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CARETS—AN EXPERIMENTAL REGIONAL INFORMATION SYSTEM USING ERTS DATA

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ABSTRACT

The U. S. Geological Survey CARETS (Central Atlantic Regional Ecological Test Site)/ERTS investigation is testing the applicability of ERTS data as input to an environmental information system for a multi-state mid-Atlantic region surrounding the Chesapeake and Delaware Bays. The "information system" framework encompasses a flow of information through several stages from sensor to user, and involving evaluation and feedback from several potential users. Basic assumptions of the CARETS project model are that there is a measurable environmental impact associated with land use and land use change as determined with remote sensor data, and that the ERTS-derived land use data sets, when properly calibrated, may thus provide regional planners and administrators with a shortcut to an understanding of the environmental changes that are going on in their regions. Mid-way through the investigation, data sets on land use from both aircraft and ERTS sources have been compiled for the 73,000 km^2 area of the test region. These data sets are being prepared for user evaluation in both graphic and digital form, and a variety of area measurement and accuracy computations are being performed to assist in evaluating the ERTS and aircraft data as aids in the planning process.

INTRODUCTION

This paper is a brief description and progress report of the Central Atlantic Regional Ecological Test Site (CARETS) demonstration project, an interdisciplinary, interagency cooperative investigation in which data from the Earth Resources Technology Satellite (ERTS-1) are being tested as input to an experimental regional environmental information system.

The project arose through a process of negotiation, beginning in 1970, among several scientists and administrators in both the National Aeronautics and Space Administration (NASA) and the U. S. Geological Survey, who had felt that something was lacking in the pattern of widely-scattered, single discipline experiments which existed at that time in NASA's program of research on remote sensing for earth resources applications.

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It was felt that the detailed experimentation with the matching of sensor records and known ground conditions at single, well-documented test sites, while necessary for establishing the feasibility of applying the space observations to earth resources problems, was not sufficient. What was needed in addition, it was determined, was the regional integration of the results of a number of experiments, with emphasis on reaching the user with data meaningful to him in terms of solving his problems. To address the need for interdisciplinary and regionally-integrated research packages, NASA developed the concept of "ecological test sites", and established a number of them throughout the U. S. In addition to economizing on the use of aircraft test flights by concentrating on fewer regions, the ecological test site concept was supposed to take advantage of the actual interaction of the various environmental phenomena which could be observed by the remote sensors. There was even some talk that ecological models might be developed which would take advantage of the availability of remotely-sensed observations of the earth's surface in unprecedented amounts, and hasten the solution of environmental problems that are characterized by complex interconnections among the phenomena involved. Thus the CARETS project was established as one of the NASA-sponsored ecological test sites.

Project Design and Structure

CARETS is a project of some complexity, addressing environmental problems in a heavily-urbanized mid-Atlantic area of some 73,000 km^2 (28,000 mi^2). Since there are a number of interdisciplinary environmental problem-solving projects or programs throughout the country at the present time, some of them statewide in scope and operated by agencies of state government, some attention will be given to an explanation of the CARETS project design and structure, so that the reader can compare it with other efforts with which he may be familiar.

The size of the test region would place it in rank between the 40th (South Carolina) and the 41st (West Virginia) of the 50 states arranged in order of total area. Only two states, however, (California and New York) have larger numbers of people than the 13,404,558 living within the confines of the CARETS area in 1970. The demonstration project is thus expected to be comparable in level of effort to that required for a similar land use information system in a typical heavily-urbanized and populous state.

The project was designed with the aim of bringing space technology and information systems technology together to assist in solving environmental problems. Its situation in the Geological Survey allows application of that agency's long-standing expertise in earth sciences and mapping, and in addition permits taking advantage of a recent USGS thrust aimed at integrating the contributions of many discipline specialists to bring the earth sciences specialties more quickly to bear on the solution of pressing environmental problems centering on the land use issue.

The basic project design takes advantage of the two-way linkage between land use and the processes and responses of the biophysical environment. According to this linkage, land use (incorporating land cover in the USGS land use classification for use with remote sensors--Anderson et al., 1972) evolves under constraints set by processes of the physical environment, with socio-economic processes determining the particulars of how a given land use pattern develops within the environmental limits; certain environmental factors, on the other hand, are functions of land use and land use change, as for example runoff, sediment yield, micro-and meso-climates, water quality, atmospheric dust, etc. Reliable and timely data on regional hydrology, geology, micro-climatology, water quality, etc., are expensive and often slow to obtain over large regions in forms suitable for analysis of environmental impact. The surface expression or resultant of all the environmental and socio-economic processes, however, can be readily observed and monitored with the aid of remote sensors carried in satellites or aircraft; that surface expression is what is here called "land use."

If the land use that is monitored and mapped can be properly "calibrated" in terms of its probable environmental impact, then a land use data base can be a powerful tool of inference concerning, for example, environmental quality--not replacing direct measurement of critical environmental parameters, but rather providing a basis for extrapolating those measurements region-wide for more rapid determination of environmental impact of new development--hopefully in time to assist in the critical decisions as to how and where that development should occur.

Further detail on project structure and integration of the various elements of the CARETS project can be gained by reference to the flow chart depicted in Figure 1. The top portion of the diagram illustrates the flow of activities involved in the preparation and checking of the land use data base, and the comparison and evaluation of ERTS and aircraft data sets on land use. The lower portion of the diagram illustrates the flow of environmental and socio-economic data largely from non-remote sensing sources. The shaded portion of each box in Figure 1 indicates the portion completed at the time of the mid-project review in October 1973.

The color infrared photography obtained by the NASA high-altitude aircraft flights over the test region in 1970 was used to provide the mapping base, a controlled photomosaic at a scale of 1:100,000 for the entire test region, except for a few border areas that were missed and were added with data from 1972 flights. The aircraft land use data base has been completed in map form for the entire region. ERTS data have been used to compile a land use data set at a scale of 1:250,000, using the aircraft-derived data only as a training set to aid in identifying land use classes by a manual (visual) photo-interpretation technique.

Land use change over a two to three year period is determined by comparison of the 1970 data base with more recent photography obtained from NASA aircraft flights. A similar procedure will be performed with ERTS data for 1973-1974. An important component of the project is the determination of accuracy figures for the land use data, first by establishing accuracy levels for the aircraft-derived data, using field checks where necessary, and then applying the measures to the ERTS-derived data sets using spatial sampling techniques.

The CARETS investigation is also making available other data sets to aid in regional environmental analysis. An entirely new geologic map is being compiled for the region, at a scale of 1:100,000, emphasizing surficial materials, slope, and engineering characteristics of the terrain; it will be used in conjunction with the land use data to aid users in estimating geological suitability of the yet-undeveloped areas. Selected hyrdological data on runoff and sediment yield are being compared with land use in small drainage basins to illustrate the calibration of land use data in terms of hydrological impact. Air quality and micro-climatological impact of land use patterns are also being investigated for portions of the test region. Overlay maps of census tracts have been prepared to the same format as the land use data base, so that land use-population relationships can be determined.

The various types of data will be overlaid and merged as indicated by the arrows in the diagram, and a demonstration will be made of how these processes can aid in regional analysis and planning assessment of the test region or portions thereof. Finally, the whole package, including the remote sensing data, the processed maps and graphics, the statistical summaries, and the analytical reports, will be presented to users in the test region, to solicit their evaluation in terms of their data needs and particularly in support of decisions they have to make about future land use in their regions. The dashed line in Figure 1, illustrating "feedback to data sources" is used to indicate a process that it is hoped will continue after the CARETS investigation is completed; that is, once the results of this and other possible approaches to improving environmental decisions are evaluated, it is hoped that the data producers indicated at the left side of the diagram will respond with whatever programs may be necessary to fulfill the federal responsibilities in assistance to states and localities in the solution of environmental problems associated with land use change.

The objectives, then, of the CARETS project may be summarized as follows:

Overall objective: to test the applicability of data from ERTS as input to a regional environmental information system for the CARETS region. The "information system" referred to encompasses a flow of data from sensor to user, incorporating a specific process of land use analysis in intermediate stages of this information flow.

Sub-objectives:

a. Land use analysis: to provide uniform quantitative data sets (maps and statistical summaries) on land use and land use change, from ERTS and aircraft data, summed by counties and other planning jurisdictional areas for the entire region; make quantitative comparisons of ERTS and aircraft data sets.

b. Environmental impact assessment: to perform sample interpretations and analyses of remote-sensor-derived land use data sets in terms of the environmental impact of land use patterns and land use changes.

c. User services: to provide for experimental use, evaluation, and critique of land use information products derived from this investigation; the use, evaluation, and critique to be obtained from representative user institutions with responsibilities for planning and managing future land uses.

Elements of the CARETS Geographic Information System

The CARETS project structure is one of a class that is beginning to be called "geographic information systems" (Tomlinson, 1972), that is, information systems in which a location identifier is carried along with each data element. Such information systems are useful where large amounts of environmental data are required, and where quantitative assessments and manipulations must be performed on the kinds of information customarily stored in map form.

In the CARETS information system maps themselves constitute one of the intermediate steps in the information flow process. Conceptually the "intermediate map" stage might be bypassed, since what is desired is a flow or communication of information about places on the earth's surface to users who are coming more and more to have requirements for environmental information in numerical form. Technological developments such as the ERTS multispectral scanner with its output potentially available in digital form with each data element identified with a spot on the earth's surface are possibly forerunners of information systems which can bypass the map in communication of vital information from the earth through the remote sensor to the user/decision maker. The CARETS information system anticipates such automated developments in the future. For the present, the CARETS data are transformed into map form for intermediate processing, using a combination of manual and machine methods which are within the capability of available technology, and which simulate the processing capabilities of future information systems that will be more fully automated.

The elements of the CARETS geographic information system may be better understood by referring to an abbreviated list of steps, as follows. Note that the list begins and ends with the users, whose needs are the reasons for existence of any information system.

a. User needs assessment. Prior to the official beginning of the CARETS project an assessment was made of the region's users of environmental information of the type available from the remote sensors. While a wide variety of users or potential users were identified, the user needs assessment concentrated on those who were in a position to make or influence decisions on land use, in accordance with the basic CARETS model. These were the various planning and management agencies of federal, state, and local governmental units. Approximately 200 individuals representing these and other regional user institutions were brought together in Washington in June 1971 for an initial users conference. Attendees were exposed to brief presentations on CARETS and on the capabilities of the sensors, and were then asked for indications of ways that the proposed systems could be of use. In addition to the initial users' conference, a study was made of Virginia State agencies and how the data of the kind to be produced in the CARETS project could be of use in their activities (Adams, Goodell, et al., 1971). The results of these efforts were the identification of a community of users with similar kinds of needs for land use data, which characteristically were required in quantitative form, retrievable for a given geographic area of the users' jurisdiction, and in such a format that the land use data could be used in conjunction with other environmental or socio-economic data sets as required for zoning, forecasting, determination of environmental impact, or other application of land use data.

b. Preparation of maps for digitizing. This step encompasses the extraction, in map form, of data sets from the remote sensing data, both aircraft and satellite, and preparing the maps so that they could be transformed into digital format. The test region has been mapped on 48 separate map sheets for the aircraft data base; locations of these sheets are indicated in Figure 2. Controlled photomosaics, land use maps, and land use change maps are available on open file at the U. S. Geological Survey, along with hydrology, census, and location maps to aid in use and interpretation of the land use data. ERTS maps, being at a smaller scale, have been compiled on sheets covering larger areas, as indicated on Figure 3. Examples of an ERTS image and corresponding land use map derived therefrom are shown in Figures 4 and 5. Key to categories of land use identified on ERTS imagery (with numerical codes that identify the land uses depicted in Figure 5) is contained in Table 1.

c. Digitizing map data. Transforming the information on the line maps to digital format followed a decision to create a data base with as much of the detail in the original maps as possible, so that even after the completion of the ERTS experiment, a valuable digital file of the region's land use would remain. This decision meant that a "polygon" system would be used, i.e. one which creates a file of all the areas or polygons bounded by a discrete line on the map. Digitizing of CARETS maps to date was done using two methods: manual line following, using a USGS coordinate digitizer; and automatic optical scanning, using the drum scanner belonging to the Canadian government, Department of the Environment, Canadian Geographic Information System, Ottawa.

d. Processing data for conversion to polygon file. This step involves computer programming and data processing which enables the raw tape or card files of the digitized boundary line data to be converted into a tape which identifies each polygon according to its location and land use type (or other appropriate label).

e. Plotting, editing and correcting errors. Errors, whether operator caused or in the data themselves, are removed by a sometimes laborious process of plotting, editing, and performing certain computer tests.

f. Preparation of area summaries. This task involves computation of areas occupied by the various land use types, a task readily performed in the computer once an error-free tape of the land use boundaries is available.

g. Merging of land use and land use change files to produce update. Once a land use data base is established for a given time (1970 for the CARETS aircraft data and 1972 for the ERTS data), its updating is perhaps most efficiently accomplished by examining later remote sensing data for indications of land use change, mapping the areas where change has taken place, and merging the two maps to produce the updated or revised map. So far the merge has been done manually, although it is hoped that the capability will soon be available for accomplishing the merge in the machine, i.e., using digital records of the original and change maps.

h. Overlaying land use maps with census, hydrology and geology maps. To achieve the desired flexibility in retrieval of the land use information, the system should have the capability of retrieving quantitative data sets geographically ordered according to the area of the user's jurisdiction, or other geographic area that may be of interest for environmental analysis, for example, within a certain distance of the coastline or an urban area, or within a certain drainage basin, or according to characteristics of surficial geology when desired for land use suitability analysis. Commonly, for data of the type dealt with in this project, "output" will be required county-by-county, since administration, planning, and other data-gathering activities are often organized by counties or groups of counties. The geographic areas represented by counties (and Virginia independent cities) are illustrated in Figure 6.

The CARETS geographic information system is developing the capability of performing the map overlay operation within the digital computer, i.e., interrogating the digital files of the land use data along with those of any other map with boundaries of areas for which land use summaries are required. This capability greatly expands the utility of the digitized land use file, making possible not only quantitative comparisons of ERTS and aircraft data for any portion of the region, but also the partitioning of the basic data set into rectangular grid cells of any specified dimensions. The overlay capability already exists in the Canada Geographic Information System, and successful system tests of a portion of the CARETS data have already been performed through a cooperative arrangement with the Canadian government. In this test land use data for the Norfolk-Portsmouth Standard Metropolitan Statistical Area were overlayed and retrieved and summed by census tracts, allowing computations of relationships among population and land use for that area. At this writing, steps are being taken to achieve an overlay capability on USGS hardware.

i. Statistical analysis of digitized data. As a final stage in the USGS processing of the CARETS data sets, a variety of analytical techniques will be utilized, for example, area summaries, comparisons of one map with another, multiple regression analyses of land use data versus other environmental or socio-economic data sets, formatting of land use data for experimental input to simulation or forecasting models, and analysis of land use time series. Examples of machine-derived data summaries for a portion of CARETS (the Norfolk-Portsmouth Standard Metropolitan Statistical Area) are shown in Table 2.

j. User evaluation and feedback. Cooperating user institutions are involved in the entire process of developing the experimental CARETS information system. A systematic evaluation of the entire range of data sets being produced by CARETS is being performed by these users, and their responses are to be fed back for inclusion in the final report. A series of questionnaires has been prepared to systematize user response to CARETS products. The first in the series, "CARETS User Indication of Interest" is reproduced as Figure 7. Potential users who respond by submitting such a form will be contacted by a CARETS staff member to provide the data requested, if possible, and to follow up with more detailed inquiry about the uses to which the products would be put. It is hoped that continuing arrangements with those users can survive the NASA-funded part of the demonstration project and provide the basis for an operational user-interactive system to follow.

ACKNOWLEDGMENTS

Most of the staff members of the Office of the Chief Geographer have contributed to the CARETS project, and their contributions have been essential to the evolution of the project and the development of its products. In particular, special acknowledgment and thanks are due to the "core" staff members in the final phase of CARETS, Peter Buzzanell, Katherine Fitzpatrick, Harry F. Lins, Jr., and Herbert K. McGinty. The project has also benefitted from the advice and assistance of the International Geographical Union Commission on Geographical Data Sensing and Processing, and the Canada Geographic Information System, Department of the Environment, Ottawa.

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Anderson, James R., Ernest E. Hardy, and John T. Roach, 1972. A land-use classification system for use with remote-sensor data, Geological Survey Circular 671.

Tomlinson, R.F., (ed), 1972. Geographical data handling, Symposium edition, I.G.U. Commission on Geographical Data Sensing and Processing, UNISCO/IGU Second Symposium on Geographical Information Systems, Ottawa, Aug 1972.

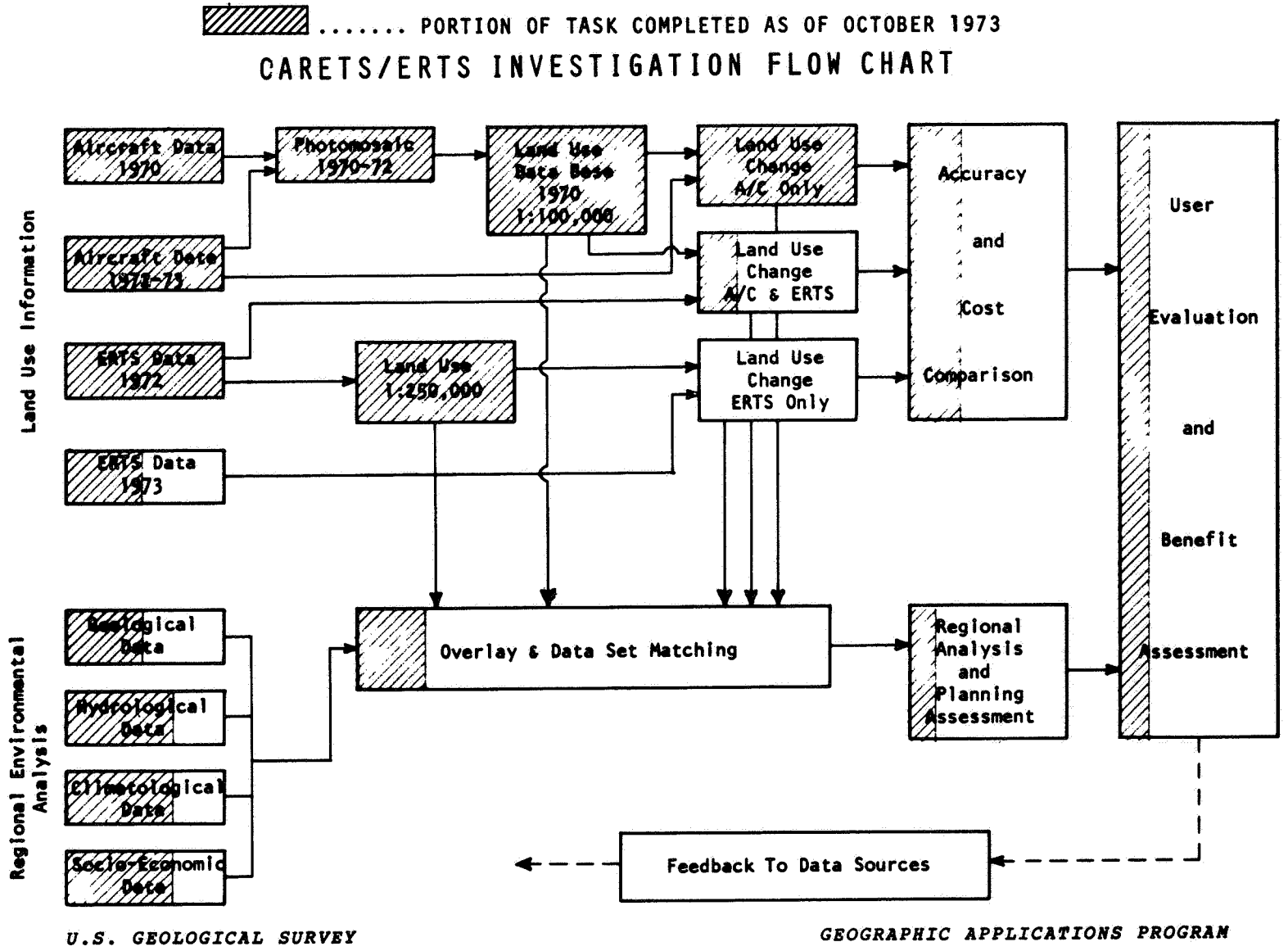
..... PORTION OF TASK COMPLETED AS OF OCTOBER 1973
CARETS/ERTS INVESTIGATION FLOW CHART
Land Use Information
Aircraft Data 1970
Photomosaic 1970-72
Land Use Data Base 1970 1:100,000
Land Use Change A/C Only
Aircraft Data 1972-73
Land Use Change A/C & ERTS
ERTS Data 1972
Land Use 1:250,000
Land Use Change ERTS Only
ERTS Data 1973
Accuracy and Cost Comparison
User Evaluation and Benefit Assessment
Regional Environmental Analysis
Geological Data
Hydrological Data
Climatological Data
Socio-Economic Data
Overlay & Data Set Matching
Regional Analysis and Planning Assessment
Feedback To Data Sources
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Figure 1

INDEX TO AIRCRAFT COMPILED, 1970, LAND USE MAPS

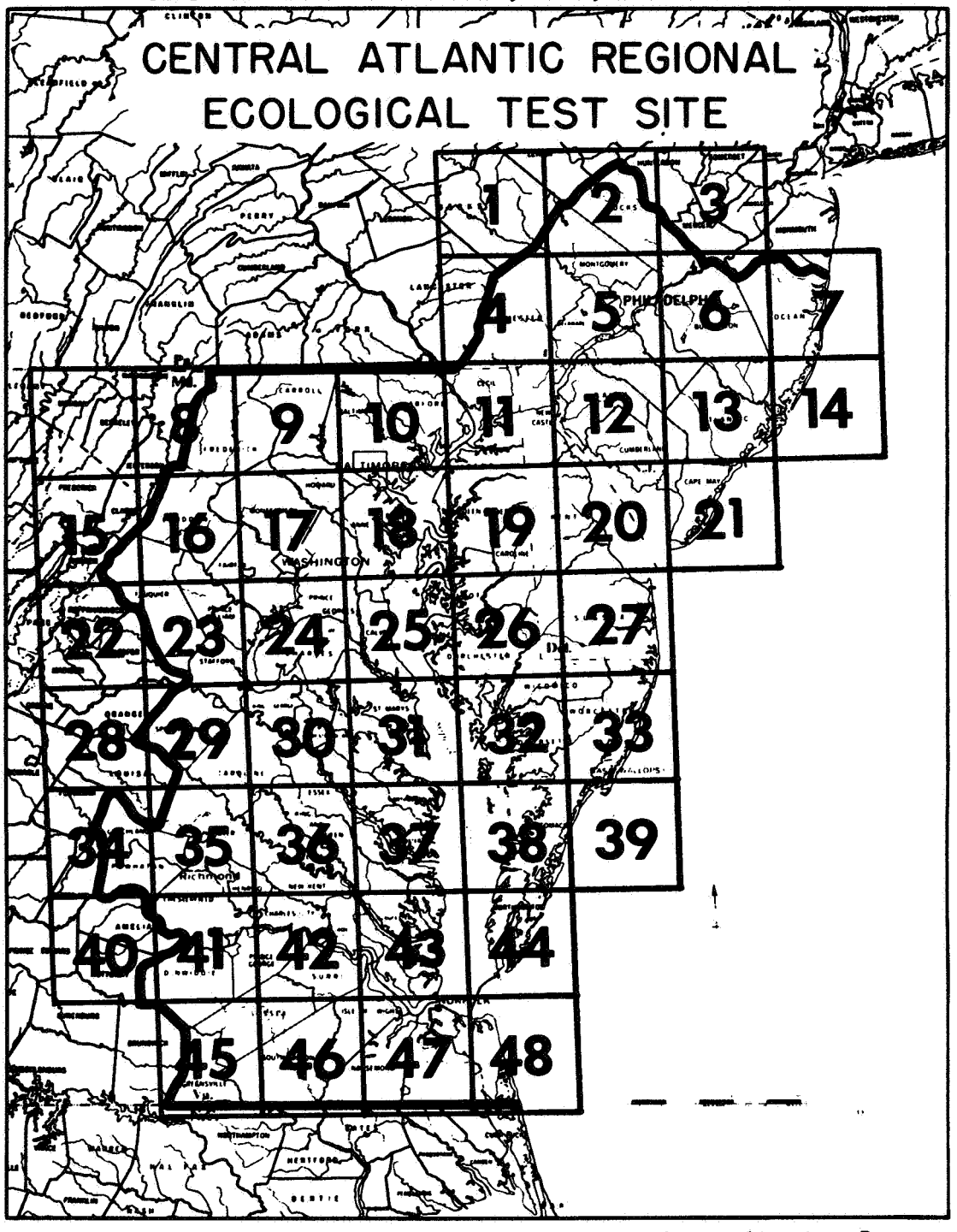

Figure 2

INDEX TO ERTS COMPILED, 1972, LAND USE MAPS

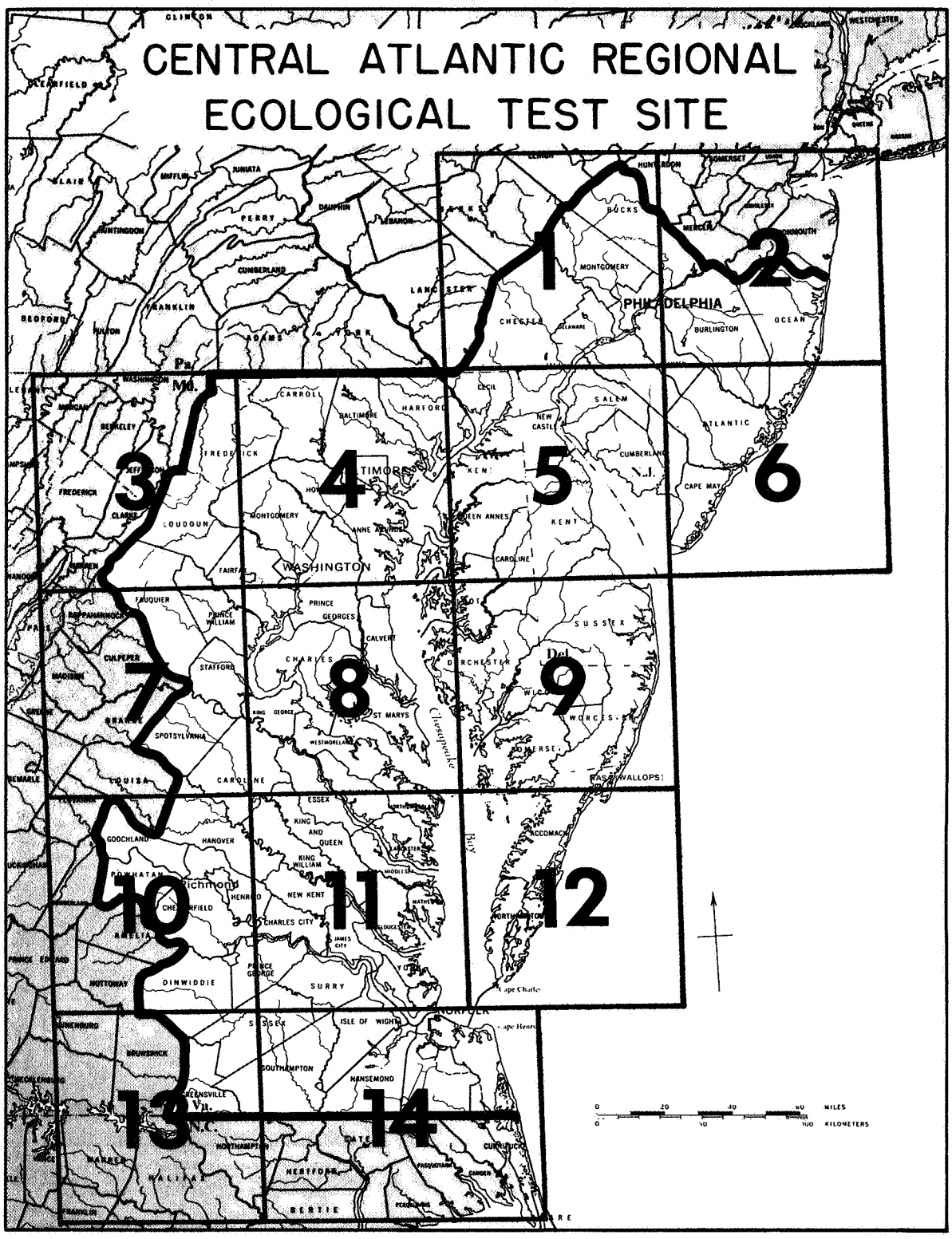

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Figure 3

ERTS Color Composite Image of the Washington, DC Area

(Frame 1080-15192/Bands 4,5,7/11Oct72)

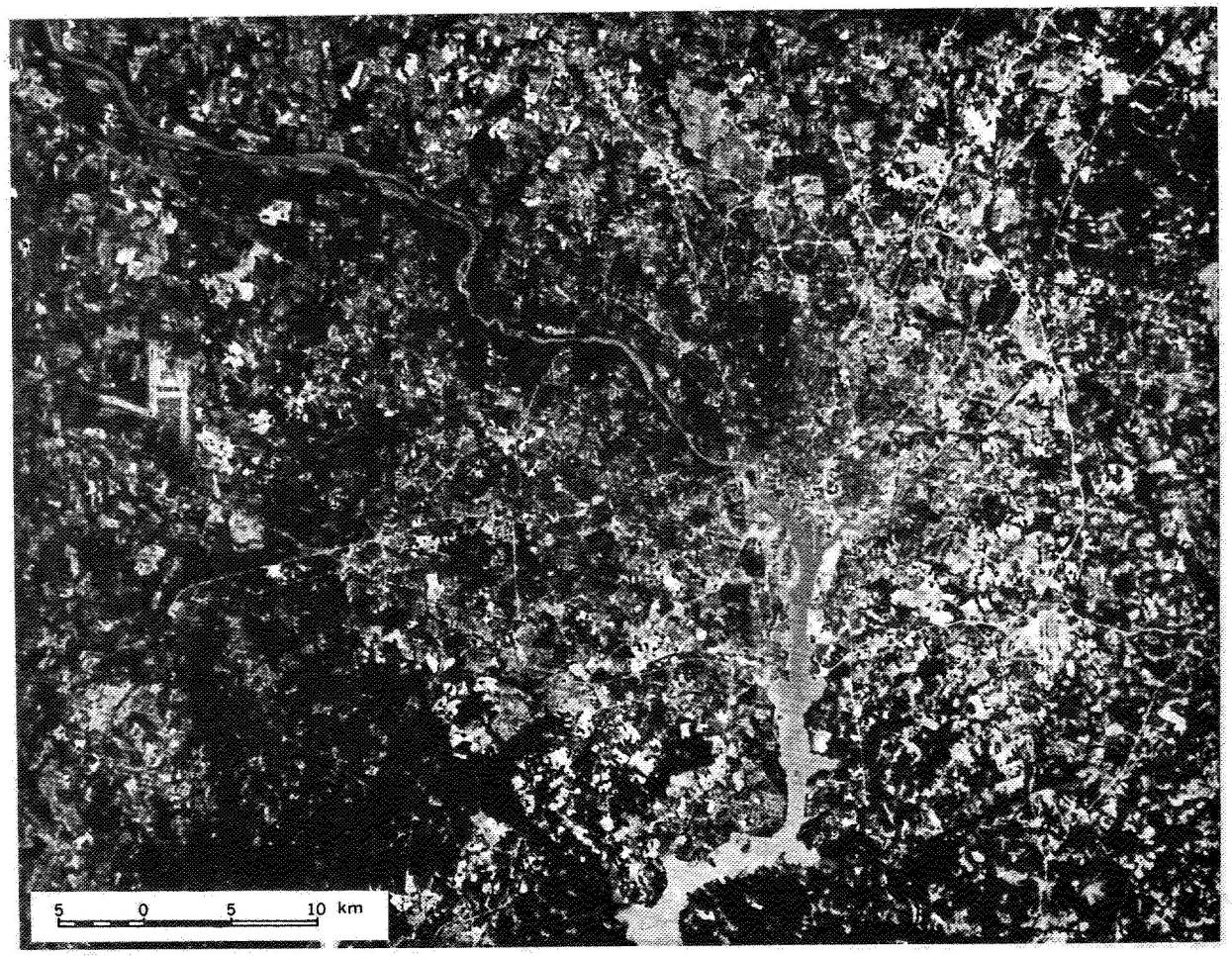

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Figure 4

Washington Area Land Use Map Derived From ERTS

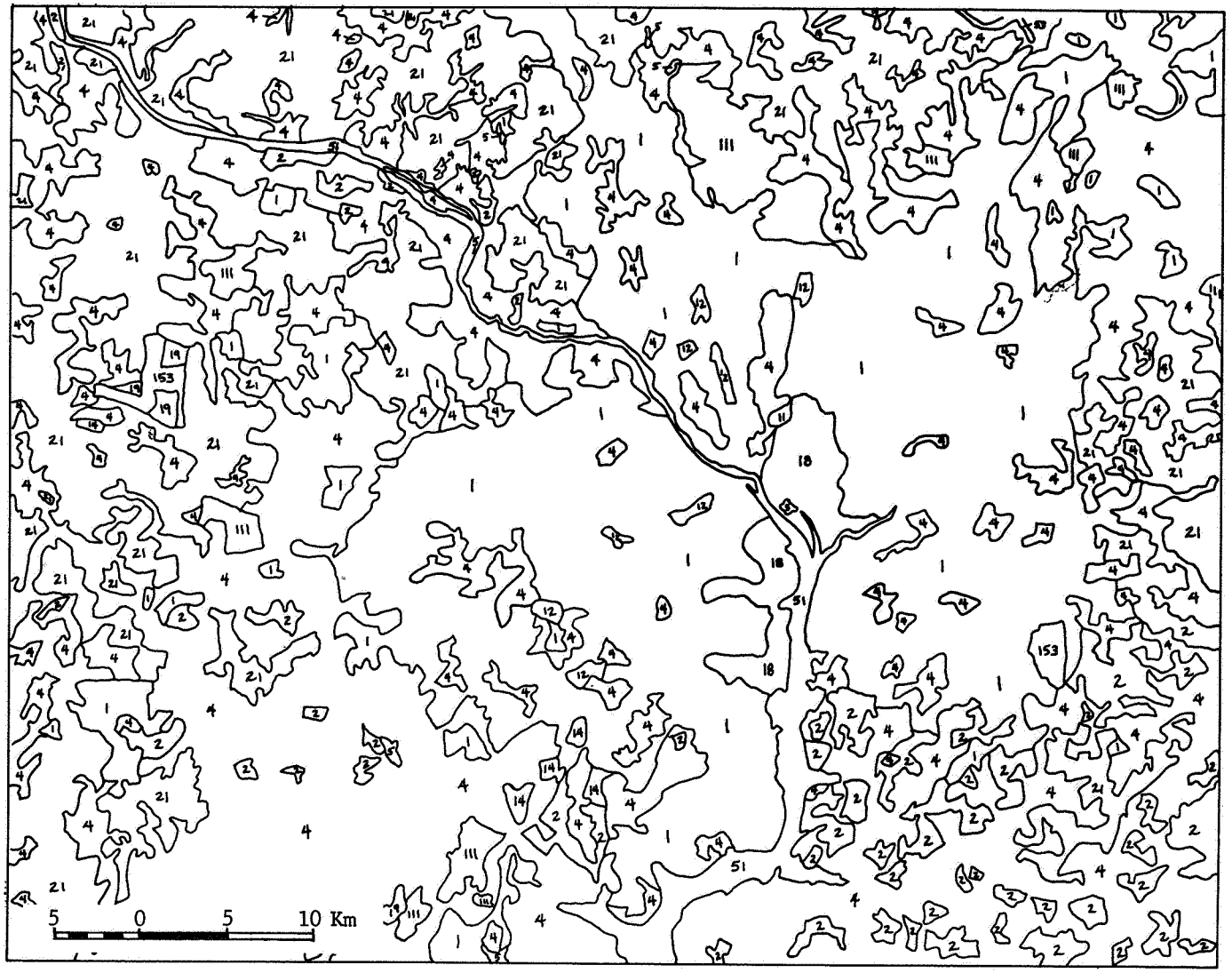

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Figure 5

COUNTY AND INCORPORATED CITY BOUNDARIES

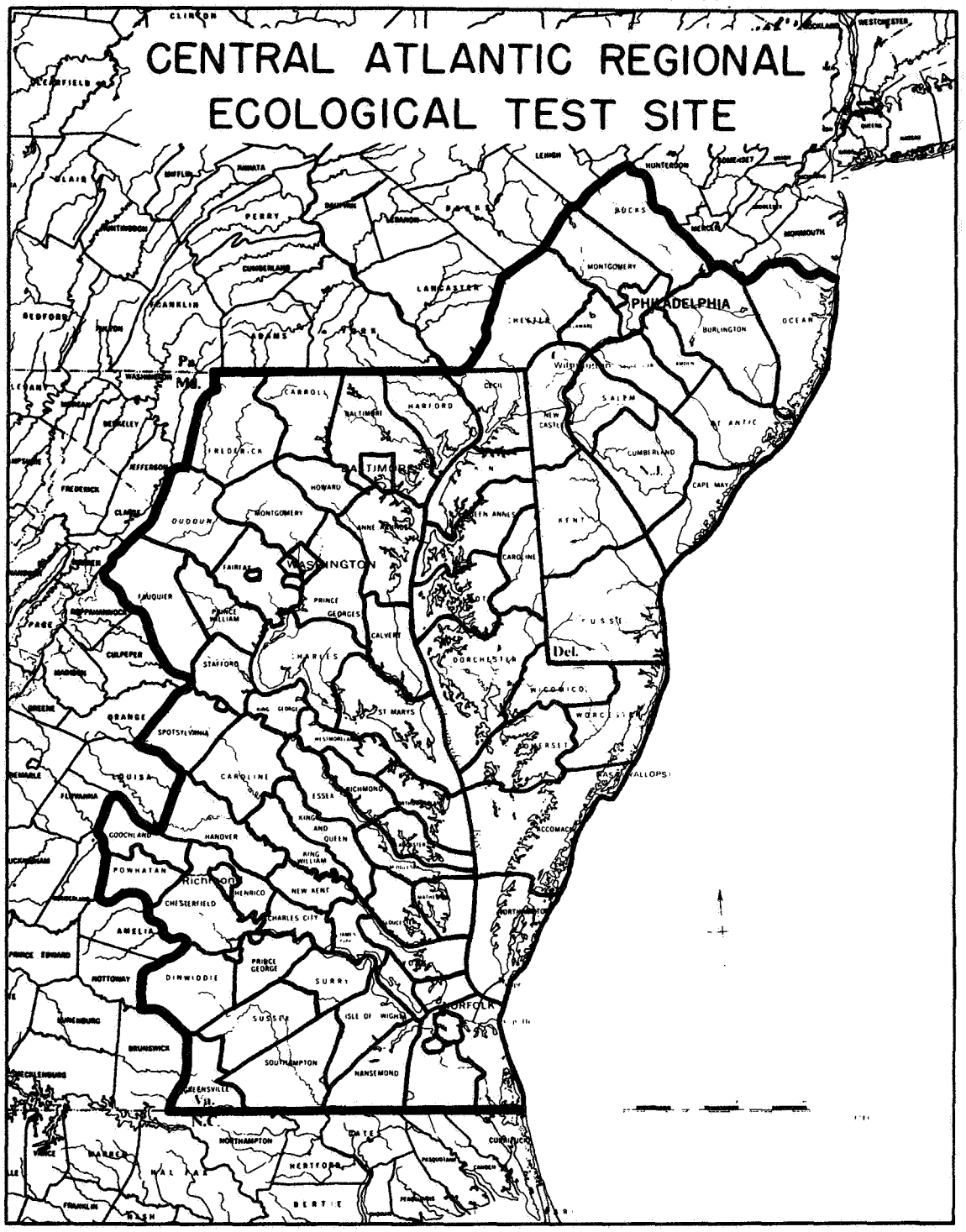

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Figure 6

CARETS USER INDICATION OF INTEREST

MEMORANDUM Date:_____

To: Robert H. Alexander Mail Stop 115
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 7

CARETS LAND USE CATEGORIES IDENTIFIED ON ERTS IMAGERY

LEVEL I	LEVEL II	LEVEL III (PROPOSED)
1 URBAN AND BUILT-UP	11 RESIDENTIAL	111 SINGLE FAMILY RESIDENTIAL UNITS
	12 COMMERCIAL AND SERVICES	121 RETAIL TRADE AREAS
	14 EXTRACTIVE	142 SAND AND GRAVEL PITS
	15 TRANSPORTATION, COMMUNICATION AND UTILITIES	151 HIGHWAYS
		152 RAILROADS AND FACILITIES
		153 AIRPORTS
		154 MARINE CRAFT FACILITIES
	16 INSTITUTIONAL	
	17 STRIP AND CLUSTERED SETTLEMENT	
	18 MIXED	
	19 OPEN AND OTHER	
2 AGRICULTURAL	21 CROPLAND AND PASTURE	
4 FOREST	41 DECIDUOUS FOREST	
	42 EVERGREEN FOREST	
5 WATER	51 STREAMS AND WATERWAYS	
	52 LAKES	
	53 RESERVOIRS	
	54 BAYS AND ESTUARIES	
6 NON-FORESTED WETLAND	61 VEGETATED	
	62 BARE	
7 BARREN LAND	74 BEACHES	

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Table 1

COMPARISON OF AIRCRAFT AND ERTS LAND USE MEASUREMENTS NORFOLK-PORTSMOUTH SMSA

	1972 AIRCRAFT DATA (HECTARES)	1972 ERTS DATA (HECTARES)
URBAN	41,207	47,148
AGRICULTURAL	49,293	47,381
FORESTED	76,124	73,848
NON-FORESTED WETLANDS	7,793	4,583
BARREN LANDS	1,446	1,749
TOTAL	175,863	174,709

Table 2

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