, 1970, WASHINGTON SHEET, D. C., MD., VA.
1973

Figure B.13--Drainage basin map: Reduced specimen sheet, original sheet 50 x 50 cm at scale 1:100,000.

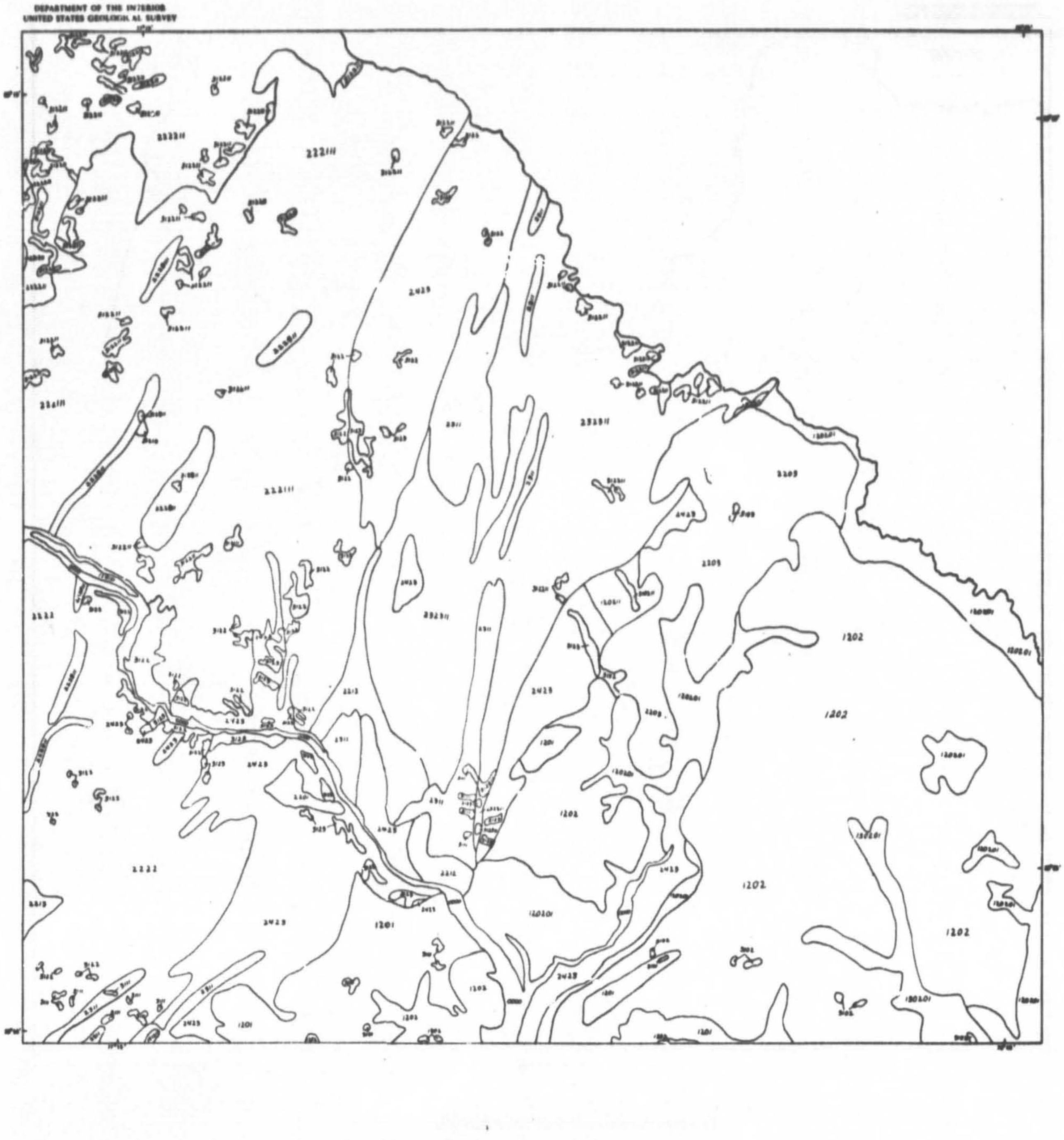


Figure B.14--Landforms and surface materials map: Reduced specimen sheet, original sheet 50 x 50 cm at scale 1:100,000.

Table B.4.--Landforms and surface materials classification legend

LANDFORMS-Digits 1 and 2		
	Water	00
	Marsh, swamp	01
No Slope, No Relief		
	Bogs	02
	Beaches	03
	Flats, undissected	11
	Flats, dissected	12
Little Slope, Small Relief		
	Flood plains	13
	Terraces	14
	Sand dunes	21
	Hills	22
Gentle to Steep Slope, Moderate Relief		
	Low Ridges	23
	Valley sides	24
	Gulley sides	25
	Ridges	31
Steep Slope, High Relief		
	Sinkholes	62
Negative Relief		
	Crater lands	64
	Vertical pits	66
	Made land (fill)	81
	Sanitary landfill	82
Man-made Features		
	Waste (mine)	83
	Quarries, pits	84
	Mined-out areas	91
Miscellaneous		
	Unstable slopes	92

LITHOGRAPHY-Digits 3 and 4 (Bedrock more than 9 feet below the surface)		
	Water	00
	Clay, silt	01
	Sand	02
	Gravel	03
Unconsolidated Deposits		
	Boulders	04
	Colluvium	05
	Talus	06
	Organic	07
	Granite	11
	Gabbro, diorite	12
Igneous Rocks		
	Basalt, diabase, felsite, rhyolite	13
	Phyllite	21
	Schist	22
	Gneiss	23
	Quartzite	24
Metamorphic Rocks		
	Metabasalt	25
	Marble	26
	Slate	27
	Serpentine	28
	Shale, siltstone, mudstone	30
Sedimentary Rocks		
	Sandstone	31
	Conglomerate	32
	Limestone, dolomite	35

MISCELLANEOUS DESCRIPTORS-Digits 5 and 6	
High water table	01
Shallow soil (bedrock less than 9 feet below surface)	11

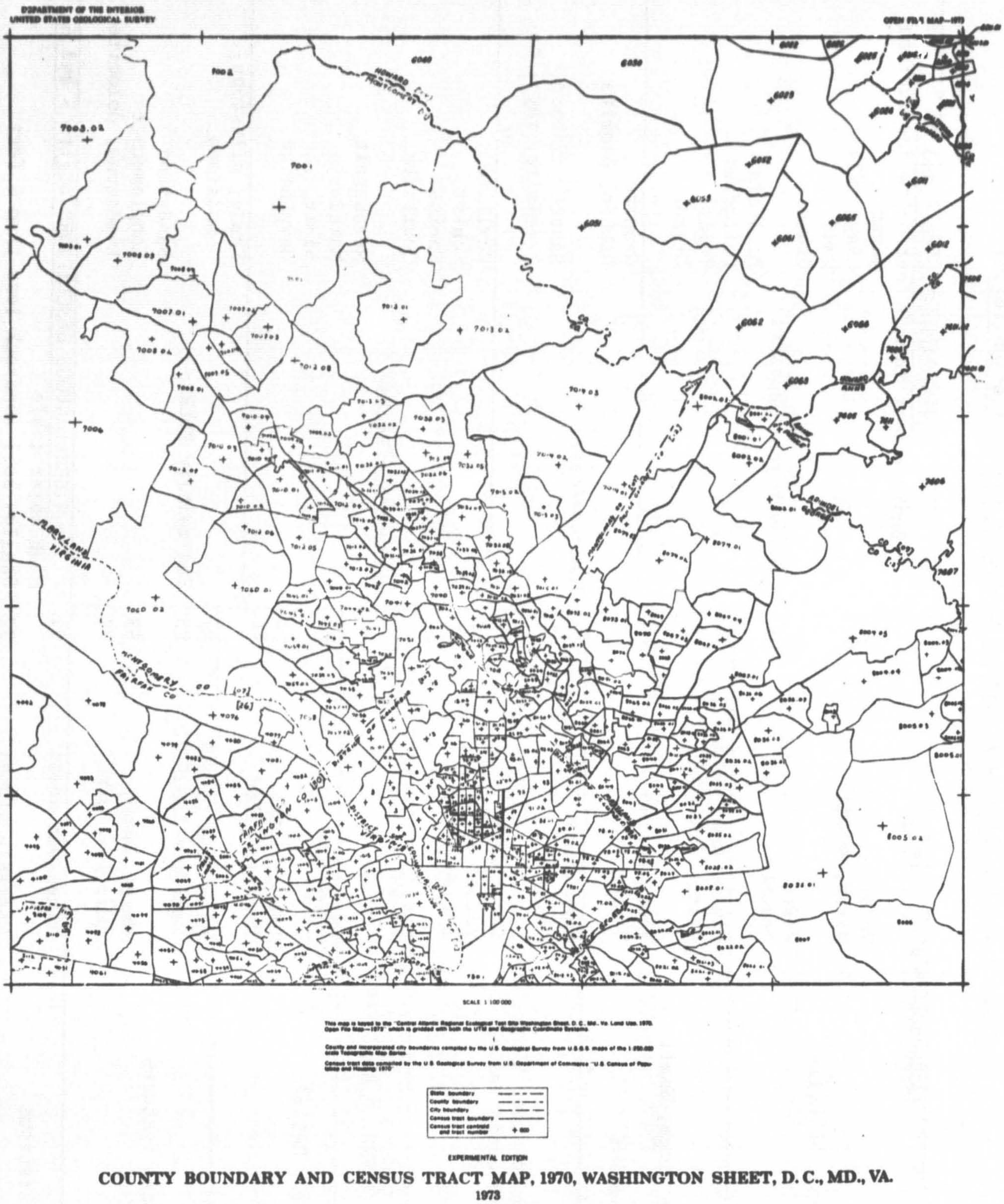


Figure B.15--County boundary and census tract map: Reduced specimen sheet, original sheet 50 x 50 cm at scale 1:100,000.

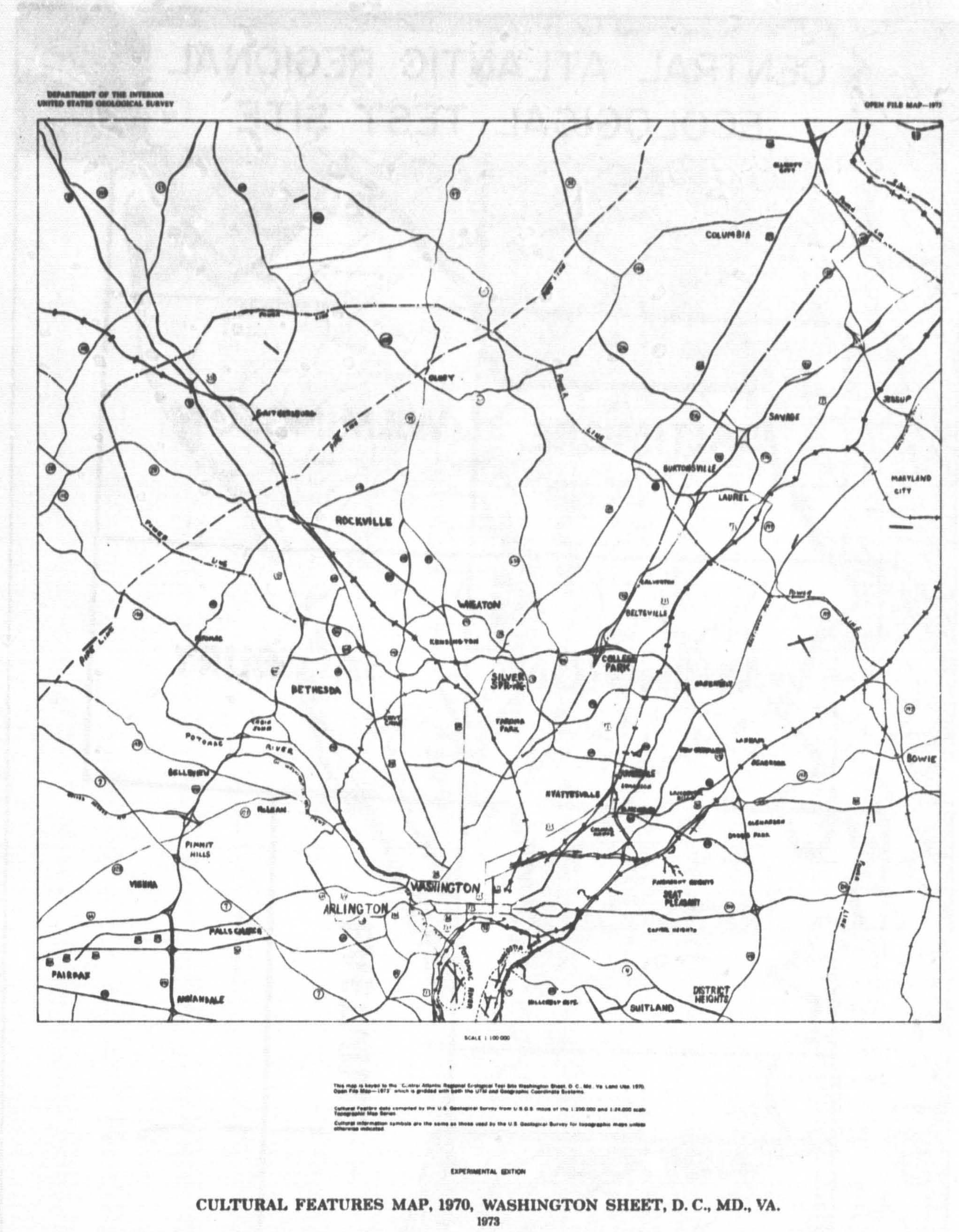


Figure B.16--Cultural features map: Reduced specimen sheet, original sheet 50 x 50 cm at scale 1:100,000.

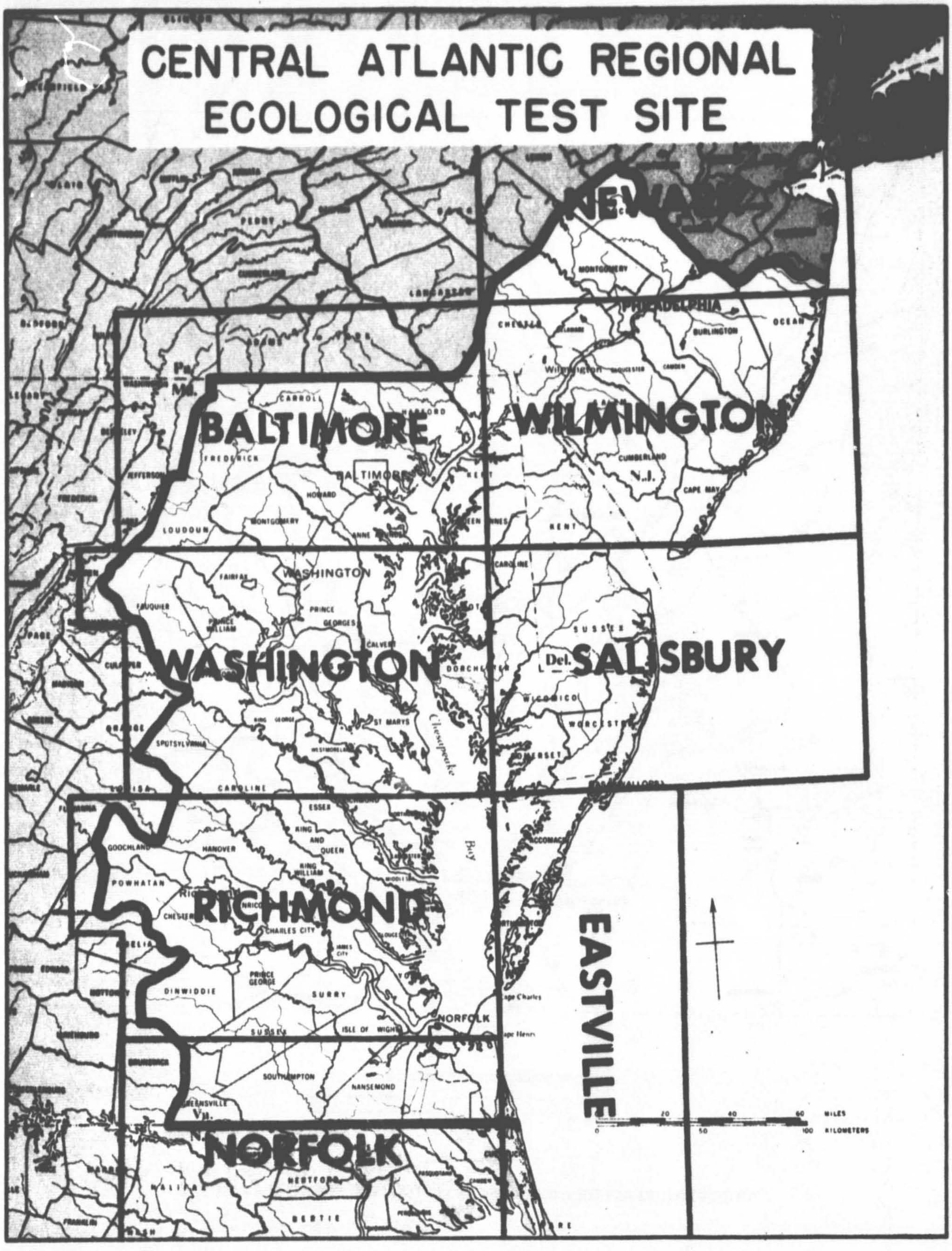


Figure B.17--Index to 8 sheets of CARETS (Landsat) 1:250,000 scale data base.

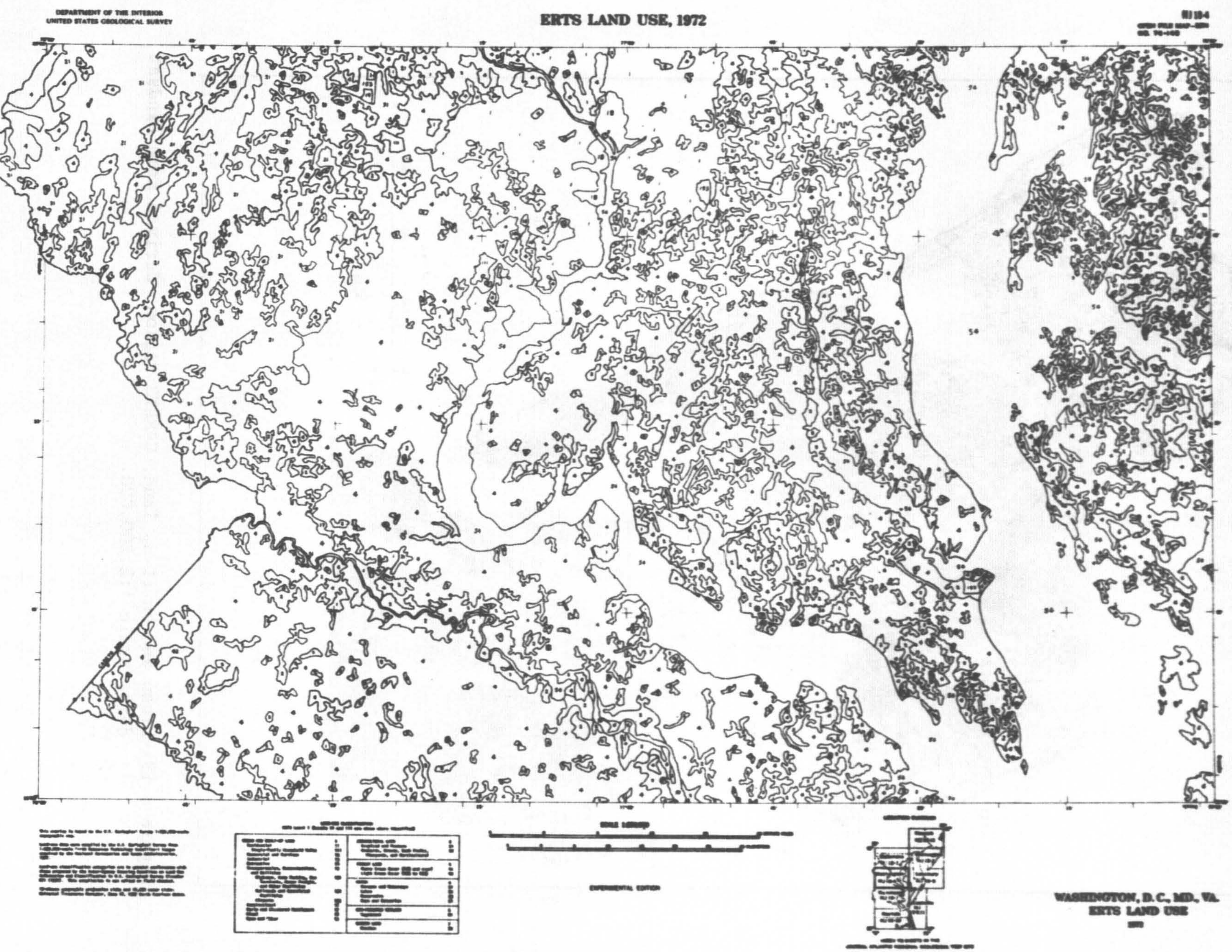


Figure B.18--Land use from Landsat imagery: Reduced specimen sheet, original sheet 44 x 71 cm at 1:250,000 scale.

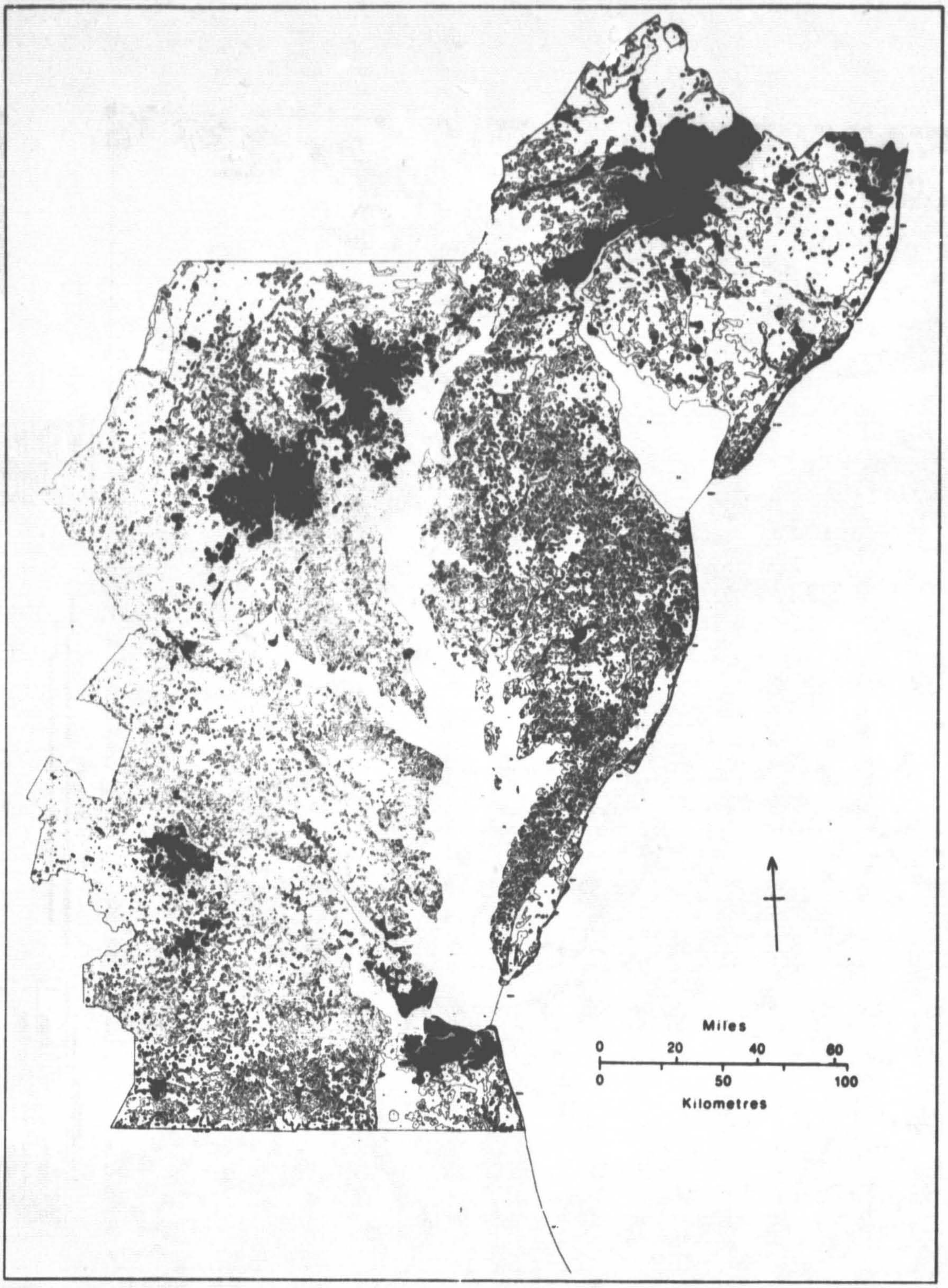


Figure B.19--Urban and built-up land, CARETS region, derived from Landsat data, scale 1:2,500,000.

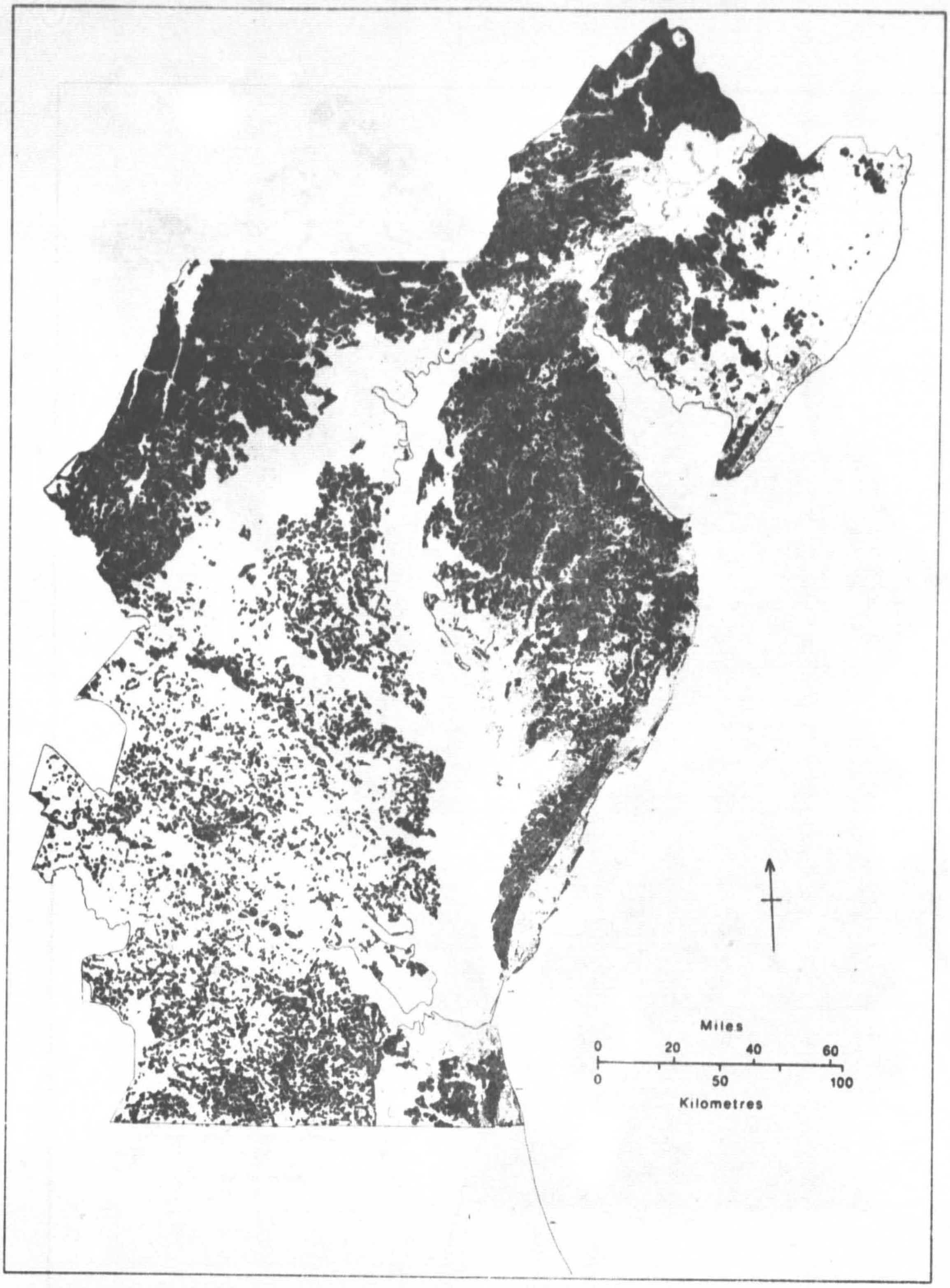


Figure B.20--Agricultural land, CARETS region, derived from Landsat data, scale 1:2,500,000.

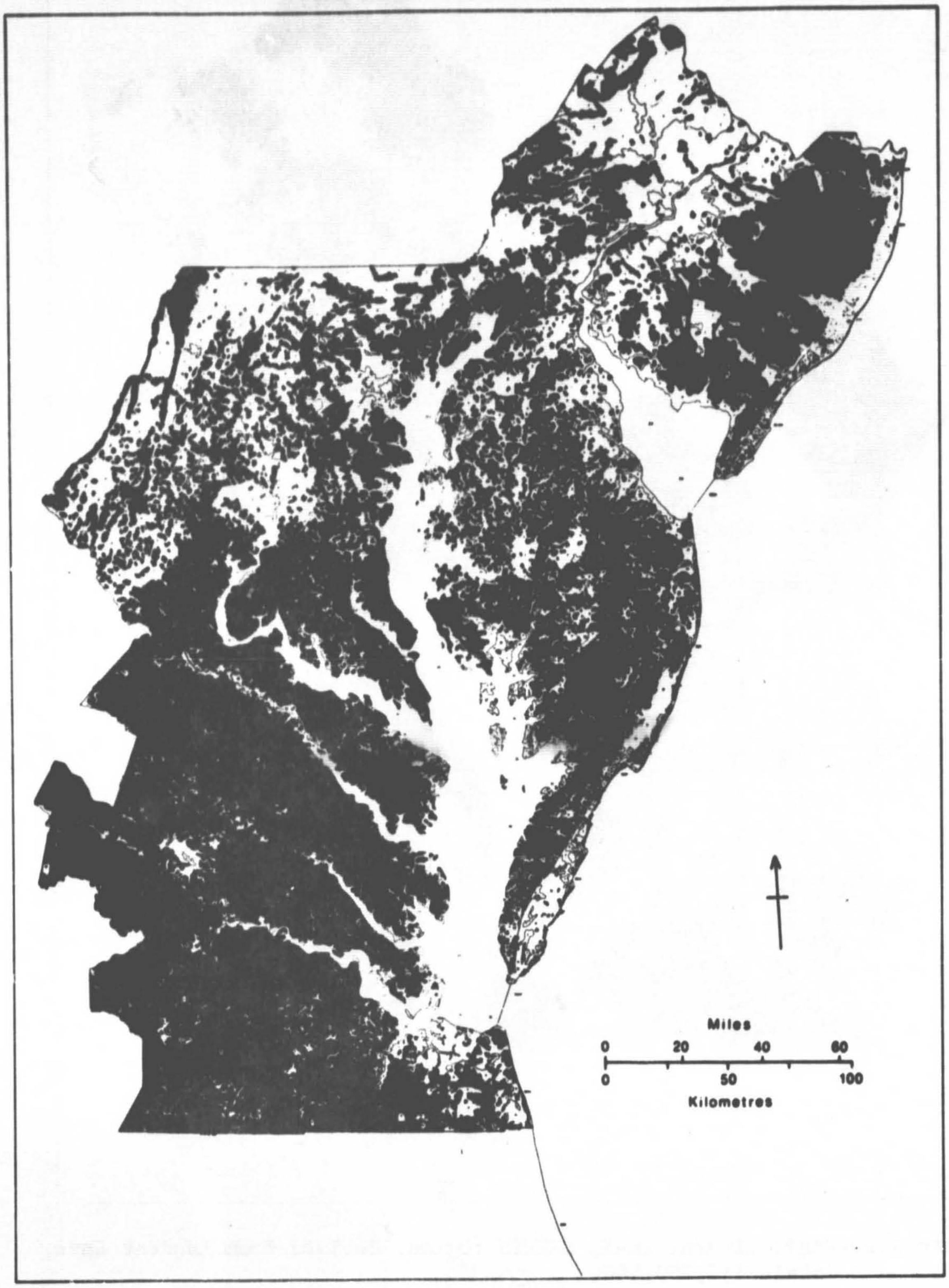


Figure B.21--Forest land, CARETS region, derived from Landsat data, scale 1:2,500,000.

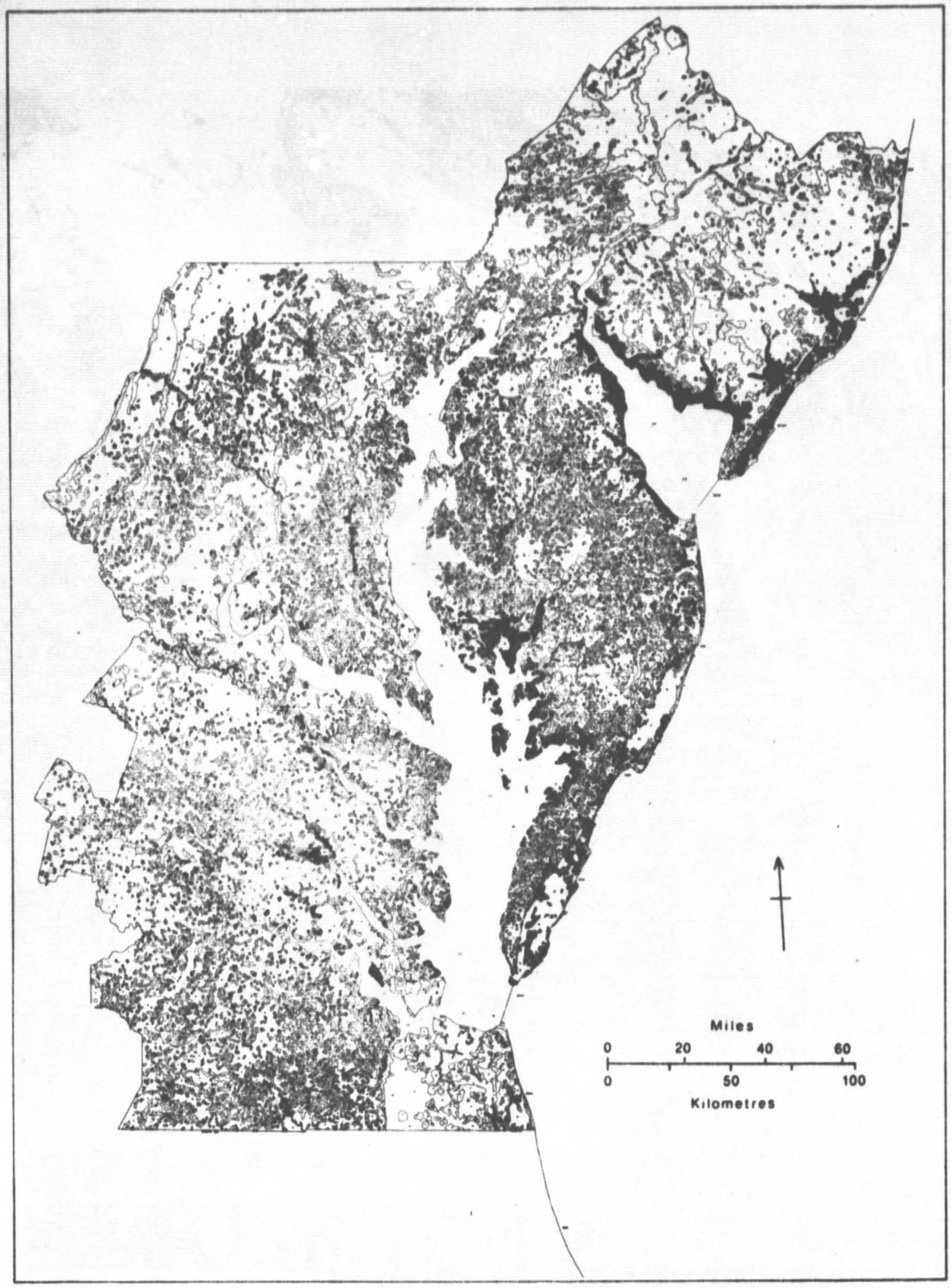


Figure B.22-Non-Forested wetland, CARETS region, derived from Landsat data, scale 1:2,500,000.

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Figure B.23--Landsat mosaic of CARETS region.

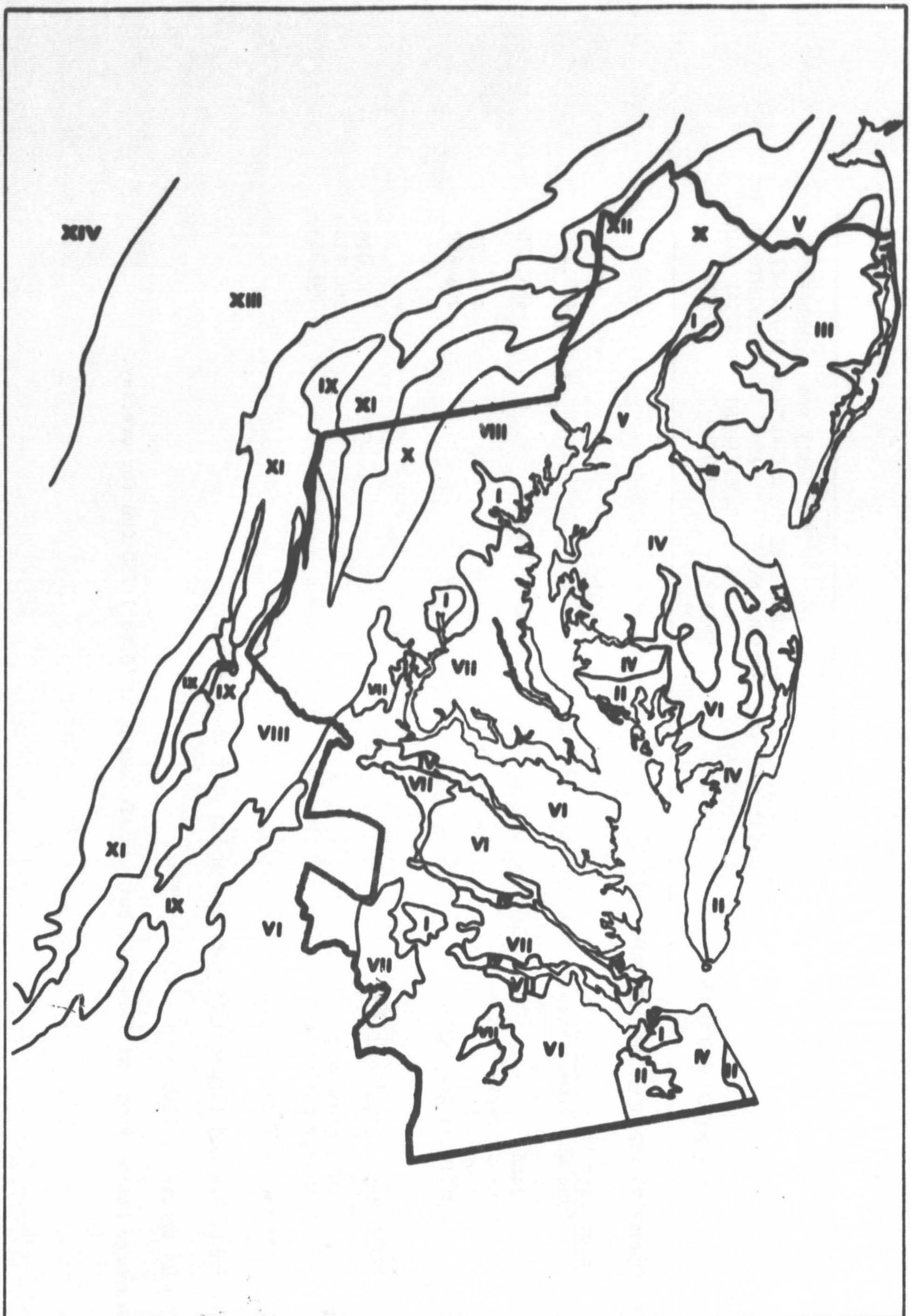

Figure B.24--Photomorphic regions derived from Landsat imagery.

Table B.5.--Information products handled by CARETS project: digital data base

INFORMATION PRODUCTS	AVAILABLE FOR ENTIRE TEST REGION	AVAILABLE FOR NORFOLK AND WASHINGTON SMSA's	AVAILABLE FOR OTHER COUNTIES AND INDEPENDENT CITIES[1]	NUMBER OF INFORMATION ELEMENTS IN DIGITAL DATA BASE
DATA SUMMARIES AND AREA MEASUREMENTS				
Input data base 1:100,000				
Land use from aircraft data		x	x	465,275
Land use change from aircraft data		x	x	465,275
Census tracts[2] and county boundaries		x	x	465,275
Surficial geology		x		208,850
Input data base 1:250,000				
Land use from Landsat	x			360,016
County boundaries	x			360,016
Drainage basins[3]	x			360,016

[1]See table B.6 and figure B.25 for list and map of these areas.

[2]Census tracts available only within SMSAs.

[3]Drainage basins input at 1:100,000 but transformed by CGIS to 1:250,000 for overlay.

Table B.6.--CARETS counties and independent cities with digital coverage in data base, scale 1:100,000

Norfolk-Portsmouth SMSA (1970)	Area (km^2) Land plus water*
Chesapeake (city)	923
Norfolk (city)	232
Portsmouth (city)	117
Virginia Beach (city)	934
TOTAL SMSA	2206
Washington, DC SMSA (1970)	
Alexandria (city)	39
Arlington	68
District of Columbia	178
Fairfax	1010
Fairfax (city)	15
Falls Church (city)	5
Loudoun	1387
Montgomery	1309
Prince Georges	1202
Prince William	935
TOTAL SMSA	6148
Other Areas	
Maryland	
Anne Arundel	1540
Baltimore (city)	235
Calvert	897
Charles	1678
Howard	654
St. Mary's	1846
Virginia	
Franklin (city)	10
Fredericksburg	16
King George	485
Nansemond	1096
Spotsylvania	1070**
Stafford	730
TOTAL OTHER AREAS	10,257
TOTAL AREA WITH COMPLETE DIGITAL COVERAGE	18,611

*Areas as obtained from CGIS computer tabulation from aircraft-derived maps, scale 1:100,000

**Excluding 2 km^2 south of latitude 38° N which was inadvertently omitted from digital data base

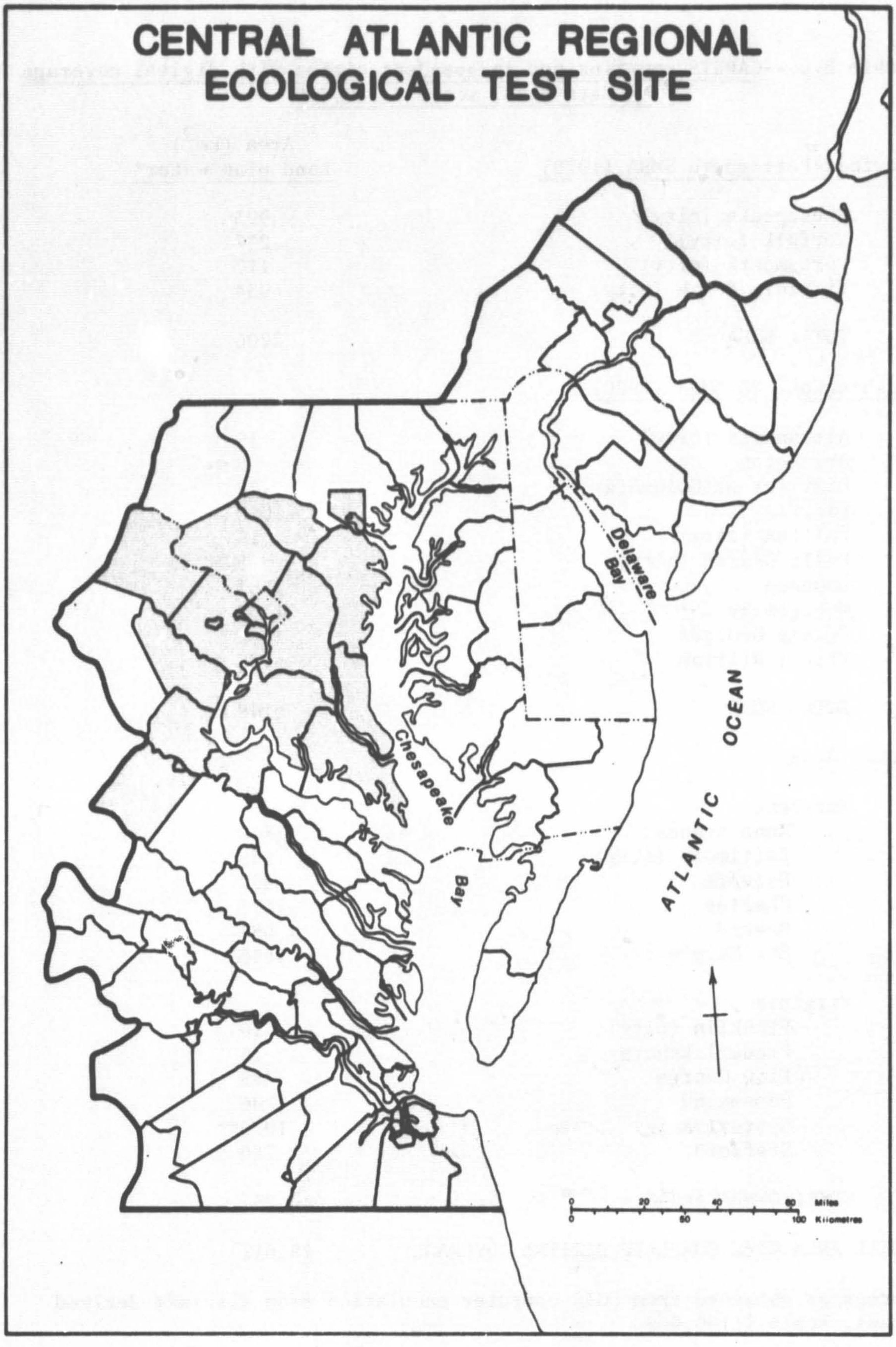

Figure B.25.--CARETS counties and independent cities with complete coverages in digital base.*

*See also figures 1.1 and C.6 and tables B.5 and B.6

APPENDIX C

DATA SUMMARIES AND COMPARISONS

Appendix C contains figures and tables designed to present some of the CARETS project results for visual display and for comparison of land use measurements from aircraft with those from Landsat data sources. The first two figures (figs. C.1 and C.2) contain reduced specimens of maps drawn from aircraft and Landsat sources respectively, colored according to Level I land use category. These figures are presented to show examples of types of data used later in the comparisons.

Tables C.1 through C.5 contain land use summary tabulations in just a few of the many possible ways that such tabulations can be obtained from the data sets produced by the CARETS project. In some cases the tables also make possible comparison of area measurements between remote sensor-derived data (aircraft and Landsat) and data from other sources.

Figures C.3 through C.13 contain maps and graphs of various other data summaries from Landsat data highlighting comparisons with other sources. Included also are maps of drainage areas, SMSA's and urbanized areas, to assist in comparison and interpretation of the other data presentations.

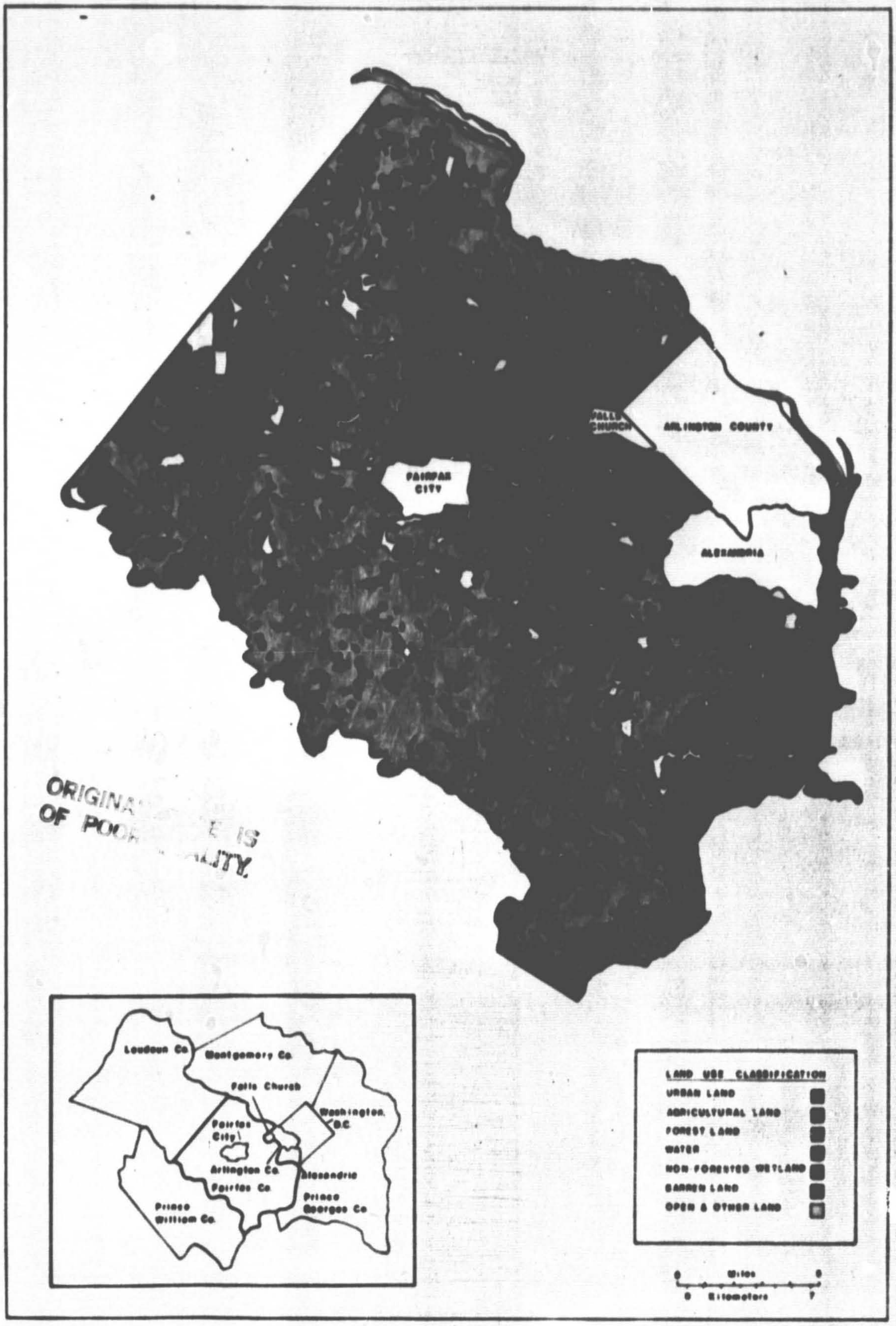

Figure C.1--Land use in Fairfax County, Vi:ginia, derived from aircraft data. Reduced copy of hand-colored map. EDC-010141

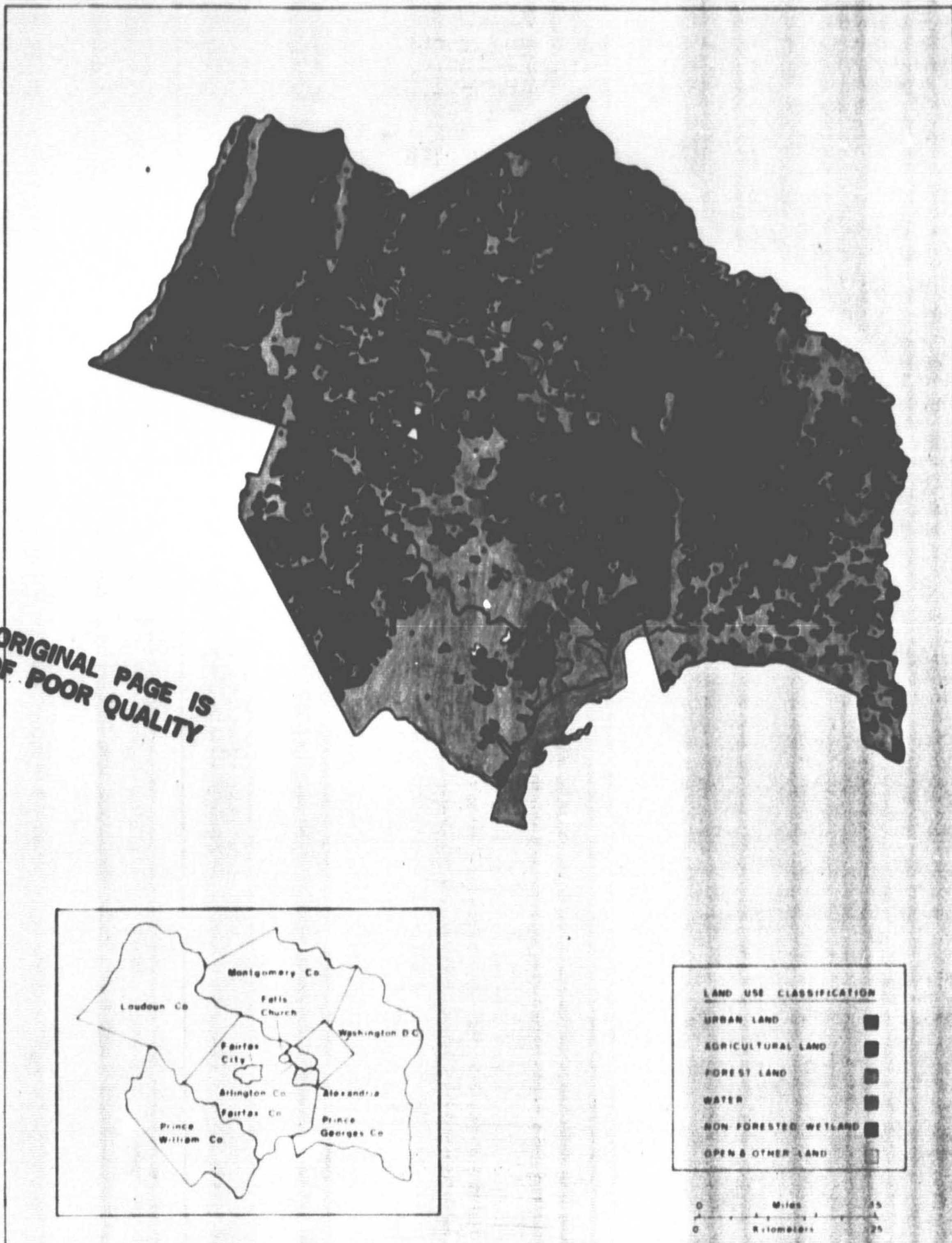

Figure C.2--Land use in Washington SMSA, derived from Landsat data.
Reduced copy of hand-colored map. EDC-010142

Table C.1.--CARETS land use area summaries, 1972, derived from Landsat data, digitized and measured by CGIS

		1 Urban	2 Agriculture	4 Forest	6 Wetland	7 Barren	Total Land	Total Water	Total Land & Water
Delaware	km^2	321.6	2,846.7	1,599.7	322.6	.7	5,091.3	1,102.2	6,193.5
	% Land Area	6.3	55.9	31.4	6.3	0			
D.C.	km^2	138.0	0	20.6	0	0	158.7	10.3	168.9
	% Land Area	87.0	0	13.0	0	0			
Maryland*	km^2	1,844.3	10,170.0	8,767.4	612.0	18.7	21,412.5	6,054.5	27,466.9
	% Land Area	8.6	47.5	40.9	2.9	.1			
New Jersey*	km^2	1,150.2	2,830.7	4,666.5	851.6	0	9,499.0	1,682.5	11,181.4
	% Land Area	12.1	29.8	49.1	9.0	0			
Pennsylvania	km^2	1,279.1	3,150.3	1,203.1	0	0	5,632.5	59.5	5,692.0
	% Land Area	22.7	55.9	21.4					
Virginia*	km^2	1,840.0	9,459.3	20,485.3	637.0	54.5	32,476.0	6,782.5	39,258.5
	% Land Area	5.7	29.1	63.1	2.0	.2			
TOTAL	km^2	6,573.2	28,457.0	36,742.5	2,432.2	74.0	74,269.9	15,691.4	89,961.3
	% Land Area	8.9	38.3	49.5	3.2	.1			

*Includes only portion of State within CARETS region.

Table C.2.--CARETS land use by county, 1972, derived from Landsat data, digitized and measured by CGIS

State	ID Code	County or City	Area Totals - km² Use/Cover Category 1	2	4	5	6	7	Total Land	Total Land & Water
Delaware	08001	Kent	30	974	377	552	164	0	1,545	2,097
	08002	New Castle	228	552	262	120	63	0	1,105	1,225
	08003	Sussex	63	1,321	961	430	96	1	2,442	2,872
District of Columbia	09001		138	0	21	10	0	0	159	169
Maryland	21002	Ann Arundel	294	187	591	448	3	1	1,076	1,524
	21003	Baltimore	416	607	524	229	0	0	1,547	1,776
	21004	Baltimore (city)	196	0	14	29	0	0	210	239
	21005	Calvert	4	179	380	330	5	1	569	899
	21006	Caroline	6	525	289	15	3	0	823	838
	21007	Carroll	6	963	186	7	0	0	1,155	1,162
	21008	Cecil	20	481	406	168	0	0	907	1,075
	21009	Charles	10	314	871	260	11	0	1,206	1,466
	21010	Dorchester	7	529	652	1,140	251	0	1,439	2,579
	21012	Frederick	26	1,183	503	5	0	0	1,712	1,717
	21013	Harford	67	626	425	245	10	0	1,128	1,373
	21014	Howard	87	343	222	3	0	0	652	655
	21015	Kent	0	527	199	314	0	0	726	1,040
	21016	Montgomery	234	702	339	15	0	0	1,275	1,290
	21017	Prince Georges	366	310	577	28	12	0	1,265	1,293
	21018	Queen Annes	2	693	275	360	2	0	972	1,332
	21019	St. Marys	8	329	613	889	1	0	951	1,840
	21020	Somerset	12	269	364	715	216	0	861	1,576
	21021	Talbot	5	500	202	538	6	0	713	1,251
	21022	Wicomico	30	458	447	56	39	0	974	1,030
	21023	Worchester	48	444	688	295	54	18	1,252	1,547
New Jersey	31001	Atlantic	96	265	920	146	186	0	1,467	1,613
	31003	Burlington	207	631	1,206	39	38	0	2,082	2,121
	31004	Camden	222	226	130	7	0	0	578	585
	31005	Cape May	59	146	281	511	190	0	676	1,187
	31006	Cumberland	52	470	542	475	238	0	1,302	1,777
	31008	Cloucester	135	459	253	22	6	0	853	875
	31015	Ocean	362	93	1,088	355	103	0	1,646	2,001
	31017	Salem	18	540	246	127	93	0	897	1,024
Pennsylvania	39009	Bucks	309	1,028	248	17	0	0	1,585	1,602
	39015	Chester	80	1,264	619	2	0	0	1,963	1,965
	39023	Delaware	212	126	139	16	0	0	477	493
	39046	Montgomery	357	733	173	4	0	0	1,263	1,267
	39051	Philadelphia	321	0	25	19	0	0	346	365
Virginia	47001	Accomack	21	478	406	1,805	261	21	1,187	2,992

Table C.2--Continued

State	ID Code	County or City	Use/Cover Category 1	2	4	5	6	7	Total Land	Total Land & Water
			Area Totals - km²							
Virginia	47007	Arlington	70	0	0	3	0	0	70	73
	47017	Caroline	4	224	1,147	10	1	0	1,376	1,386
	47019	Charles City	1	77	391	52	15	0	484	536
	47021	Chesterfield	48	142	919	28	1	0	1,110	1,138
	47027	Dinwiddie	33	329	965	5	0	0	1,327	1,332
	47028	Essex	2	150	506	65	17	0	675	740
	47029	Fairfax	366	158	466	47	0	0	990	1,037
	47030	Fauquier	0	1,123	571	1	0	0	1,694	1,695
	47036	Gloucester	20	132	407	633	7	0	566	1,199
	47037	Goochland	5	171	572	0	0	0	748	748
	47040	Greensville	42	175	560	3	0	0	777	780
	47042	Hanover	5	397	827	1	[illegible]	0	1,229	1,230
	47043	Henrico	113	131	373	13	0	0	617	630
	47046	Isle of Wight	5	331	484	125	6	0	826	951
	47047	James City	2	51	329	81	16	0	398	479
	47048	King and Queen	2	135	676	26	4	0	817	843
	47049	King George	7	98	361	87	0	0	466	553
	47050	King William	2	168	528	26	19	0	717	743
	47051	Lancaster	0	117	232	230	0	0	349	579
	47053	Loudoun	26	966	402	18	0	0	1,394	1,412
	47057	Mathews	0	85	134	385	6	0	225	610
	47059	Middlesex	0	91	250	171	1	0	342	513
	47061	Nansemond	10	332	675	71	9	0	1,026	1,097
	47063	New Kent	1	58	463	33	20	0	542	575
	47064	Northampton	12	269	124	1,336	126	18	549	1,885
	47065	Northumberland	0	215	286	235	1	0	502	737
	47071	Powhatan	5	127	569	0	0	0	701	701
	47073	Prince George	16	160	540	37	4	0	720	757
	47074	Prince Williams	66	323	516	37	0	0	905	942
	47077	Richmond	0	113	369	65	8	0	490	555
	47085	Southampton	0	585	950	10	13	0	1,548	1,558
	47086	Spotsylvania	20	186	862	22	0	0	1,068	1,090
	47087	Stafford	30	99	570	66	1	0	700	766
	47088	Surry	4	161	556	80	4	0	725	805
	47089	Sussex	8	343	926	1	6	0	1,283	1,284
	47093	Westmoreland	3	173	433	247	2	0	611	85[illegible]
	47096	York	28	57	224	111	15	0	324	435
	47097	Alexandria (city)	39	0	1	3	0	0	40	43
	47101	Chesapeake (city)	85	279	523	21	1	0	888	909
	47103	Colonial Heights (city)	11	0	9	0	0	0	20	20
	47106	Fairfax (city)	13	0	0	0	0	0	13	13
	47107	Falls Church (city)	6	0	0	0	0	0	6	6
	47108	Franklin (city)	1	9	4	0	0	0	14	14
	47111	Hampton (city)	103	0	32	62	0	1	136	198
	47113	Hopewell (city)	13	0	9	1	0	0	22	23
	47116	Newport News (city)	73	20	62	125	20	0	175	300
	47117	Norfolk (city)	138	0	1	92	0	0	139	231
	47119	Petersburg (city)	15	1	8	0	0	0	24	24
	47120	Portsmouth (city)	71	0	4	29	10	0	85	114
	47122	Richmond (city)	107	11	39	4	0	0	157	161
	47126	Suffolk (city)	3	5	3	0	0	0	11	11
	47127	Virginia Beach (city)	183	202	224	280	44	15	668	948
	47129	Williamsburg (city)	3	0	1	0	0	0	4	4

Table C.3.--Comparison of Landsat, aircraft, and census area measurements for selected counties and cities, (areas in km²)

County/City	Landsat Area Measurement: Land Area	Landsat Area Measurement: Total land and water	Aircraft Area Measurement: Land Area	Aircraft Area Measurement: Total land and water	Land Area Census*
Norfolk-Portsmouth SMSA					
Chesapeake (city)	888	909	879	924	883
Norfolk (city)	139	231	137	231	137
Portsmouth (city)	85	114	79	116	75
Virginia Beach (city)	688	948	658	933	671
Washington SMSA					
Alexandria (city)	40	43	38	39	39
Arlington	70	73	66	68	67
District of Columbia	159	169	162	179	158
Fairfax	990	1037	981	1009	1033
Fairfax (city)	13	13	15	15	16
Falls Church (city)	6	6	5	5	5
Loudoun	1394	1412	1382	1384	1339
Montgomery	1275	1290	1286	1309	1282
Prince Georges	1265	1293	1192	1202	1256
Prince William	905	942	914	935	899

*Source: U.S. Bureau of the Census, 1973

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Table C.4.--Land use area comparisons for selected CARETS counties and cities: aircraft (A) and Landsat (L) data[1]

Areas in km² County/City	(1) Urban (A)	(L)	(2) Agriculture (A)	(L)	(4) Forest (A)	(L)
Norfolk-Portsmouth SMSA						
Chesapeake (city)	80	85	264	279	523	523
Norfolk (city)	132	138	1	0	3	1
Portsmouth (city)	61	71	8	0	6	4
Virginia Beach (city)	137	183	216	202	228	224
Washington SMSA						
Alexandria (city)	33	39	0	0	6	1
Arlington	61	70	0	0	5	0
District of Columbia	140	138	0	0	21	21
Fairfax	299	366	187	158	489	466
Fairfax (city)	12	13	0	0	3	0
Falls Church (city)	5	6	0	0	0	0
Loudoun	53	26	929	966	400	402
Montgomery	283	234	643	702	360	339
Prince Georges	309	366	335	310	535	577
Prince William	60	66	300	323	550	516

[1]From CGIS Complete Area Measurement

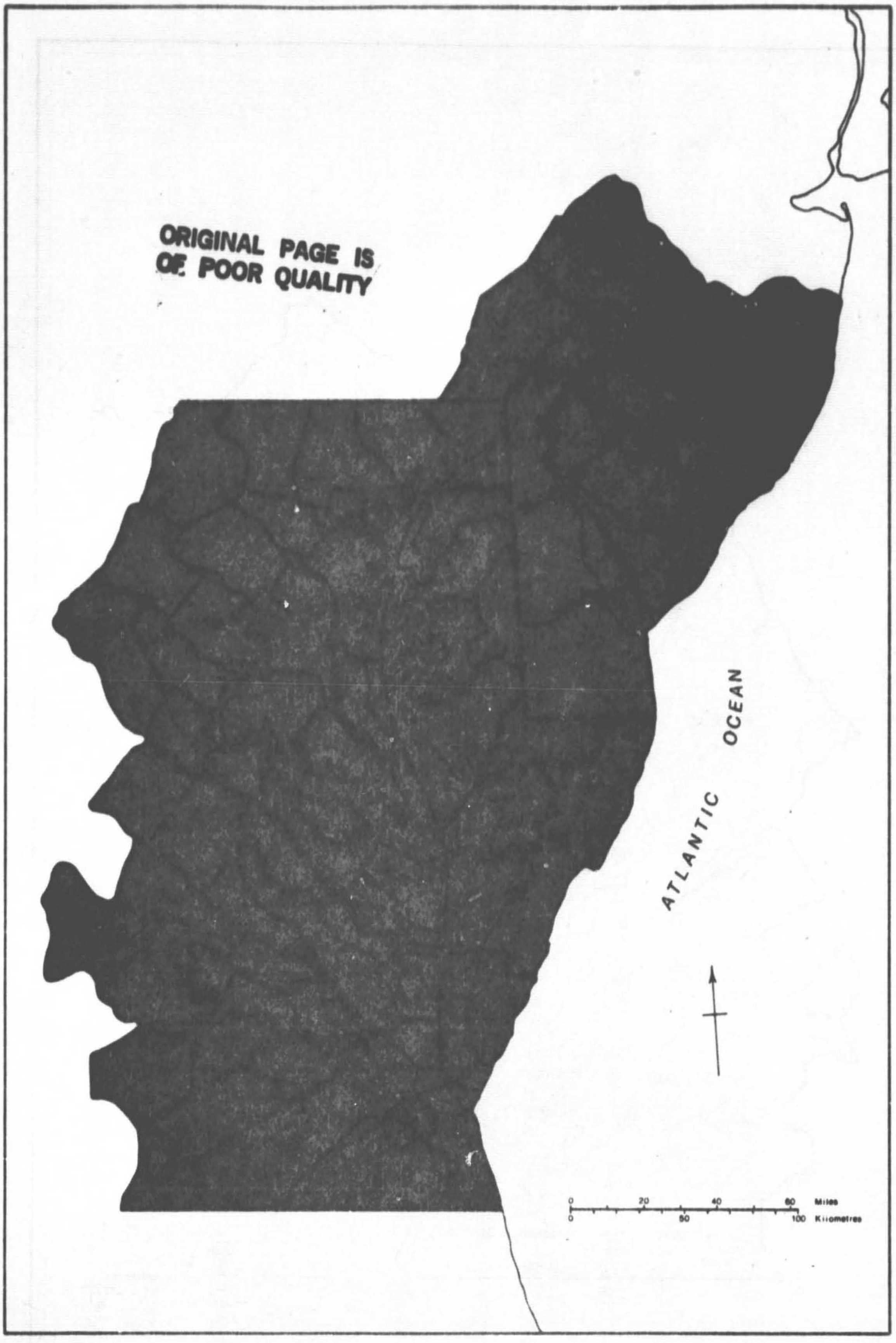

Figure C.3--Major CARETS data retrieval areas: counties and independent cities.

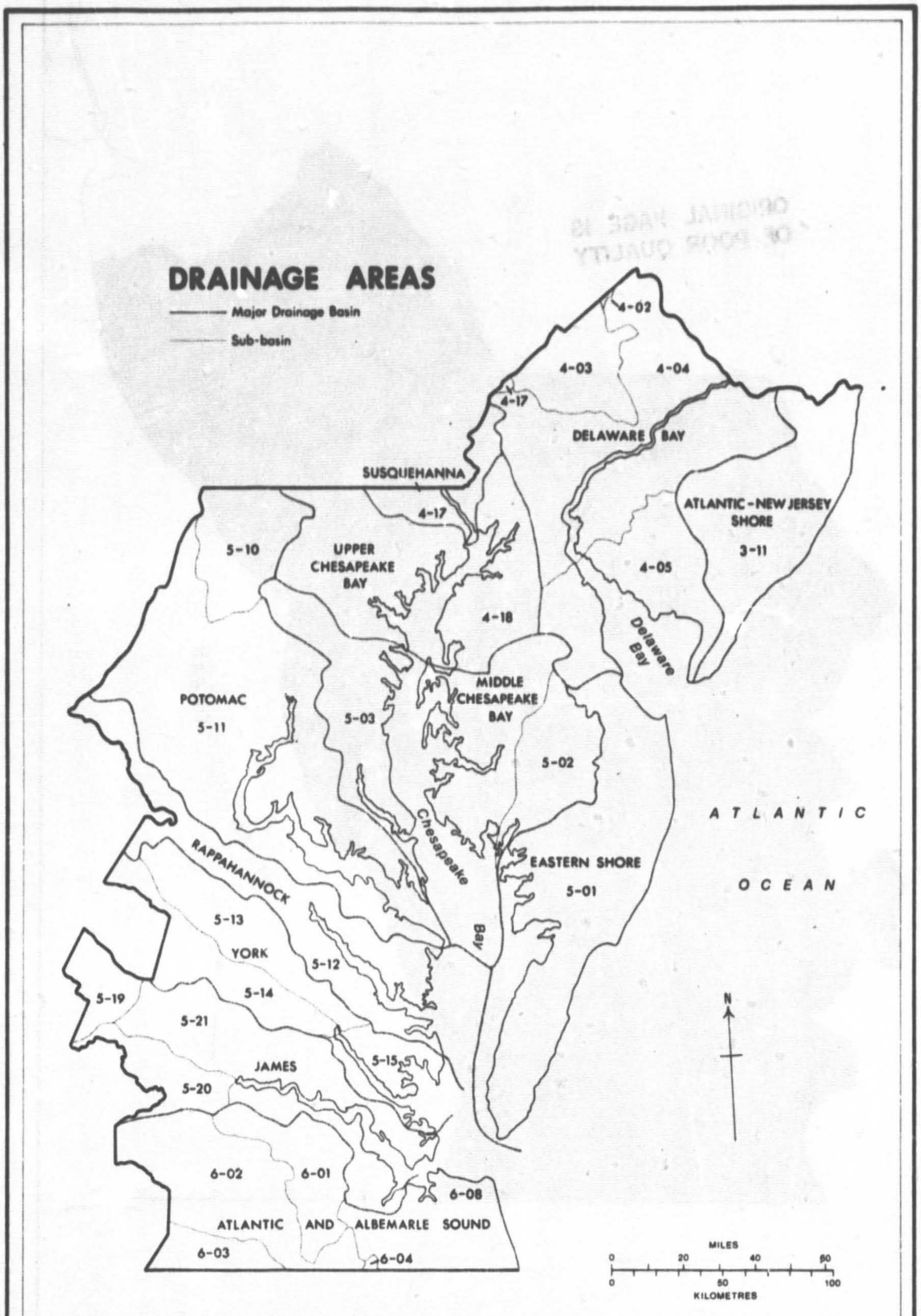

Figure C.4--CARETS drainage areas.

Table C.5 -- CARETS land use by drainage basin, 1972, derived from Landsat data, digitized and measured by CGIS

Drainage Basin	ID Code	Level I Land Use Area Totals (km^2)						Total Land	Total Land & Water
		1	2	4	5	6	7		
Atlantic-New Jersey Shore	3-11	504	613	2,991	518	459	0	4,567	5,085
Delaware Bay									
	4-02	0	6	6	0	0	0	12	12
	4-03	60	209	197	74	0	0	466	540
	4-04	1,819	3,499	1,566	290	117	0	7,001	7,291
	4-05	113	1,476	1,034	1,491	487	0	3,110	4,601
Total Delaware Bay		1,992	5,190	2,803	1,855	604	0	10,589	12,444
Upper Chesapeake Bay									
Susquehanna R.	4-17	13	647	221	51	0	0	881	932
	4-18	841	2,887	1,916	1,136	10	0	5,654	6,790
Total Upper Chesapeake Bay		854	3,534	2,137	1,187	10	0	6,535	7,722
Eastern Shore-Atlantic	5-01	127	1,860	1,954	2,554	620	56	4,617	7,171
Middle Chesapeake Bay									
	5-02	30	1,094	895	70	66	0	2,085	2,155
	5-03	350	2,823	2,810	3,567	296	2	6,281	9,848
Total Middle Chesapeake Bay		380	3,917	3,705	3,637	362	2	8,366	12,003
Lower Chesapeake Bay									
Potomac R.	5-10	18	685	249	1	0	0	952	953
	5-11	1,257	3,884	4,716	1,439	13	0	9,870	11,309
Total Potomac R.		1,275	4,569	4,965	1,440	13	0	10,822	12,262
Rappahannock R.	5-12	50	1,342	2,899	1,425	30	0	4,321	5,746
York R.	5-13	9	550	1,521	46	27	0	2,107	2,153
	5-14	3	397	1,903	21	9	0	2,312	2,333

Table C.5 --- Continued

Drainage Basin	ID Code	Level I Land Use Area Totals (km^2) 1	2	4	5	6	7	Total Land	Total Land & Water
	5-15	52	265	764	929	32	0	1,113	2,042
Total York R.		64	1,212	4,188	996	68	0	5,532	6,528
James R.									
	5-19	5	172	725	-*	0	0	902	902
	5-20	53	151	1,008	19	0	0	1,212	1,231
	5-21	470	909	2,830	645	74	1	4,284	4,929
Total James R.		528	1,232	4,563	664	74	1	6,398	7,062
Total Lower Chesapeake Bay		1,917	8,355	16,615	4,525	185	1	27,073	31,598
Atlantic & Albemarle Sound									
	6-01	9	650	1,272	4	-	0	1,931	1,935
	6-02	46	989	2,493	12	18	0	3,546	3,558
	6-03	24	249	549	7	1	0	823	830
	6-04	0	10	32	0	0	0	42	42
	6-08	489	591	1,131	855	59	15	2,285	3,140
Total Atlantic & Albemarle Sound		568	2,489	5,477	878	78	15	8,627	9,505

*The "-" symbol indicates an area of greater than zero but less than 0.5 km^2.

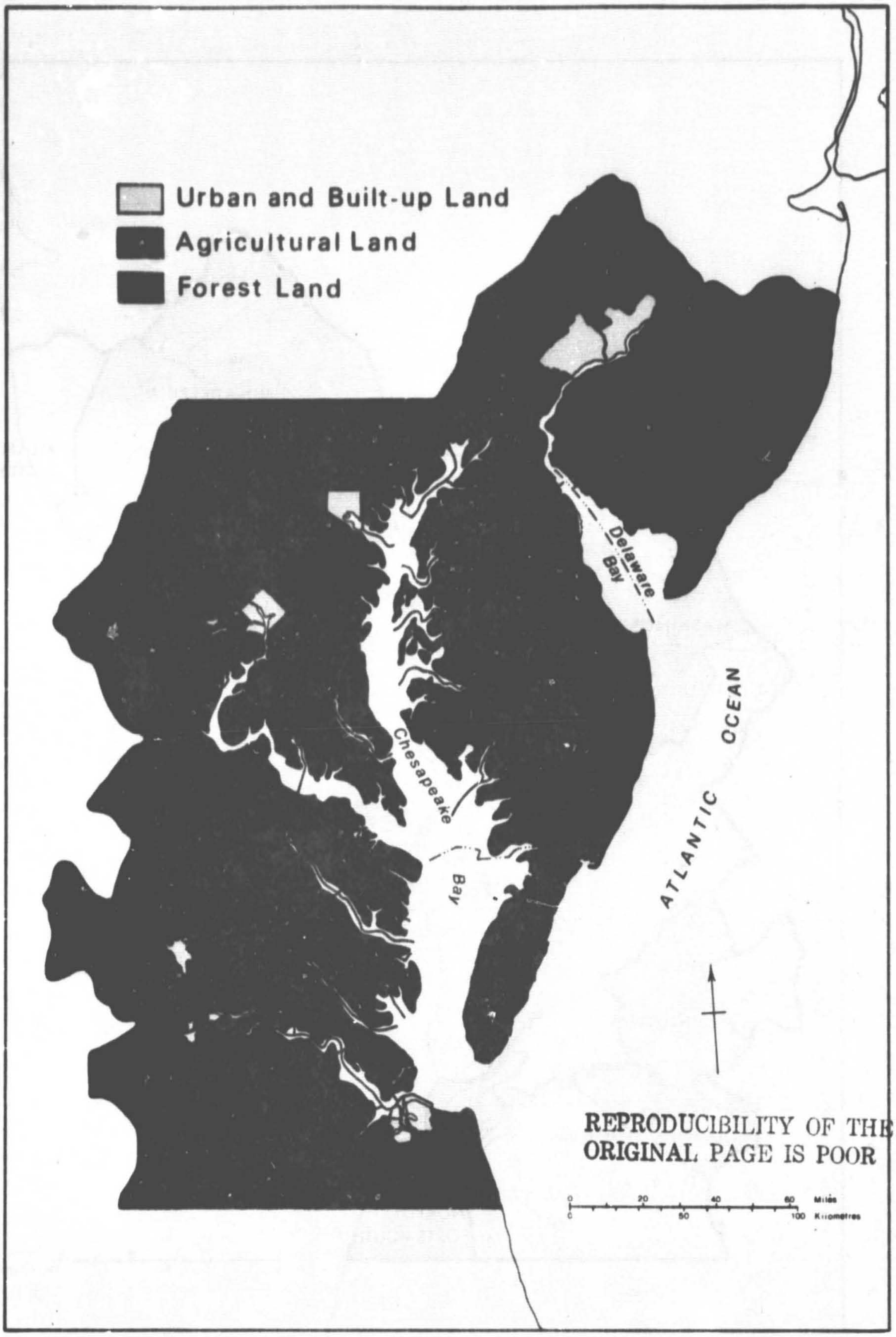

Figure C.5--CARETS predominant land cover by county, derived from CGIS-digitized Landsat data.

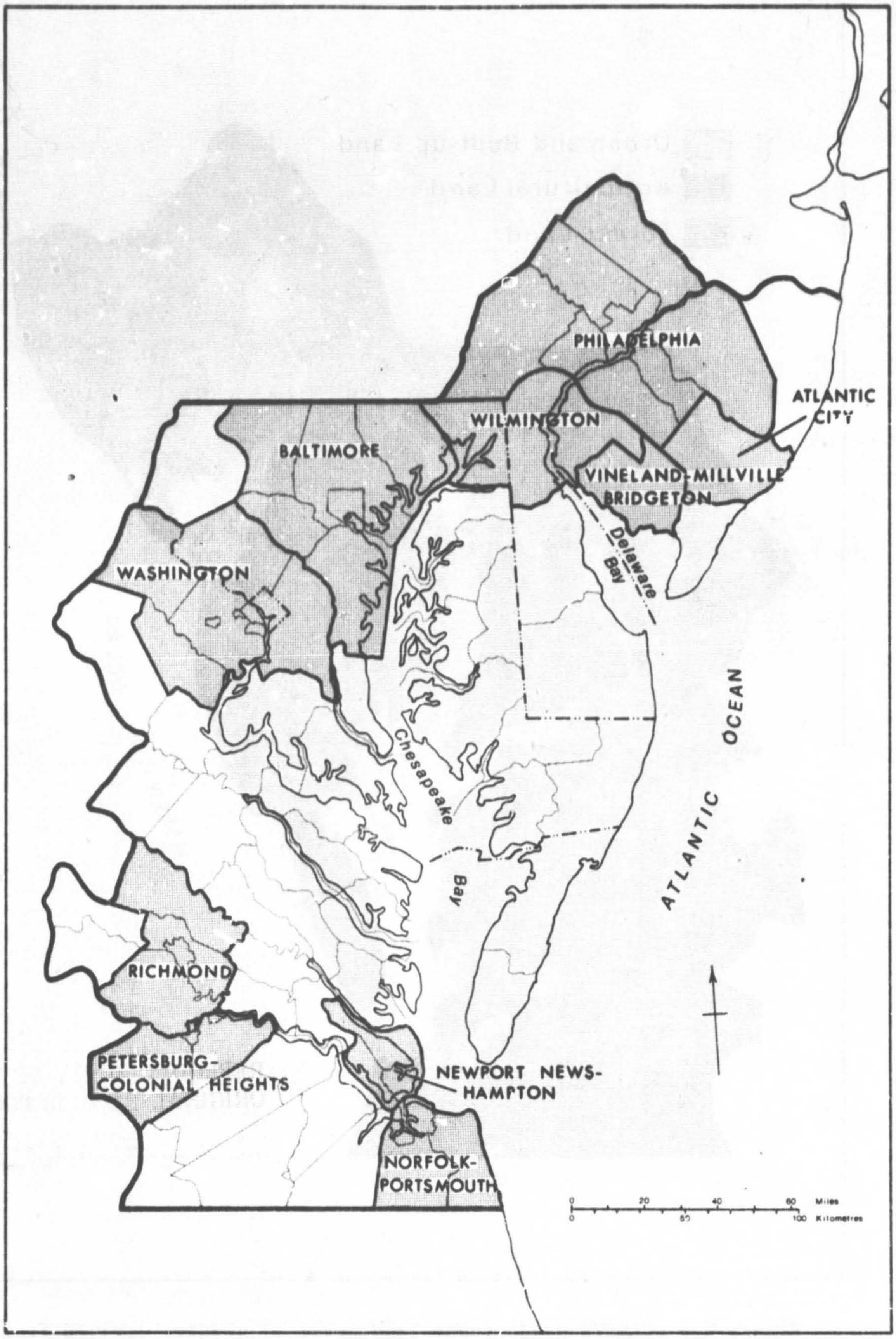

Figure C.6--CARETS SMSA's, 1970.

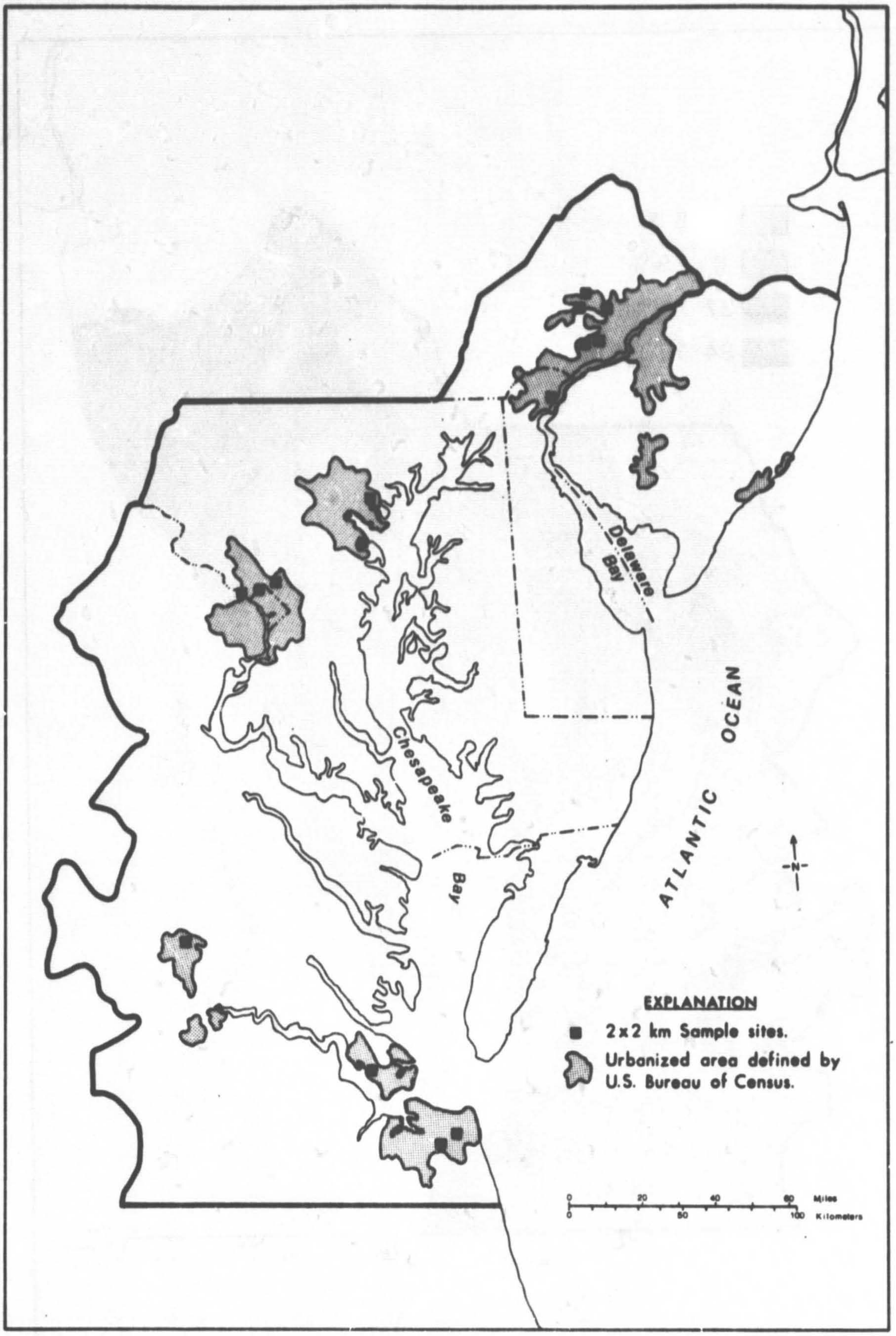

Figure C.7--CARETS urbanized areas, showing locations of 2 x 2 km sample sites for urban accuracy study.

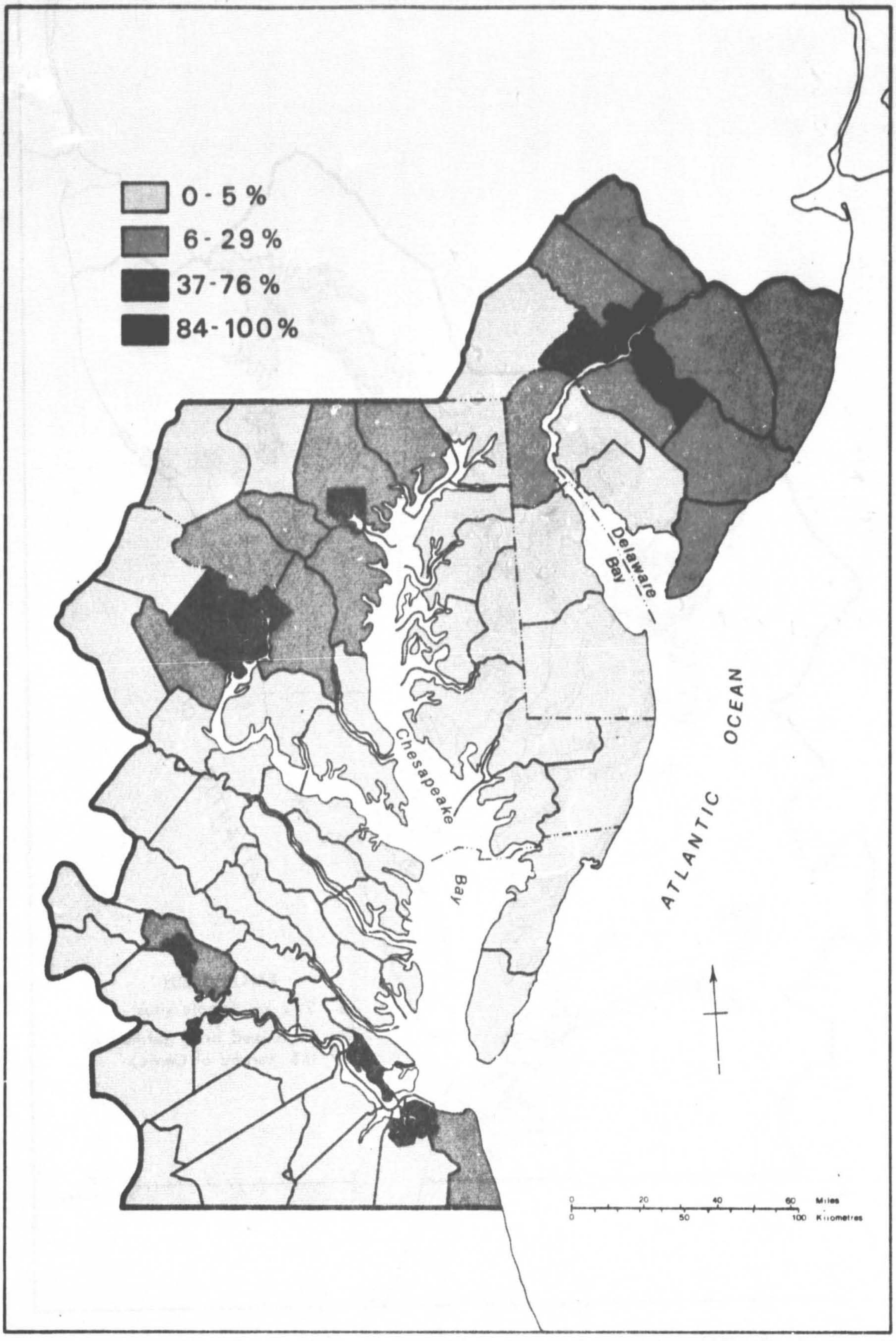

Figure C.8--CARETS percent urban and built-up land use, derived from Landsat data and CGIS measurements.

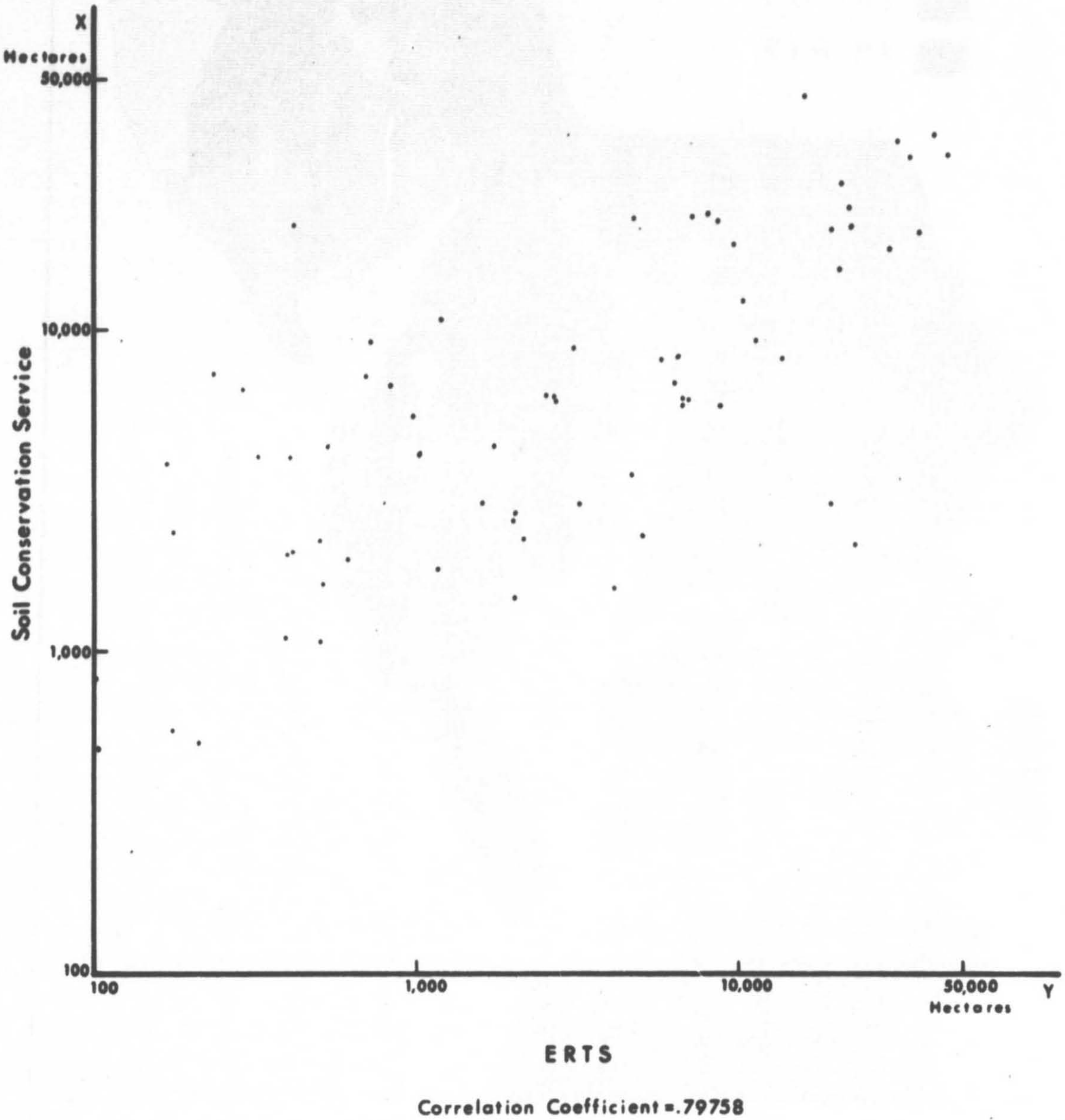

Figure C.9--CARETS county measurements of urban and built-up land: Landsat versus USDA Soil Conservation Service.

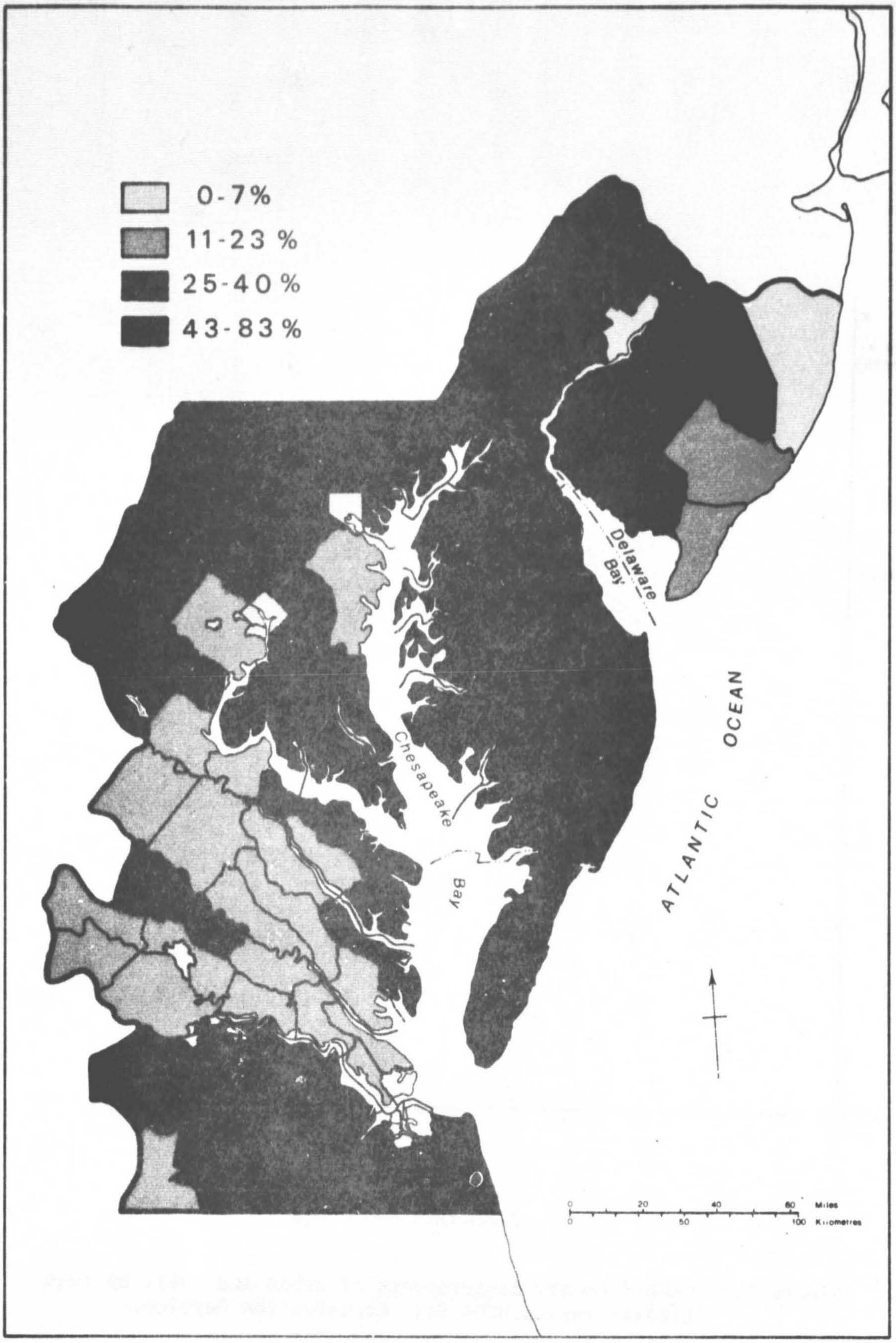

Figure C.10--CARETS percent agricultural land use, derived from Landsat data and CGIS measurements.

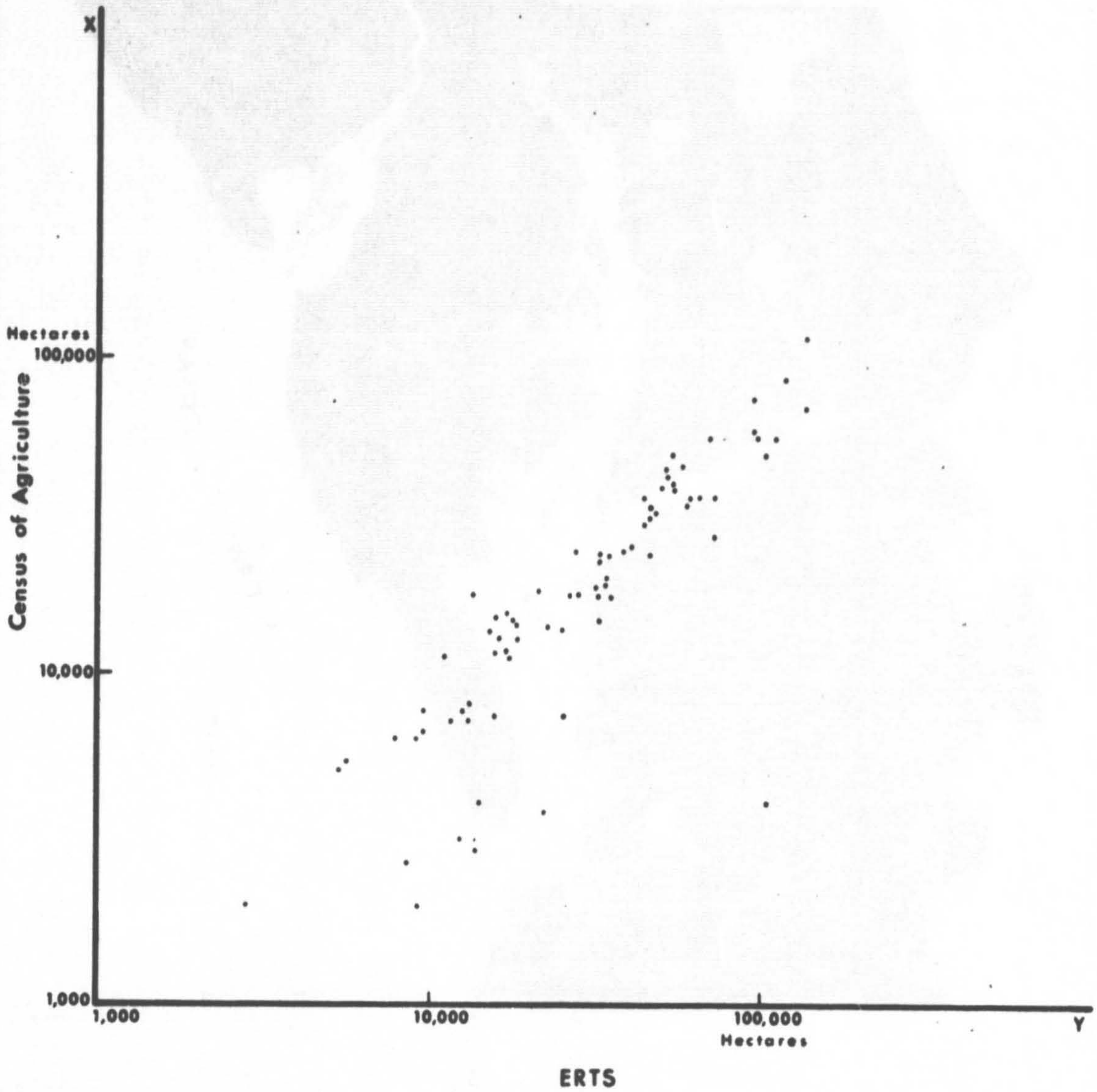

Figure C.11--CARETS county measurements of agricultural land: Landsat versus census data.

Source: U.S. Bureau of the Census, 1972; Landsat 1972, CARETS project.

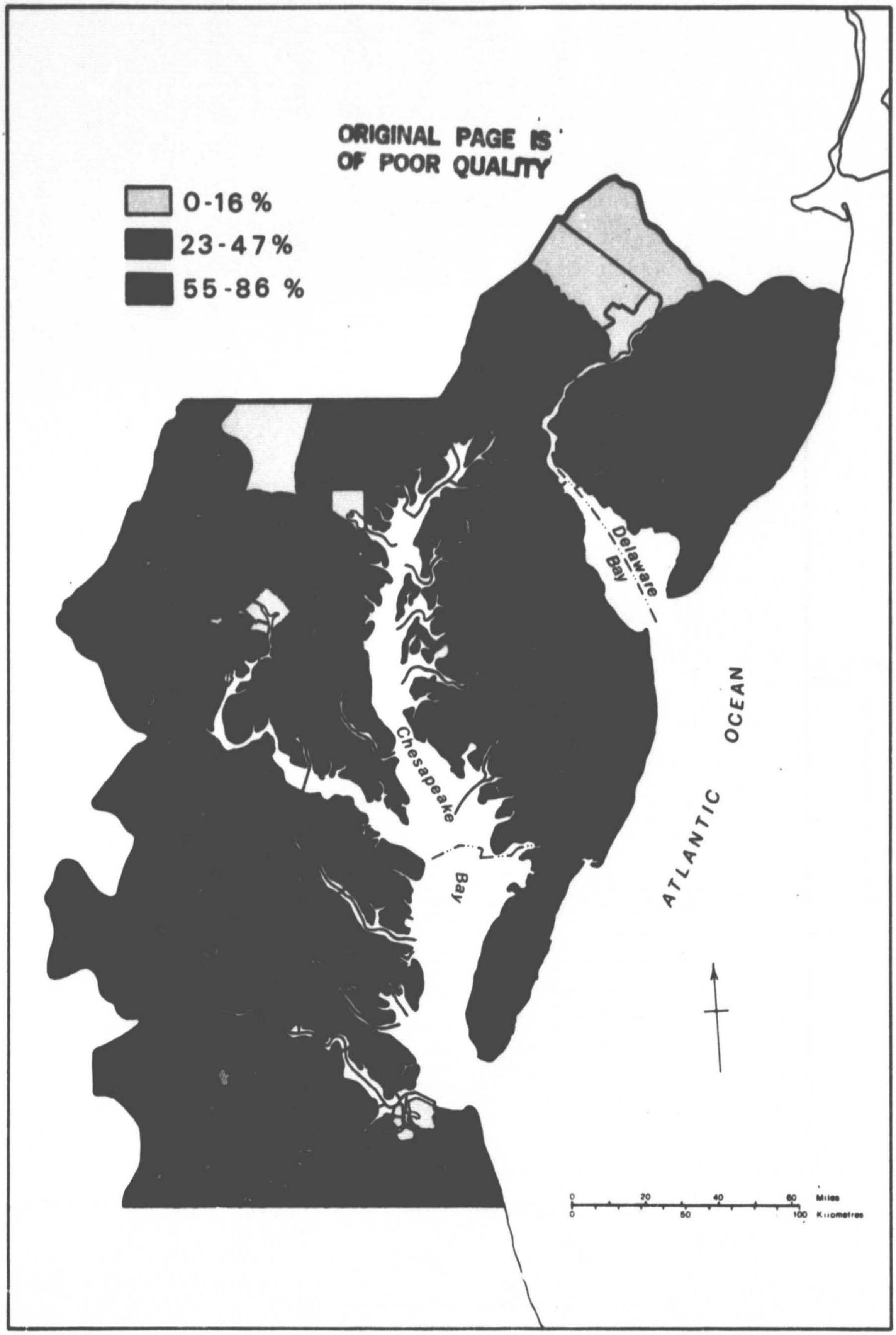

Figure C.12--CARETS percent forest land use, derived from Landsat data and CGIS measurements.

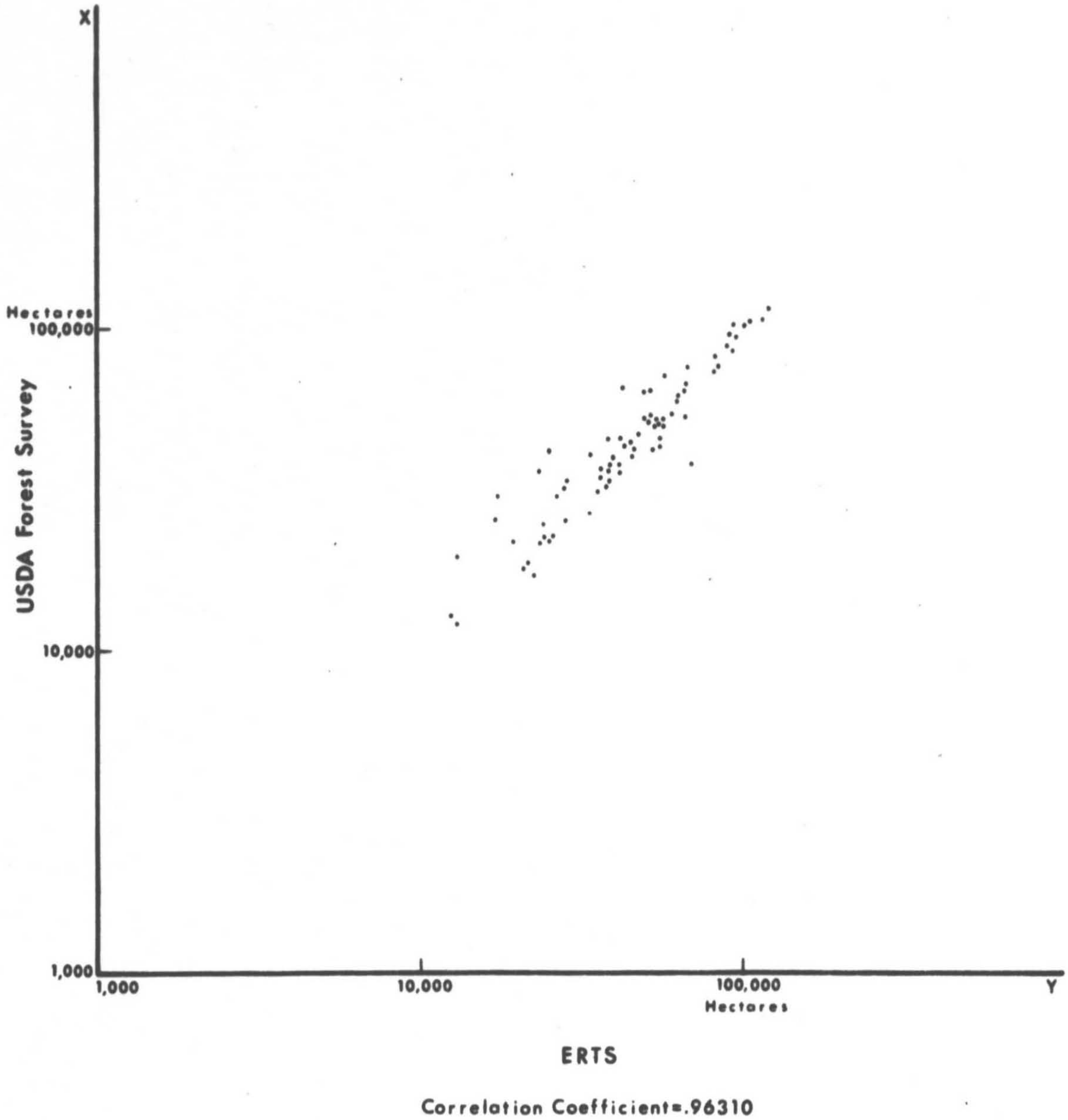

Figure C.13--CARETS county measurements of forest land: Landsat versus U.S. Forest Service data.