NASA CONTRACTOR REPORT 166498

ABAG Biogenic Hydrocarbon Emissions Inventory Project
Final Report

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Charlotte Carson-Henry
Editor

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ABAG Biogenic Hydrocarbon Emissions Inventory Project Final Report

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ABSTRACT

The ability to identify the role of biogenic hydrocarbon emissions in contributing to overall ozone production in the Bay Area, and to identify the significance of that role, were investigated in a joint project of the Association of Bay Area Governments (ABAG) and NASA/Ames Research Center. Ozone, which is produced when nitrogen oxides and hydrocarbons combine in the presence of sunlight, is a primary factor in air quality planning. In the past, air quality models have not included biogenic (natural) sources of hydrocarbon emissions in predicting ozone production, having focused solely on anthropogenic (man-made) sources. In investigating the role of biogenic emissions, this project employed a pre-existing land cover classification to define areal extent of land cover types. Emission factors were then derived for those cover types. The land cover data and emission factors were integrated into an existing geographic information system, where they were combined to form a Biogenic Hydrocarbon Emissions Inventory. The emissions inventory information was then integrated into an existing photochemical dispersion model. Air quality modeling efforts using the emissions inventory are on-going, and the land cover inventory has successfully been applied to several other environmental planning problems.

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ACKNOWLEDGEMENTS

As Editor, it has been my task to compile this document from project files and working papers written by the participants during the course of the project. The participants were very supportive of my efforts, answering multitudes of questions and closely reviewing the report draft.

The project itself benefitted substantially from the support provided by the following persons and agencies: Dr. Dale Lumb, Branch Chief, and Ms. Susan Norman, Assistant Branch Chief, Technology Applications Branch, NASA/Ames Research Center; Mr. William J. Todd and later Mr. David R. Morse, California Operations Contract Manager, Technicolor Government Services, Inc.; Mr. Don Olmstead, BASIS Program Manager, Association of Bay Area Governments; Mr. Paul Wilson, Geogroup Technical Consultant; the members of the California Integrated Remote Sensing System (CIRSS) Task Force, under the chairmanship first of Mr. Don Olmstead, ABAG, and later of Mr. Glenn Sawyer, California Department of Water Resources; the members of the Delphi Survey Panel; and the members of the Biogenic Hydrocarbon Emissions Advisory Committee.

Charlotte Carson-Henry
Editor

INTRODUCTION

ABAG BIOGENIC HYDROCARBON EMISSIONS INVENTORY PROJECT
FINAL REPORT

Introduction

Background

The ABAG Hydrocarbon Emissions Inventory Project was initiated in response to a need identified when the Association of Bay Area Governments (ABAG), along with the Bay Area Air Quality Management District (BAAQMD), the Metropolitan Transportation Commission, and other agencies set out to revise their 1979 regional air quality plan. In the Bay Area, ambient levels of ozone, which is a secondary pollutant formed by the interaction of hydrocarbons and nitrogen oxides in the presence of sunlight, exceed Federal standards. Strategies to reduce ambient ozone levels in the Region have previously focused on attempting to reduce the amount of hydrocarbon generated by society's activities, virtually ignoring any contribution from biogenic sources. In order to formulate ozone control strategies for the revised air quality plan, it was necessary to relate ambient ozone levels to both anthropogenic (man-made) and biogenic (natural) sources of hydrocarbon emissions.

The traditional approach to air pollution control in the United States has been to reduce ambient pollutant levels below specified standards by controlling anthropogenic emissions of the pollutants or their precursors. This approach has been based on the assumption that man is the sole cause of the problem and that natural sources contribute an insignificant fraction of the total emissions. If this assumption is not true, and natural sources contribute to pollution problems at a level comparable to that of anthropogenic sources, solving air quality problems will be difficult in the future because attempts to control natural emissions would be unfeasible. Furthermore, the proportion of total emissions contributed by natural sources is probably becoming more significant with time, although to a minor degree, as controls are imposed on man-made emissions.

Over the last two decades, scientists have attempted to assess the contribution of biogenic sources by conducting three basic types of research: 1) developing emission factors for natural sources, 2) compiling global and regional inventories of natural emissions, and 3) studying the atmospheric chemistry of natural emissions. Although a wide variety of natural emissions have been studied -- such as sulfur compounds, hydrocarbons, particulates, nitrogen oxides, etc. -- the ABAG project focused only upon biogenic sources of hydrocarbon emissions. These biogenic emissions are organic gases given off by living vegetation, bodies of water, wetlands, and decaying vegetative and animal tissue.

The Federal Ozone Standard that must be attained by 1987 is .12 parts per million (ppm), and the Bay Area has reached a peak level of .17 ppm recently. A primary objective in revising the 1979 Bay Area Air Quality Plan to create the 1982 Plan was to devise emission control strategies that would enable attainment of the Federal Standard by 1987, as required by law. Controls placed on anthropogenic hydrocarbon emitters affect only one of two emission sources; biogenic sources are not realistically controllable. The agencies revising the 1979 Plan felt, therefore, that any chance for attainment of the Federal Standard was dependent upon assessment of the relative contributions of both anthropogenic and biogenic sources to overall ozone production, and on devising more stringent controls of anthropogenic sources if biogenic sources were found to be significant contributors.

Project Objectives

The ABAG project was undertaken as a NASA/Ames Research Center Applications System Verification and Transfer (ASVT) project funded by NASA/Ames and conducted under the auspices of the California Integrated Remote Sensing System (CIRSS) Task Force. The primary objectives of the project were to 1) investigate the ability to identify the role of biogenic hydrocarbon emissions in contributing to overall ozone production in the Bay Area and attempt to identify the significance of that role, and 2) train ABAG personnel in the remote sensing analysis techniques involved in generating and using the land cover inventory, so that that inventory could be used by ABAG for future applications. Secondarily, the CIRSS Task Force was interested in two concepts of a more general nature: 1) vertical data integration, and 2) integration of remote sensing analysis software and techniques with geographic information systems (GIS). (See Appendix C for references to two excellent papers by Paul Wilson regarding CIRSS objectives.) These two CIRSS objectives were taken into consideration when the ABAG project was designed, forming the secondary project objectives.

Methodology

The issue of the extent to which biogenic hydrocarbon emissions combine with anthropogenic hydrocarbon and nitrogen oxide emissions to produce ozone in the Bay Area was addressed through creation of a biogenic hydrocarbon emissions inventory and input of that inventory to an existing air quality model. Two major data sets -- a land use/land cover data set, and hydrocarbon emission factors for the classes comprising that data set -- were identified as necessary components of the biogenic hydrocarbon emissions inventory (BHEI). A pre-existing land cover inventory was selected for use in creating the land use/land cover data set: a portion of the statewide Landsat classification created during the California Department of Forestry (CDF) Project at NASA/Ames. That classification was modified to reflect the predominantly urban nature of portions of the Bay Area. This modification was facilitated by the preservation of the CDF original Landsat clusters, which allowed regrouping and relabeling of those clusters by ABAG. After the relabeling had been performed, stratification to correct conflicts between classes was performed at Ames. The modified classification was then registered to the UTM map base and integrated with ABAG's geographic information system, BASIS, where additional urban-area stratification was performed via modeling to further fine-tune the classification to the needs of the ABAG project. Photointerpretation, ground sampling, and statistical analysis techniques were employed in evaluating the accuracy of the modified classification, which in turn influenced the accuracy of the emissions inventory. Hydrocarbon emission factors were assigned to the Landsat-based classes, and BASIS was used to generate the Biogenic Hydrocarbon Emissions Inventory (BHEI). The BHEI data set was then made compatible with the LIRAQ photochemical dispersion model at Lawrence Livermore Laboratory and LIRAQ was subsequently used to ascertain the degree of hydrocarbon emissions control required to attain the Federal ozone standard in the Region before 1987.

The training objective was addressed through participation of the ABAG staff in user workshops during which nearly all phases of the digital processing was performed.

The secondary objectives were addressed through: 1) use of a pre-existing classification, 2) integration of the land use/land cover data into ABAG's Bay Area Spatial Information System (BASIS), and 3) integration of the Biogenic Hydrocarbon Emissions Inventory of (BHEI) data into the Livermore Regional Air Quality (LIRAQ) photochemical dispersion model.

Figure 1 presents an overview of the project's digital processing phases.

Project Participants/Roles

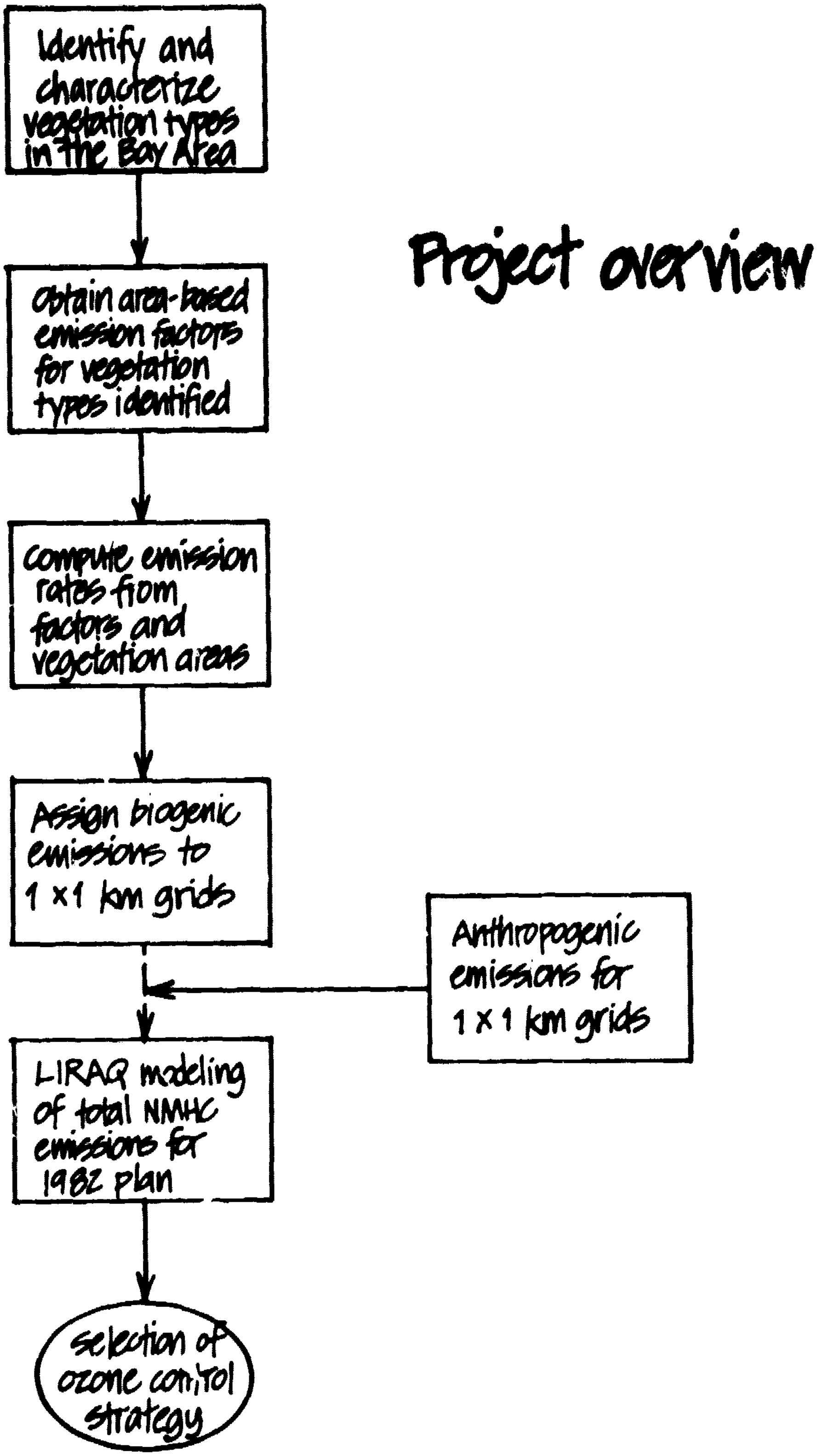
Several agencies were involved in various portions of the project and their roles were widely varied:

* Association of Bay Area Governments: ABAG took the lead role in the project, having been the lead agency for air quality planning in the Bay Area for the last three years. It was ABAG's task to merge the biogenic hydrocarbon emission rates and the land use/land cover data to obtain the BHEI. ABAG was also responsible for concurrently developing the expertise needed to refine the BHEI, if necessary, and to conduct further remote sensing activities in the future. Besides fulfilling these roles, ABAG provided substantial contributions of both personnel and computer time.

* <u>NASA/Ames Research Center</u>: In addition to funding the project the role of NASA/Ames, together with its support services contractor Technicolor Government Services, Inc. (TGS), was to provide the expertise and facilities necessary to train and assist ABAG personnel in production of the land use/land cover data set, and in the integration of that data set into BASIS.

* <u>Biogenic Hydrocarbon Emissions Advisory Committee</u>: The role of the Advisory Committee was 1) to monitor the creation of the land use/land cover data set to ensure inclusion of all relevant vegetation classes in that data set, and 2) to provide technical guidance in the collection of realistic biogenic hydrocarbon emission rates for all land cover classes to be used in generating the Biogenic Hydrocarbon Emissions Inventory. The Committee was comprised of representatives from two of the agencies involved in Bay Area air pollution control -- the Bay Area Air Quality Management District and the California Air Resources Board -- as well as academia and industry.

Participating personnel from these agencies are listed in Table 1, following.



Source: ABAG, 1980

Figure 1

Table 1

PROJECT PARTICIPANTS

ABAG (Association of Bay Area Governments)

Roberta M. Moreland	BASIS Coordinator
Malcolm Gilmour	Local Vegetation Specialist
Don Hunsaker	Air Quality Specialist
Paul M. Wilson	Geogroup Technical Consultant
Donald Olmstead	BASIS Program Manager

NASA/TGS (NASA/Ames and Technicolor Government Services, Inc.*)

Eugene A. Fosnight (TGS)	Project Technical Manager
Charlotte Carson-Henry (TGS)	Project Technical Manager (from 11/81)
David Sinnott (NASA)	Project Monitor
Susan D. Norman (NASA)	CIRSS Program Manager

Biogenic Hydrocarbon Emissions Inventory Advisory Committee

Rob DeMandel	Bay Area Air Quality Mgmt. District
Carolyn Stromberg	California Air Resources Board
Mei-Kao Liu	Systems Applications, Inc.
Howard Linnard	California Air Resources Board
Harold Mooney	Stanford University
David Lincoln	Stanford University
Michael Rothenberg	Bay Area Air Quality Mgmt. District
James Sandberg	Bay Area Air Quality Mgmt. District

Biogenic Delphi Survey Panel of Experts

Elgene Box	University of Georgia
Ken Knoerr	Duke University
David Lincoln	Stanford University
Harold Mooney	Stanford University
Reinhold Rasmussen	Oregon Graduate Center
David Tingey	U.S. Environmental Protection Agency
Hal Westberg	Washington State University
Patrick Zimmerman	National Center for Atmospheric Research

*Formerly Technicolor Graphic Services, Inc.

Study Area

The study area was geographically defined as the nine counties surrounding the San Francisco Bay: Alameda, Contra Costa, Marin, Napa, San Francisco, San Mateo, Santa Clara, Solano, and Sonoma (see Figure 2). Both the land use/land cover data set and the Biogenic Hydrocarbon Emissions Inventory were created for this entire region. The LIRAQ model was applied only to that part of the data within the Bay Area Air Quality Management District (BAAQMD) (Figure 3).

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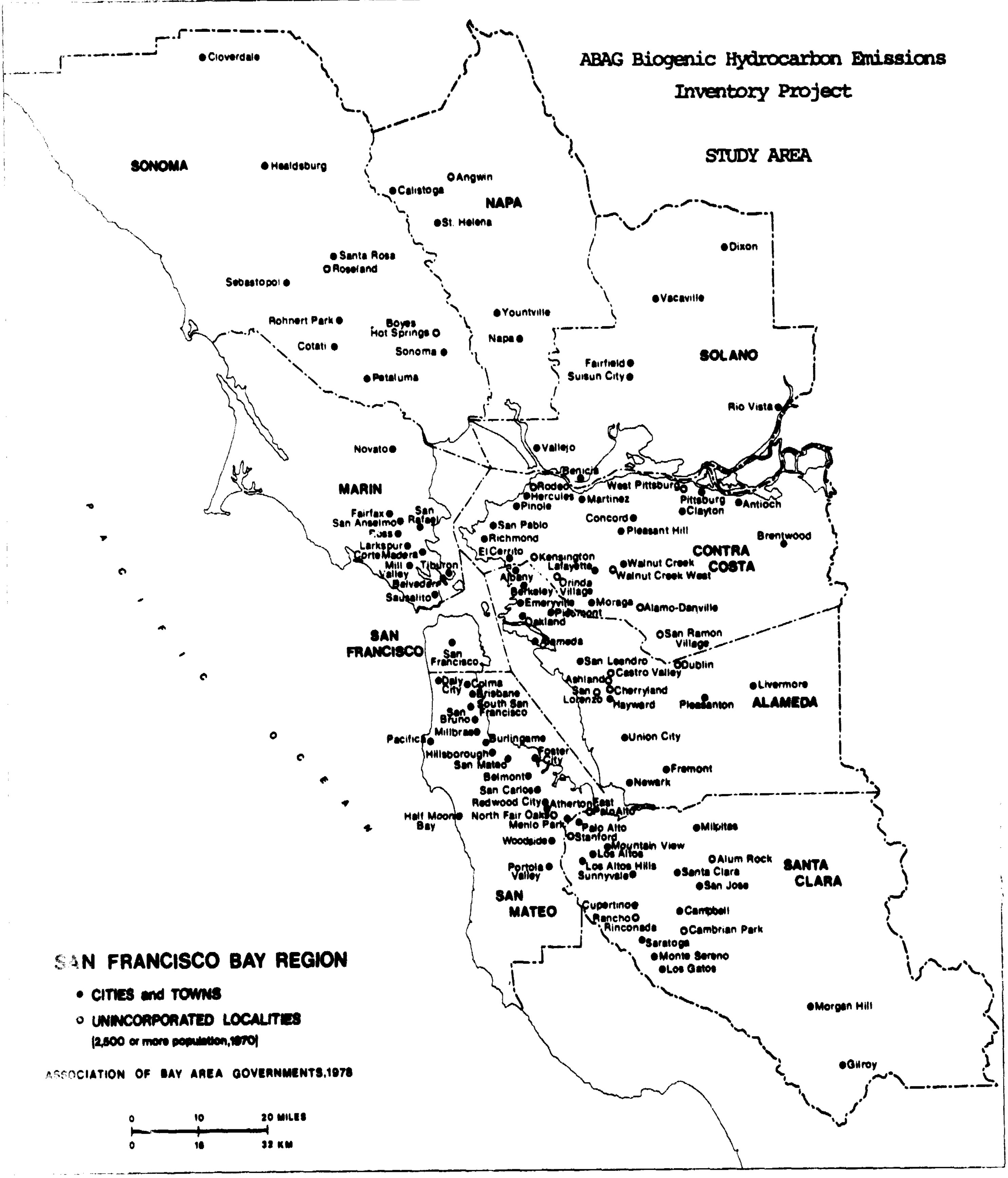

Figure 2

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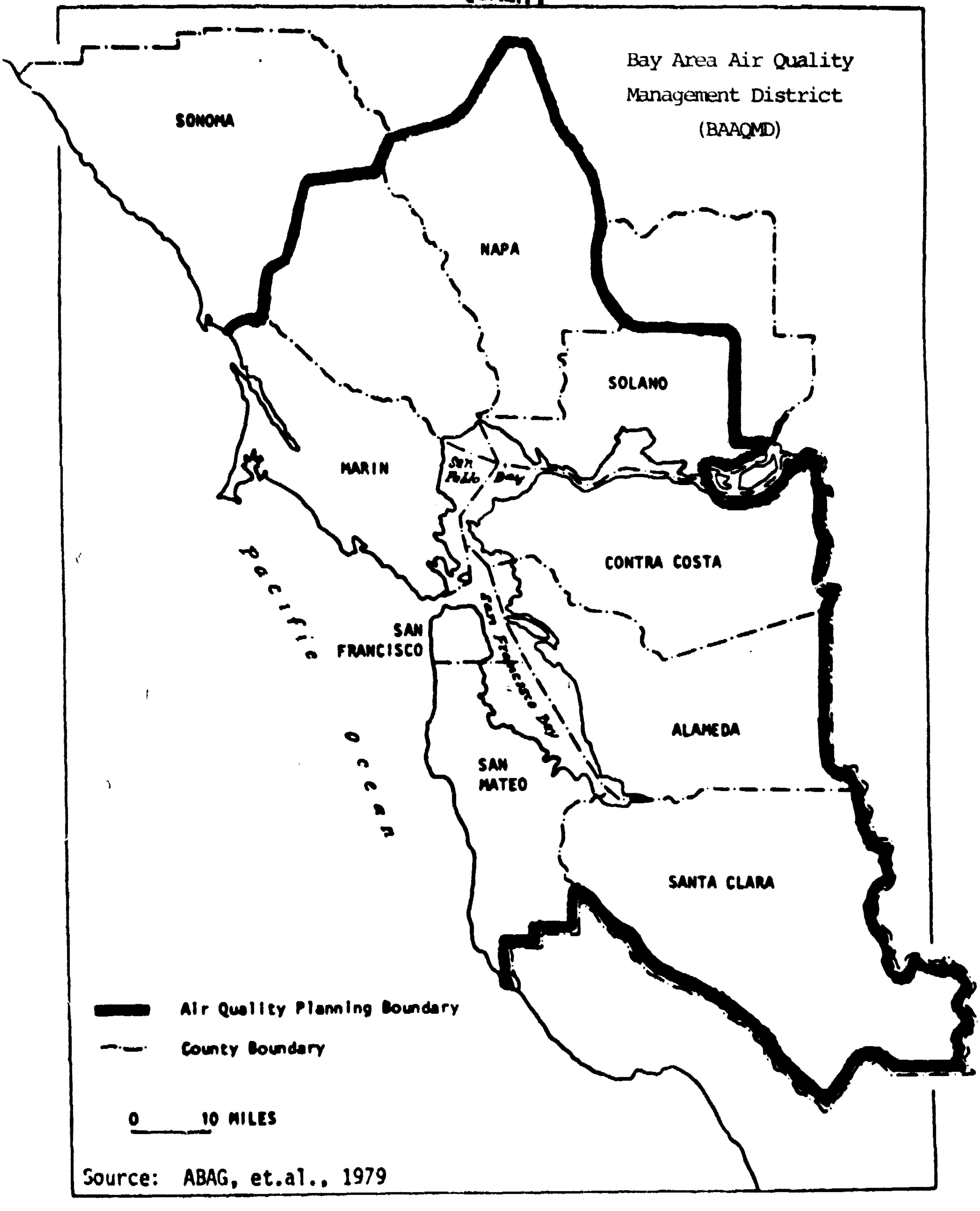

Figure 3

Project Design

The design of the ABAG project was based on the following considerations:

1) Full user participation in all aspects of the project, particularly in the digital work performed

2) Utilization of workshops to meet training objectives

3) Performance of digital processing activities at the location (NASA/Ames or ABAG) at which computer capabilities were best suited to the task at hand

4) Investigation of the potential for using pre-existing classifications in unrelated projects (CIRSS Task Force interest)

5) Investigation of vertical data integration concept, with emphasis on integration of remotely-sensed data (also a CIRSS Task Force interest)

Project goals, objectives, and design were finalized before any work was initiated. A workshop was then held to introduce the participating ABAG staff to basic remote sensing analysis techniques. During this workshop, the types of information extractable from Landsat data were identified and the reasons for limitations, such as resolution of the satellite imagery, were discussed. Once these theoretical limits were identified, several analysis options were discussed and considered. The following constraints emerged during that discussion: the land use/land cover data set had to contain vegetation sufficiently detailed for the biogenic hydrocarbon emissions inventory (BHEI), yet that same data set had to be general enough to satisfy the requirements of other ABAG projects still in the planning phase. A target classification scheme comprised of 22 information classes that met both of these constraints was subsequently developed. At the first Biogenic Hydrocarbon Emissions (BHE) Advisory Committee meeting, the scheme was discussed with reference to the information needed for the BHEI. Each of the 22 information classes were then defined, specifying average percent composition of the vegetation types for which biogenic hydrocarbon emission (BHE) rates could be derived, since BHE rates were to be determined on the basis of land use/land cover classes. Because a literature survey had revealed that no satisfactory emission rates for Bay Area vegetation types had previously been defined, the Committee recommended use of a Delphi survey for derivation of the emission factors to be used in the BHEI generation.

Throughout the project, additional workshops were conducted to perform the digital analysis tasks necessary for creation of the land use/land cover data set. An additional, specialized workshop was conducted for training in photointerpretation (PI) techniques prior to the PI portion of the verification and evaluation that was conducted on the land use/land cover data.

Computer Systems Used

A variety of computer systems were available both at NASA/Ames and at ABAG, and a number of these hardware/software systems were utilized during the course of the project. Capabilities at Ames Research Center ranged from two interactive minicomputers (the HP 3000 and tne SEL 32/77) housed at the Technology Applications Branch to large computers at the Center-wide computing facility, like the IBM 360/67 and ILLIAC-IV. The minicomputers hosted software whose emphasis lay in interactive digital image processing, while the image processing capabilities of the large Center computers were comprised of utility programs that performed large tasks requiring substantial and rapid computing capability. The BASIS system at ABAG, on the other hand, was a geographic information system with an expandable data base focused on the needs of the various ABAG regional planning efforts. BASIS resided on an in-house VARIAN minicomputer.

Table 2 summarizes the systems used in the ABAG project, and the tasks to which they were applied.

Tasks which could be most expediently performed using a system with an interactive display were conducted at Ames on one of the two interactive minicomputers. Large CPU-intensive jobs, such as registration to the UTM map base, were done on the larger computers at the Ames Center-wide computing facility, but were processed in batch mode to minimize costs. Urban modeling was conducted on ABAG's operational geographic information system, as was the actual compilation of the biogenic hydrocarbon emissions inventory.

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Table 2

SYSTEMS UTILIZED IN PROJECT

Processing Phase/Task	Site/System/Software Utilized	
Modification of CDF Classification		
Land Cover Class Identification	Ames HP 3000/III;	IDIMS[1] display package
Stratification to Resolve Class Confusion	Ames HP 3000/III;	IDIMS ZIP function
Urban Mask Stratifications	ABAG Varian V76;	BASIS
Registration to UTM Grid		
Control Point Selection	Ames SEL 32/77;	ILEX[2]
Control Point Digitization, Manipulation, & Development of Regression Equations	BBN[3] PDP 10;	EDITOR[4]
Registration	Ames IBM 360/67 & ILLIAC-IV	Utilities: FLDMASK, GROUP, I4CATS, NREFORM, NINDEX
Reformatting for Transfer to ABAG	Ames HP 3000/III;	IDIMS TRANSFER function
	Ames SEL 32/77;	Tapecopy utility
Mosaicking/Evaluation of Land Cover Data Set	ABAG Varian V76;	BASIS
Compilation of Biogenic Hydrocarbon Emissions Inventory	ABAG Varian V76;	BASIS
Verification & Evaluation of Land Cover Data Set		
Sample Extraction/Data Preparation	Ames SEL 32/77;	ELAS[5] & ILEX
Data Preparation/Regressions	Ames HP 3000/III;	IDIMS SAMPLET function & ERIS[6]
Photo Product Generation		
Image Annotation	Ames HP 3000/III;	IDIMS ANNOTATE function
Dicomed Input Image Creation	Ames SEL 32/77;	CIE[7]
Dicomed Generation	Ames HP 3000/III;	IDIMS DICOMED function
Slide Generation	Ames HP 3000/III;	IDIMS display package with Dunn Camera System

1 IDIMS: Interactive Digital Image Manipulation System, written by Electromagnetic Systems Laboratories (ESL), Inc.
2 ILEX is a software package on the SEL 32/77 at Ames; accesses Versatec plotter.
3 BBN: Bolt, Beranek, and Newman in Boston, Massachusetts.
4 EDITOR is a USDA-supported image processing software package.
5 ELAS: Earth Resources Applications Software, written at NASA/ERL.
6 ERIS: Earth Resources Inventory System, ESL statistical analysis software.
7 CIE: Classified Image Editor software, written at NASA/Ames.

The Bay Area Spatial Information System (BASIS)

BASIS is a geographic data base developed for the 7,000 square mile San Francisco Bay Area. The data base is large (160 million data items) and runs on a minicomputer system. BASIS is administered by the Association of Bay Area Governments (ABAG).

BASIS is a grid cell system; that is, the nine-county area covered by BASIS is represented by an array of square grid cells. and all data are stored and manipulated in terms of these cells. Since the system was designed to be used for local government applications performed on a regional scale, the grid cells are relatively small in size: 100 meters square, or one hectare. Coverage of the Bay Area, including all land area and the Bay itself, requires more than two million of these cells. The cell array is based on the UTM coordinate system.

The BASIS data base is designed to contain 80 data items for each of the two million hectare cells. The structure of the data base is simply a three-dimensional array (2100 columns x 2250 rows x 80 data items). Following are some of the layers in the BASIS data base.

Geology	1970 Census Tracts
Soil Types	LAFCO (City) Boundaries
USGS Flood Plains	Zip Code Boundaries
HUD Flood Plains	440 Analysis Area Boundaries
Precipitation	County Boundaries
Wind Speed	Coastline, Lakes, Marshes
Dam Inundation Areas	USGS Quad Sheet Boundaries
Tsunami Inundation Areas	Marsh Lands (San Mateo County)
Elevation/Bay Depth	Land Use (San Mateo County)
Slope	Air Pollution (CO)
Slope Stability 1	Air Pollution (NOX)
Slope Stability 2	Air Pollution (SO2)
Well Yield	Air Pollution (SP)
Earthquake Fault Zones	Air Pollution (Ozone)
Maximum Earthquake Intensity	Water Quality Segments
Industrial Sites	Highways (San Mateo County)
Wastewater Districts	Scenic Roads (San Mateo County)
Airports	Vegetation (San Mateo County)
Seaports	Prime Agricultural Lands (San Mateo County)
Landfill Sites	Detailed Geology (San Mateo County)
Solid Waste Collection Areas	Precipitation (San Mateo County)

Source: ABAG (1981)

Scope and Organization of this Report

At the request of the ABAG users, an attempt has been made to document in this report all analysis tasks -- as fully as possible, and in detail.

Working papers covering phases of the project were generated following completion of some of those phases. These served as interim documentation and technical memoranda to the participating agencies, and have been incorporated into this report.

Organization of this report is as follows:

Chapter 1 discusses all aspects of the land use/ land cover data set creation.

Chapter 2 details the process through which emission factors were assigned to the land use/land cover classes.

Chapter 3 covers the compilation of the biogenic hydrocarbon emissions inventory and preparation of that data for input to the LIRAQ photochemical model.

Chapter 4 contains conclusions pertaining to the project as a whole, and addresses the issues of vertical data integration and the utility of the land use/land cover data set that was created.

Appendix A provides detailed technical information on the process that was employed in registering the modified land cover data set to the UTM map grid.

Appendix B details the output products generated during the project, including their distribution and cost.

Appendix C outlines the papers that were planned at the beginning of the project and provides citations for those that were actually generated, including symposia papers and related technical papers.

CHAPTER 1

Chapter 1

DEVELOPMENT OF A LAND USE/LAND COVER DATA SET FOR THE BAY AREA

Introduction

A land cover inventory was one of two inputs required for creation of the biogenic hydrocarbon emissions inventory of the Bay Area, since emission rates are based on vegetative land cover. This chapter addresses the methods used in generating such a vegetation inventory. The chapter is divided into ten sections, each of which treat a separate phase of the land cover inventory creation. The first five sections describe the CDF data and the modifications made by ABAG, including descriptions of: the CDF Landsat data; the procedure used by ABAG in relabeling the CDF information classes; the evolution of the classification scheme adopted for the ABAG project; where confusion between information classes occurred, and why; and the ABAG stratification procedures and why they were necessary. Section 6 details the processes used to register the modified CDF data to a UTM grid and concurrently resample from 80-meter to 100-meter grid cells. Sections 7, 8, and 9 cover transfer of the modified registered data to ABAG, integration of the data into their spatial information system (BASIS), and the urban modeling performed on BASIS to complete the stratification process. The final section outlines the verification and evaluation performed on the land cover data set in its final form, and presents conclusions regarding the accuracy of the land cover inventory . References for the chapter follow Section 10.

Section 1 -- The CDF Data

The ABAG Landsat-based vegetation inventory was created by modifying part of the pre-existing statewide classification generated during the 1979 California Department of Forestry (CDF) project. Creation of the CDF classification from August, 1976 Landsat-1 imagery of the entire State of California is described below.

Pre-classification processing of the original Landsat data was performed by Jet Propulsion Laboratory (JPL) in Pasadena, using the VICAR/IBIS system. JPL performed geometric correction, registration of the data to a Lambert Conic Conformal projection, and resampling of the data from the original 57- by 79-meter Landsat pixels to 80-meter square pixels. Geometric correction was performed using a linear transformation equation. Registration to Lambert Conic Conformal and the resampling to 80-meter pixel size were accomplished concurrently using a bilinear interpolation algorithm. These processes altered the geometry of the data, but also facilitated merging of adjacent and overlapping scenes into a mosaicked statewide data set. The original spectral values in all four bands were then stretched to cover the greylevel range of 0 through 255, during which overlapping areas were used to spectrally match and adjust adjacent scenes for the purpose of reducing the variability in spectral data between scenes. The mosaicked data set was subsequently subsectioned into six one-degree by one-degree segments (quads), and each quad was stored on a separate magnetic tape.

The nine-county project study area, which corresponded to the ABAG Region, was covered by the following 1-degree quads: Santa Rosa West, Santa Rosa East, Sacramento West, San Francisco East, San Jose West, and Monterey West. Figure 4 illustrates quad locations. The Landsat data for this study area was acquired (by the satellite) on 7 August 1976.

Before the classification process commenced, CDF divided the state into ecological units or ecozones in order minimize the effects of variation in vegetative cover and to ultimately aid in the prevention of class confusion. The ecozone boundaries were based on A.W. Kuchler's <u>Natural Vegetation of California</u> and were digitized by CDF. The following ecozones were entirely or partially located in the ABAG study area: Central Coast North, Central Coast South, North Central Coast, North Central Interior, South Coast Interior, San Francisco Bay North, San Francisco Bay South, Central Valley, and North Valley. Figure 5 illustrates their location.

The Coast ecozones can be defined as areas dominated by forests and grasslands. Coast vegetation includes redwood forests, mixed hardwood forests, blue oak/digger pine forests, chaparral, and coastal prairie scrub.

Bay ecozones are areas dominated by urban land uses, but containing extensive marsh areas and scattered agricultural land as well. Vegetation includes mixed hardwood forests, coastal prairie scrub, coastal salt marsh, and tule marsh.

The Coastal Interior ecozones are dominated by brush and grasses, with forests occurring in wetter canyons and ravines. Blue oak/digger pine forests, mixed hardwood forests, valley oak savanna, and chaparral comprise the remaining Coastal Interior vegetation types.

Valley ecozones are areas dominated by agricultural uses. Brush and grasslands are also present. Vegetation includes riparian forests, chaparral, California prairie, and tule marsh.

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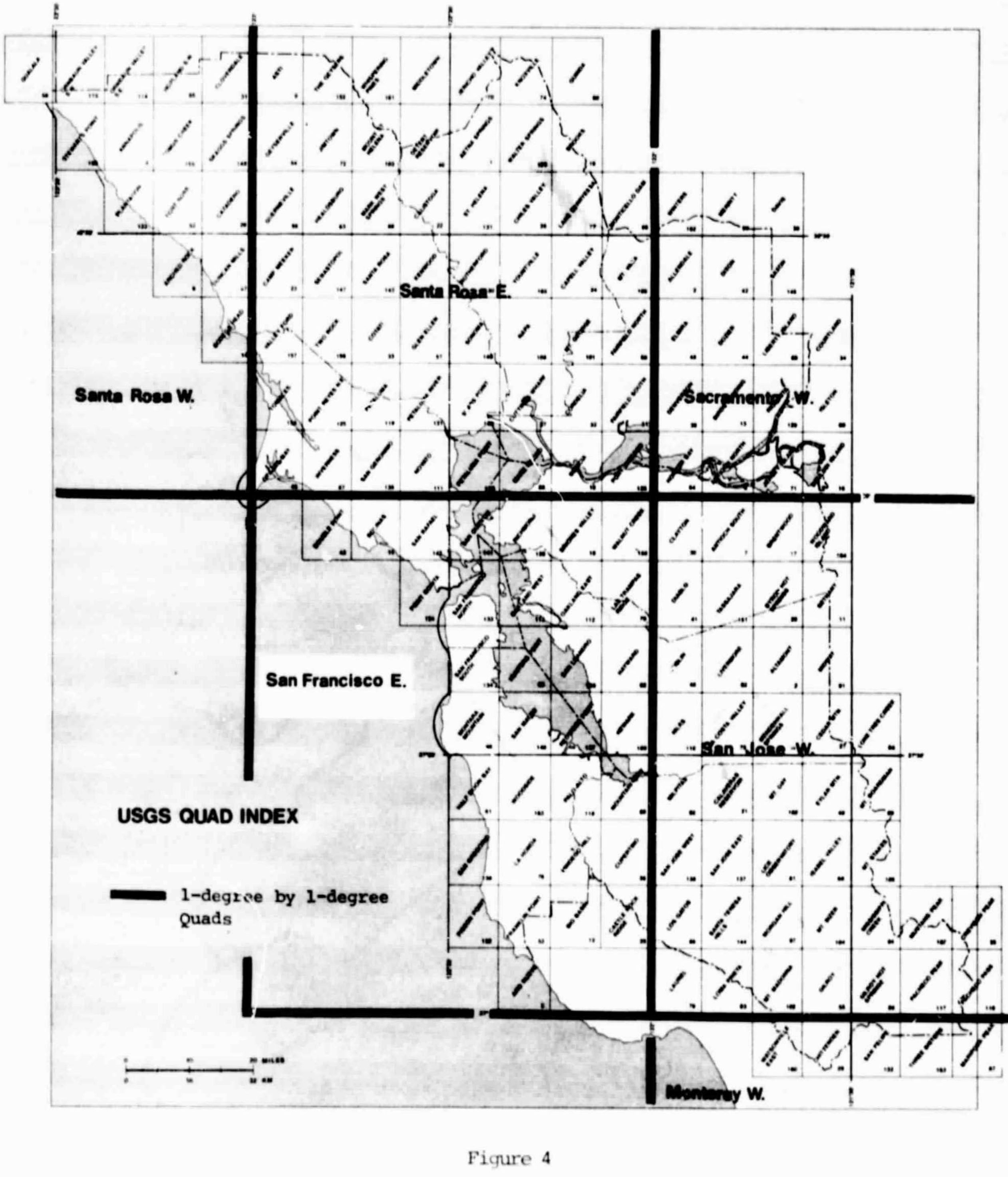

Figure 4

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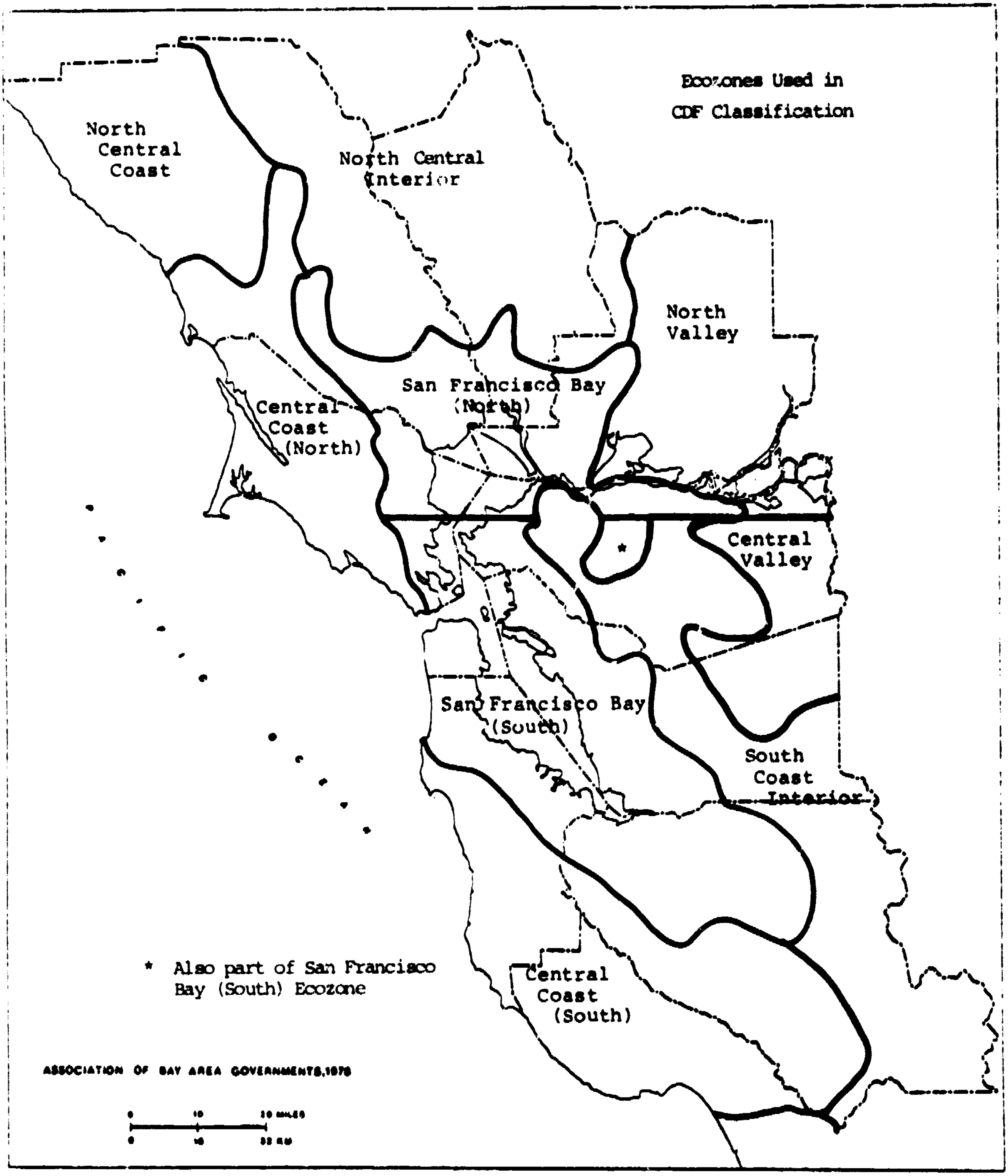

Figure 5

An unsupervised clustering process was then employed, on the EDITOR system, to develop spectral clusters for all of the land cover categories within each ecozone. Statistical summaries -- means, variances, separability matrices, and two-dimensional spectral plots (concentration ellipses) -- were generated during this process for all classes within each ecozone. The classes were evaluated, and the spectral clusters were subsequently edited. The spectral classes were then interpreted using the IDIMS system interactive display and the cluster statistical summaries. That interpretation process, which resulted in identification of the information category represented by each spectral cluster, formed the basis for further editing of the cluster statistics and ultimately led to creation of a final set of cluster statistics. A maximum likelihood classification algorithm was then utilized to classify the data within each ecozone.

The cluster statistics that were generated during the CDF clustering on EDITOR were among the materials used by ABAG in re-identifying spectral clusters and in re-labeling the information classes comprising the CDF classification. Examples of the cluster information appear on the following pages, in Figure 6 and Tables 3 through 7.

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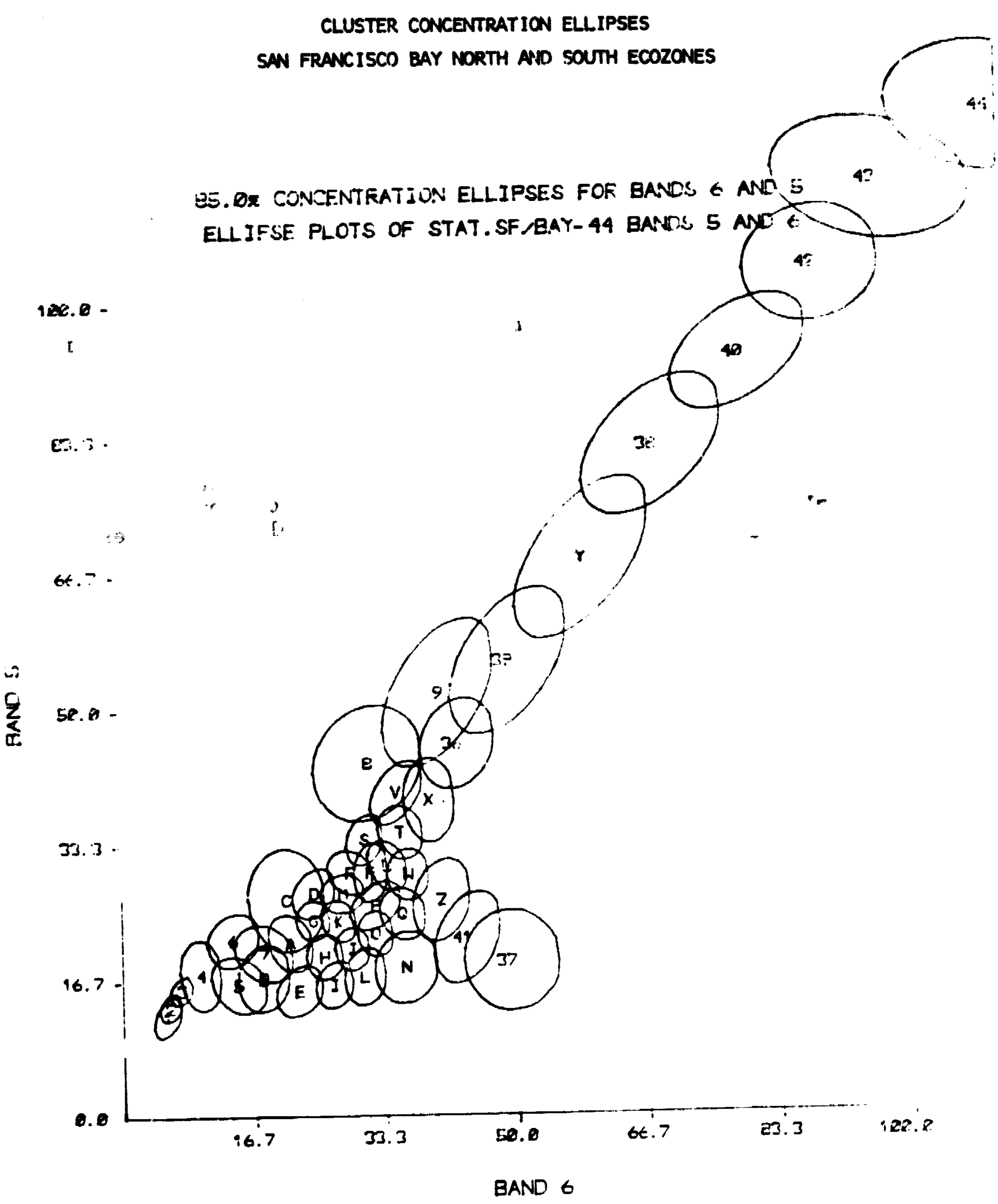

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Figure 6

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Table 3

Cluster Pixel Counts

San Francisco Bay North and South Ecozones

*NUMBER OF POINTS (DISPLAY NUMBER OF POINTS FOR CATEGORIES)

CAT*	1	2	3	4	5	6	7	8
* POINTS	65681	33592	27236	19334	7334	5980	11062	1624
CAT*	9	A	B	C	D	E	F	G
* POINTS	1285	18305	5933	2429	8301	8082	39078	17012
CAT*	H	I	J	K	L	M	N	O
* POINTS	12692	11204	15732	18694	9491	47429	5340	15026
CAT*	P	Q	R	S	T	U	V	W
* POINTS	50876	9212	57487	16618	32559	42520	7451	15000
CAT*	X	Y	Z	a	b	c	d	e
* POINTS	18602	1506	4986	11016	1494	1605	2458	1948
CAT*	f	g	h	i				
* POINTS	3720	2307	2331	2211				

TOTAL NUMBER OF POINTS= 693783

Table 4

Cluster Means

San Francisco Bay North and South Ecozones

*MEANS (DISPLAY MEANS)

MEANS:

CAT*	CHANNELS 1	2	3	4
1	23.22	12.38	5.68	2.79
2	24.43	13.51	6.07	0.76
3	26.11	15.59	7.46	3.04
4	25.84	17.46	9.88	4.99
5	24.19	16.22	14.74	8.82
6	28.59	21.70	14.07	6.81
7	27.23	20.06	17.99	11.94
8	31.76	43.39	31.49	13.17
9	33.42	52.01	40.59	17.38
A	26.35	21.30	21.36	18.89
B	23.27	17.01	17.92	16.21
C	31.08	26.62	20.91	11.04
D	31.90	27.37	24.47	19.01
E	21.98	15.40	22.49	22.94
F	33.60	29.91	29.11	24.21
G	27.52	24.08	24.31	22.65
H	24.88	19.59	25.71	25.34
I	22.76	16.18	26.97	28.29
J	25.76	20.53	29.23	29.68
K	27.69	24.00	27.53	26.51
L	23.54	17.15	30.85	33.52
M	29.96	27.33	28.12	25.93
N	24.56	18.19	36.04	39.77
O	27.26	22.36	32.26	33.44
P	29.93	25.84	32.28	31.42
Q	29.02	24.77	35.68	36.89
R	32.60	29.89	31.75	28.86
S	37.32	33.94	31.04	24.55
T	36.02	34.82	35.53	31.89
U	33.08	30.75	33.82	31.84
V	42.17	39.70	35.07	27.34
W	32.49	29.64	36.46	35.59
X	38.59	38.80	39.26	35.35
Y	70.06	68.43	59.08	46.95
Z	30.92	26.47	40.62	42.06
a	45.04	45.70	42.90	36.24
b	27.02	18.92	49.38	57.66
c	84.52	82.21	68.25	54.28
d	56.05	55.88	49.50	39.12
e	96.00	93.41	79.40	61.15
f	28.42	21.82	43.79	48.43
g	106.59	104.17	88.80	67.78
h	116.51	114.50	96.57	74.31
i	124.09	123.08	111.08	81.13

Table 5

Cluster Variances

San Francisco Bay North and South Ecozones

VARIANCES:

	CHANNELS			
CAT #	1	2	3	4
1	2.13	1.71	0.86	2.42
2	0.83	0.78	0.53	0.66
3	1.15	0.83	0.62	1.66
4	4.84	4.87	1.88	2.30
5	2.69	3.15	3.36	3.99
6	3.22	2.90	2.99	2.44
7	2.38	3.29	3.82	5.11
8	10.49	13.64	12.50	11.51
9	11.95	22.08	13.27	12.84
A	3.27	3.25	2.35	5.54
B	2.82	4.45	3.02	3.65
C	9.23	10.59	6.51	6.98
D	2.89	2.52	2.06	2.58
E	1.85	2.60	2.48	3.18
F	2.41	1.94	2.28	5.13
G	1.29	1.55	1.34	2.00
H	1.25	1.98	1.52	1.81
I	1.34	2.17	1.67	2.36
J	1.35	1.85	1.31	1.81
K	1.13	1.76	1.44	1.43
L	1.56	3.24	1.93	3.04
M	1.30	1.50	2.17	3.60
N	2.93	5.13	4.32	5.93
O	1.56	2.06	1.44	2.07
P	1.98	2.43	2.80	3.16
Q	1.98	2.72	2.34	2.62
R	3.49	3.46	1.29	1.72
S	2.45	2.63	1.56	2.24
T	3.44	2.82	2.26	6.95
U	2.07	2.47	1.80	1.50
V	4.65	4.12	2.99	3.96
W	1.94	2.63	1.98	2.17
X	7.78	7.09	2.88	7.73
Y	35.02	26.07	19.35	28.16
Z	4.03	6.74	3.63	4.84
a	15.11	8.27	6.03	12.70
b	6.90	10.01	9.74	19.76
c	27.40	19.66	20.95	19.42
d	26.98	21.46	14.61	21.31
e	18.78	13.18	19.52	11.30
f	4.90	8.39	4.77	6.80
g	15.55	13.65	19.45	10.04
h	14.01	15.20	41.37	8.05
i	11.97	17.12	41.19	15.39

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Table 6

Separability Matrices

San Francisco Bay North and South Ecozones

*SEPARABILITY MATRIX (DISPLAY SEPARABILITY MATRIX)
ENTER TYPE OF DISTANCE TO USE: SWAIN-FU DISTANCE

DO YOU WANT TO MARK VALUES BELOW A THRESHOLD (Y OR N)? Y

THRESHOLD VALUE=.5

SEPARABILITY MATRIX (SWAIN-FU DISTANCE):

CAT*	1	2	3	4	5	6	7	8
1	0.00	0.51	0.71	0.95	1.68	1.74	2.23	3.26
2		0.00	0.77	1.17	1.97	2.02	2.64	3.42
3			0.00	0.60	1.46	1.44	2.11	3.11
4				0.00	0.78	0.78	1.36	2.56
5					0.00	0.78	0.73	2.40
6						0.00	0.81	2.01
7							0.00	2.02
8								0.00

CAT*	9	A	B	C	D	E	F	G
1	3.51	3.15	2.32	2.43	3.74	3.37	5.07	4.34
2	3.58	3.73	2.81	2.73	4.56	4.04	6.16	5.41
3	3.42	3.02	2.29	2.28	3.85	3.47	5.28	4.47
4	2.95	2.16	1.55	1.61	2.83	2.53	3.98	3.28
5	2.72	1.49	0.85	1.28	2.22	1.76	3.30	2.37
6	2.46	1.42	1.22	0.91	1.99	2.20	2.93	2.40
7	2.45	0.79	0.69	0.75	1.40	1.61	2.33	1.54
8	0.60	1.98	2.18	1.24	1.47	2.45	1.61	1.97
9	0.00	2.58	2.69	1.77	2.05	2.98	2.14	2.62
A		0.00	0.68	0.83	0.94	0.78	1.88	0.71
B			0.00	1.07	1.43	0.80	2.31	1.36
C				0.00	0.85	1.66	1.51	1.28
D					0.00	1.69	0.88	0.80
E						0.00	2.28	1.29
F							0.00	1.43
G								0.00

CAT*	H	I	J	K	L	M	N	O
1	4.58	4.77	5.63	5.35	5.27	4.50	5.05	6.28
2	5.62	5.71	6.89	6.74	6.21	5.32	5.78	7.68
3	4.72	4.91	5.85	5.63	5.40	4.52	5.17	6.56
4	3.48	3.64	4.37	4.17	4.16	3.47	4.14	5.00
5	2.49	2.69	3.29	3.10	3.25	2.81	3.41	3.92
6	2.77	3.05	3.50	3.20	3.51	2.59	3.58	4.03
7	1.96	2.37	2.66	2.27	2.85	1.95	3.03	3.19
8	2.24	2.47	2.32	2.08	2.49	1.89	2.51	2.38
9	2.81	3.01	2.86	2.67	3.00	2.47	2.99	2.87
A	0.83	1.18	1.49	1.29	1.68	1.40	2.05	2.09
B	1.36	1.58	2.04	1.89	2.14	1.95	2.42	2.62
C	1.76	2.09	2.19	1.83	2.41	1.47	2.58	2.54
D	1.47	1.95	1.80	1.24	2.16	0.85	2.32	2.10
E	0.70	0.72	1.25	1.43	1.33	1.88	1.76	1.82
F	1.89	2.22	1.66	1.25	1.96	0.69	1.79	1.44
G	0.85	1.47	1.32	0.73	1.76	0.86	2.02	1.84
H	0.00	0.66	0.78	0.80	1.17	1.38	1.64	1.48
I		0.00	0.73	1.27	0.72	1.86	1.31	1.32
J			0.00	0.78	0.67	1.31	1.16	0.74
K				0.00	1.35	0.66	1.64	1.22
L					0.00	1.74	0.69	0.74
M						0.00	1.75	1.32
N							0.00	0.81
O								0.00

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CAT#	P	Q	R	S	T	U	V	W
1	4.79	6.41	6.56	5.17	6.12	6.74	4.79	6.46
2	5.75	7.72	8.46	6.34	7.39	8.55	5.62	7.89
3	5.14	6.70	7.25	5.59	6.51	7.38	5.10	6.91
4	4.05	5.26	5.38	4.25	5.11	5.60	4.08	5.43
5	3.09	4.28	4.22	3.55	4.37	4.51	3.59	4.44
6	3.41	4.32	4.20	3.33	4.07	4.47	3.37	4.46
7	2.54	3.52	3.17	2.68	3.40	3.48	2.90	3.57
8	2.21	2.44	1.86	1.57	1.80	2.07	1.68	2.30
9	2.65	2.81	2.24	1.95	2.06	2.39	1.82	2.56
A	1.73	2.57	2.42	2.24	2.98	2.78	2.60	2.83
B	2.07	3.02	2.81	2.57	3.27	3.14	2.83	3.19
C	2.25	2.82	2.36	1.86	2.47	2.66	2.15	2.86
D	1.77	2.40	1.72	1.34	2.09	2.12	1.83	2.41
E	1.61	2.29	2.30	2.56	3.04	2.69	2.88	2.62
F	1.01	1.44	0.61	0.69	1.31	1.05	1.41	1.40
G	1.39	2.30	1.87	1.93	2.61	2.30	2.40	2.47
H	1.21	2.06	1.87	2.29	2.80	2.36	2.71	2.38
I	1.48	1.88	1.91	2.58	2.91	2.47	2.95	2.36
J	0.90	1.41	1.32	2.16	2.40	1.87	2.59	1.84
K	0.82	1.75	1.28	1.80	2.29	1.79	2.31	1.95
L	1.31	1.21	1.53	2.43	2.38	1.98	2.78	1.82
M	0.82	1.48	0.82	1.33	1.70	1.21	1.90	1.44
N	1.30	0.75	1.64	2.30	1.85	1.68	2.50	1.38
O	0.66	0.73	1.10	2.02	1.88	1.39	2.38	1.27
P	0.00	0.80	0.67	1.66	1.38	0.80	1.99	0.71
Q		0.00	1.34	2.00	1.39	1.13	2.17	0.74
R			0.00	0.80	1.01	0.62	1.19	1.20
S				0.00	0.84	1.24	0.77	1.72
T					0.00	0.68	0.80	0.80
U						0.00	1.44	0.67
V							0.00	1.75
W								0.00

CAT#	X	Y	Z	a	b	c	d	e
1	6.03	5.06	5.76	5.12	4.94	6.30	4.75	8.15
2	7.19	5.53	6.67	5.84	5.35	6.95	5.28	9.13
3	6.45	5.28	6.02	5.38	4.94	6.68	4.95	8.77
4	5.21	4.69	4.93	4.51	4.20	5.93	4.30	7.72
5	4.53	4.48	4.08	4.11	3.68	5.76	4.07	7.56
6	4.35	4.32	4.22	3.89	3.71	5.58	3.86	7.33
7	3.69	4.09	3.52	3.48	3.34	5.36	3.59	7.07
8	2.02	2.62	2.45	2.01	3.13	3.61	2.02	4.83
9	2.01	2.08	2.67	1.84	3.59	2.96	1.54	4.06
A	3.26	3.96	2.76	3.19	2.72	5.24	3.38	6.90
B	3.46	4.02	3.06	3.34	3.01	5.22	3.48	6.77
C	2.88	3.50	2.97	2.78	2.90	4.63	2.97	6.13
D	2.56	3.50	2.66	2.57	2.72	4.74	2.87	6.34
E	3.16	3.97	2.39	3.20	2.56	5.20	3.42	6.77
F	1.92	3.35	1.80	2.18	2.17	4.66	2.63	6.33
G	2.94	3.89	2.58	2.96	2.72	5.21	3.24	6.91
H	2.98	3.95	2.29	3.07	2.51	5.28	3.34	6.98
I	2.95	3.97	2.04	3.12	2.28	5.28	3.38	6.94
J	2.55	3.79	1.78	2.81	2.17	5.12	3.15	6.81
K	2.60	3.79	2.13	2.76	2.46	5.14	3.11	6.85
L	2.39	3.74	1.45	2.75	1.83	5.03	3.11	6.63
M	2.14	3.56	1.82	2.41	2.31	4.88	2.85	6.52
N	1.79	3.28	0.81	2.26	1.18	4.45	2.65	5.82
O	2.05	3.57	1.27	2.46	1.86	4.90	2.88	6.54
P	1.62	3.22	1.24	2.06	1.97	4.45	2.54	5.91
Q	1.51	3.27	0.70	2.05	1.54	4.56	2.55	6.11
R	1.61	3.19	1.81	1.92	2.31	4.48	2.43	6.08
S	1.44	2.91	2.18	1.66	2.47	4.13	2.16	5.66
T	0.70	2.79	1.21	1.27	1.89	4.05	1.96	5.55
U	1.24	3.13	1.42	1.74	2.14	4.44	2.34	6.03
V	0.75	2.22	2.07	0.89	2.43	3.31	1.45	4.59
W	1.04	3.00	0.86	1.64	1.79	4.28	2.24	5.79
X	0.00	2.24	1.07	0.64	1.76	3.38	1.39	4.66
Y		0.00	2.66	1.57	2.76	0.74	0.79	1.48
Z			0.00	1.55	1.10	3.74	2.00	4.97
a				0.00	2.01	2.56	0.75	3.62
b					0.00	3.72	2.21	4.84
c						0.00	1.63	0.71
d							0.00	2.50
e								0.00

Table 6 (continued)

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CAT#	f	g	h	i
1	5.91	9.63	10.38	11.61
2	6.72	10.79	11.62	12.73
3	6.14	10.44	11.27	12.44
4	5.08	9.18	9.96	11.19
5	4.27	8.93	9.75	11.20
6	4.46	8.75	9.57	10.73
7	3.86	8.42	9.24	10.67
8	2.83	5.93	6.90	8.20
9	3.12	5.04	5.99	7.37
A	3.00	8.37	9.26	11.13
B	3.28	8.11	8.94	10.57
C	3.29	7.32	8.11	9.29
D	3.12	7.74	8.60	10.24
E	2.59	8.13	9.06	10.96
F	2.28	7.83	8.79	10.76
G	2.99	8.51	9.49	11.66
H	2.61	8.49	9.51	11.74
I	2.24	8.38	9.47	11.70
J	2.15	8.32	9.44	11.81
K	2.60	8.46	9.51	11.86
L	1.64	8.04	9.22	11.50
M	2.37	8.09	9.18	11.27
N	0.84	7.06	8.23	10.16
O	1.72	8.06	9.24	11.68
P	1.92	7.26	8.27	10.21
Q	1.25	7.57	8.79	11.13
R	2.44	7.59	8.63	10.84
S	2.79	7.03	7.92	9.64
T	1.79	7.03	8.06	10.19
U	2.13	7.58	8.67	10.99
V	2.66	5.77	6.58	8.02
W	1.61	7.25	8.38	10.63
X	1.53	5.97	6.95	8.82
Y	2.77	2.21	2.80	3.68
Z	0.68	6.13	7.20	8.99
a	1.91	4.69	5.51	6.94
b	0.57	5.87	7.15	8.67
c	3.78	1.42	2.02	2.80
d	2.20	3.35	4.02	5.05
e	4.94	0.71	1.37	2.08
f	0.00	6.01	7.16	8.79
g		0.00	0.68	1.44
h			0.00	0.72
i				0.00

Table 6 (continued)

Table 7

Initial ABAG Information Class Assignments

San Francisco Bay North and South Ecozones

Cat#	Assignment
1	Water
2	Water
3	Water
4	Shallow Water
5	Shallow Water
6	Shallow Water
7	Shallow Water
8	Salt Flat
9	Salt Flat
A	Grass
B	Open Shrub
C	Barren
D	Mixed Urban
E	Hardwood/Brush
F	Low Vegetation Residential
G	Open Shrub
H	Brush
I	High Vegetation Residential
J	High Vegetation Residential
K	Low Vegetation Residential
L	High Vegetation Residential
M	Low Vegetation Residential
N	Urban Open Space
O	Moderate Vegetation Residential
P	Low Vegetation Residential
Q	Low Vegetation Residential
R	Low Vegetation Residential
S	Mixed Urban
T	Low Vegetation Residential
U	Low Vegetation Residential
V	Commercial,Services, and Industrial
W	Low Vegetation Residential
X	Barren
Y	Barren
Z	Urban Open Space
a	Barren
b	Urban Open Space
c	Barren
d	Barren
e	Barren
f	Urban Open Space
g	Agricultural Land
h	Wetland
i	Cloud

Section 2 -- The ABAG Class Relabeling Procedure

The majority of the ABAG land cover data set creation process took place at NASA/Ames. Each CDF spectral cluster was evaluated using a variety of sources and was then assigned to the appropriate information class. Two display media were available for locating the spatial positions of each of the spectral clusters: line printer maps and a color display device. The extremely large number of spectral clusters (over 400 spectral clusters existed for the Bay Area -- an average of 45 clusters for each of nine ecozones) resulting from the unsupervised clustering approach used for the CDF project, made the use of line printer maps impractical. The grouping of the CDF spectral clusters into the ABAG classification scheme was more effectively accomplished using a color cathode ray tube (CRT) device. The color CRT display on the IDIMS system was utilized with the following general working procedure:

1. The CDF clusters for an ecozone within a quad were displayed on the screen. Each cluster had been assigned a grey tone. A generally recognizable landscape pattern was usually easily discernable on the screen.

2. One cluster was then displayed in color. Areas in which that cluster was dominant were enlarged for more detailed evaluation. Orthophoto quads were used to locate the general area of occurrence; U-2 photography, at 1:32,500 and 1:130,000 scales, was used to determine its land cover type. The concentration ellipses were also used to empirically study the spectral characteristics of that cluster.

3. Once a decision was made regarding the land cover class to which the cluster would be assigned, a comparison to the CDF assignment list was made. If disagreement between ABAG's identification and that of CDF occurred, further checking was done on the cluster.

4. Each cluster, within each ecozone and within each quad, was handled in the above manner. Cross-checking within the same ecozone in different quads was also performed.

This relabeling procedure took place over approximately two months and involved about 16 working days (10 days longer than anticipated) on IDIMS. No major problems were encountered.

Section 3 -- Evolution of ABAG Classification Scheme

The ABAG classification scheme evolved from a series of workshops held at NASA/Ames in February 1980. The first step involved preparing a list of the most desirable information classes that could be obtained. This list was based primarily on Anderson's USGS Land Use and Land Cover Classification System, Levels I and II. Refinement of this initial classification scheme took place at the workshops. During the first session held on 13 February 1980, the ABAG staff looked at the CDF clusters using IDIMS. The second workshop, held on 3-4 March 1980 with Robin Welch of Airview Specialists, Inc. (contractor to NASA) involved training ABAG participants in basic photointerpretation techniques. These sessions helped in establishing more reasonable expectations for the vegetation classification effort using the CDF clusters. They also helped in determining the information sources which would be necessary for grouping the clusters into information categories.

Some disparity, in the assignment of spectral clusters to information classes, between the ABAG and CDF projects inevitably occurred due to the divergent focus of the two projects. The CDF effort was a statewide classification of forestry cover types, while the ABAG project focused on a wider range of information classes and dealt with a more localized area. In addition, the ABAG area encompassed only portions of nine ecozones, while the CDF information classes related to each ecozone in its entirety. The primary differences between the CDF and ABAG information classes were as follows:

1. No obvious Conifer Woodland or Hardwood Woodland clusters were detected by ABAG. Clusters which were labeled Conifer or Hardwood Woodland in the CDF classification scheme were primarily absorbed into ABAG's Hardwood/Brush or Conifer/Brush classes (which did not exist in the CDF scheme) or into the Open Shrub class.

2. The Bare Rock, Barren, and Alkalai Flat classes of the CDF scheme were redistributed into the Mixed Barren class of the ABAG scheme.

3. The CDF Water class was divided into 3 ABAG classes: Shallow or Turbid Water, Deep Water, and Salt Evaporation Ponds.

4. The CDF Grassland class was divided into a Grassland and an Urban Open Space class in the ABAG scheme.

5. Differences between the CDF classification scheme and that of ABAG were most noticeable in the urban classes. The CDF scheme contained only one urban class (which was the product of CDF stratification)

while the ABAG scheme contained five: High Vegetation Residential; Moderate Vegetation Residential; Low Vegetation Residential; Mixed Urban; and Commercial, Services, and Industrial.

6. A Non-Forested Wetland class was created, in the ABAG scheme, by post-relabeling stratification.

Section 4 -- Class Confusion

Spectral confusion, which can be defined as the representation of two or more information classes by a single spectral cluster, is often inherent within and between information classes that are composed of elements defined by spectral characteristics. Confusion can be caused by two primary factors. Firstly, pixels composed of landscape elements below the sampling size of the satellite detector (57 x 79 meters) represent the combined reflectance of those elements. Urban areas tend to contain pixels comprised of various combinations of vegetative cover, structures, and pavement; few pixels in an urban area contain just one of these elements but instead represent a combination of the reflectance from all three of these types of land cover. Secondly, ground features having very similar spectral signatures but belonging to different information classes sometimes appear in the same spectral cluster. For example, wheat that is ready for harvest may have the same spectral signature as grass in the hills, or heavily wooded urban areas may have the same spectral signature as forested areas.

After ABAG had relabeled CDF clusters and assigned them to information classes within the ABAG classification scheme, two major sources of class confusion remained, requiring stratification. The first source, clouds, presented a problem because clouds, "whitish" roofing materials, and salt flats all have high reflectance values in all four Landsat spectral bands. Six ABAG information classes were confused with clouds: (1) Mixed Barren Lands, (2) Commercial, Services, and Industrial, (3) Mixed Urban, (4) Salt Evaporation Ponds, (5) Grasslands and (6) Low Vegetation Residential areas. Like Clouds, all six of these information classes contained land cover with relatively high reflectivity, due in all cases to the presence of barren land, buildings, dry vegetation, or concrete. In addition, the leading edge of the cloud bank was somewhat transparent, thereby modifying the reflectance values of the underlying land and water. The longer wavelength infrared (IR) radiation penetrated the clouds better than did reflectance from green vegetation, creating a zone of confusion along the leading edge of the clouds. The same six information classes listed above were also misclassified within this zone of confusion.

The second major class confusion problem occurred in wetland areas. The imagery was collected in a drought year, when wetlands had unusually high reflectance values. This caused confusion between wetlands and both dry vegetation and barren type classes.

The confusion problems involving clouds and wetland areas were given special attention because (1) in terms of land use (although not necessarily of emissivity) the misclassification was extensive, and (2) the problems could be resolved in a straightforward manner by post-classification stratification.

Confusion within vegetation classes also was found, and was apparently caused by natural variation in species type, species density and moisture availability. The fact that some information classes (unlike spectral classes) were defined by land use rather than land cover, such as vegetated-residential classes (land use) vs. natural vegetation classes (land cover), caused additional confusion. Both of these sources of confusion were ameliorated by judicious stratification.

Another type of class confusion in the CDF classification could not be addressed by this project: the discontinuity observed along the edges of adjacent CDF ecozones. While use of the ecozone approach provided the means for an overall improvement in classification accuracy, the edges of ecozones are not discrete in the natural world. A continuous transition frequently occurs between two adjacent ecozones in the natural world, and the delineation of a single line (like a digitized ecozone boundary) constitutes a break that is often visible in the classified data. The boundary of the San Francisco Bay North ecozone, in the CDF classification, was particularly apparent -- partially because the boundaries of that ecozone were largely based on land use rather than land cover or separation by ecological unit.

Section 5 -- The ABAG Stratification Procedure

Stratification is the process of partitioning an area into relatively homogeneous sub-areas. Pre-classification stratification, as in the CDF ecozones, seeks to define spatial areas inside which informational variation within spectral clusters is minimized. For example, a grassland along the coast may not possess the same spectral signature as one in the Central Valley on a given date. Likewise, wheat in Southern California will ripen before wheat in Northern California, therefore possessing a different spectral signature on a given date.

The aim of post-classification stratification is to optimally increase the classification accuracy by modifying the information class label for given spectral clusters. The broad confusion problems discussed above -- cloud-to-barren, barren-to-wetland, and vegetation-to-wetland -- were extensive enough to justify this stratification. The cloud-to-barren class confusion was resolved by empirically defining a mask derived from viewing the imagery. The stratification was then performed, using the mask which enclosed all pixels in the cloud bank, and relabeling all clusters falling in the cloud bank within the mask to cloud, and all outside the mask to their correct land cover class (usually consisting of barren, wetland, or salt evaporation pond). Next, wetlands and salt evaporation ponds were identified by analyzing 7-1/2' quads and color infrared (CIR) U-2 photography. A series of masks was then created defining the wetland/salt evaporation pond region of the Bay. For small evaporation ponds, vegetation classes were not a problem, and the major source of confusion, barren land, was relabeled Salt Evaporation Pond. For areas of the Bay with wetlands, both barren land and vegetated land were relabeled Wetland within the mask, the result of which left all spectral clusters not included within either mask as their original barren or vegetation class.

These masks were created using the ZIP function on IDIMS. Areas of 512 x 512 or fewer pixels were displayed on the color CRT. The ZIP function allows masks to be created by interactively defining a polygon around each area of confusion. Within each polygon, the spectral class identifiers can be selectively changed. Using this capability, the areas of cloud boundary were changed according to clouds visible on false-color Landsat images of the area, and wetlands were corrected according to information on 7 1/2' quads and CIR U-2 photography.

The Landsat data set was registered to the UTM map grid and integrated into BASIS prior to further stratification. This registration and integration made it possible to perform further stratification to delineate urban classes more suited to the project objectives. This additional stratification will be addressed later, following the sections on registration and integration.

The land cover data set underwent one additional process prior to registration: the land cover classes were digitally grouped into information categories in order to reduce the number of classes contained within the image. This process involved a simple mapping of class numbers in the digital data set: all class numbers identified as belonging to the same information category (of the final 22 classes) were mapped to a single class number. The grouping was performed on the IBM 360 at Ames, where the grouped data were then translated into a data format compatible with the system on which registration was to be performed.

Section 6 -- Registration of the Modified CDF Data to UTM

Registration to a map base requires the development of a mathematical model which relates every pixel position in the image to a coincident location in the map base. The mathematical mapping may be developed from: 1) a model of the differences between the image and the map, 2) a set of least-squares polynomial regression equations, or 3) a combination of the first two methods. Since the geometry of the CDF data had been modified by JPL's pre-classification processing (addressed in Section 1 of this chapter), a valid mathematical model could not be developed. Therefore, least-squares polynomial regression equations were developed for registering each of the six CDF quads to the UTM map base.

The use of least-squares requires that a set of coincident control points be identified both in the image and on the map base. Two image analysis systems, ILEX and EDITOR, were used in selecting, entering, and processing control points for the ABAG registration effort. Image coordinates were determined by locating sharp high-contrast features on grey scale maps of Band 5 (generated on ILEX) and on 7-1/2' topographic and orthophoto quad sheet maps. Coincident points, when located, were marked on the grey scale maps and on the orthophoto quads. An EDITOR file was then created which contained line/sample coordinates from the image and latitude/longitude coordinates from the map base, for each control point. This file was created by digitizing each control point from the orthophoto quad, and then entering line/sample coordinates for that point on the terminal.

Figure 7 illustrates the set of control points used in the ABAG registration.

After creating the control point file, first-degree equations were developed. Root mean square (RMS) errors generated during the development of these equations were used to evaluate the fit of the control points to the equations. Errors of less than one pixel, which is the level of accuracy desirable for most applications, were sought. In evaluating the ABAG control points, errors higher than one pixel did emerge for some points. Those points generating errors were re-assessed to determine probable cause of the errors: whether the coincident point coordinates had been incorrectly identified or recorded, whether the points had been digitized inaccurately, or whether the source was a local distortion inherent in the CDF Landsat data set.

Evaluation and editing of the first-degree results was followed by calculation of second-degree and third-degree equations, which usually improve the "fit" of the equation. Although the best results for the six 1-degree quads were generated by third-degree equations, the registration program allowed use of only a second-degree equation. Registration of the ABAG data was therefore performed using the second-degree equations developed, and the total overall RMS error for each quad was less than one pixel with the exception of Santa Rosa East.

Appendix A is a more detailed description of the ABAG registration process; it discusses the Santa Rosa East quad RMS errors, and includes the EDITOR listings generated for each quad during regression equation development.

Once regression equations had been computed, the registration procedure was straightforward. A file containing the coordinates of the input data, the calculated coordinates of the output data in UTM space, and the coefficients of the second-degree equation for each quad, was created. The land cover data was subsectioned so that it contained only the area defined by that file. A program was then run to create an Index File that contained X and Y shift values for each pixel in the subsectioned land cover data file. The land cover data and the Index File were input to a program that placed the land cover pixels in appropriate positions in the UTM coodinate system. The registered land cover data was subsequently converted into a format compatible with IDIMS. At this point, the land cover data had been registered to the UTM map base and was ready for transfer to ABAG to be integrated into BASIS.

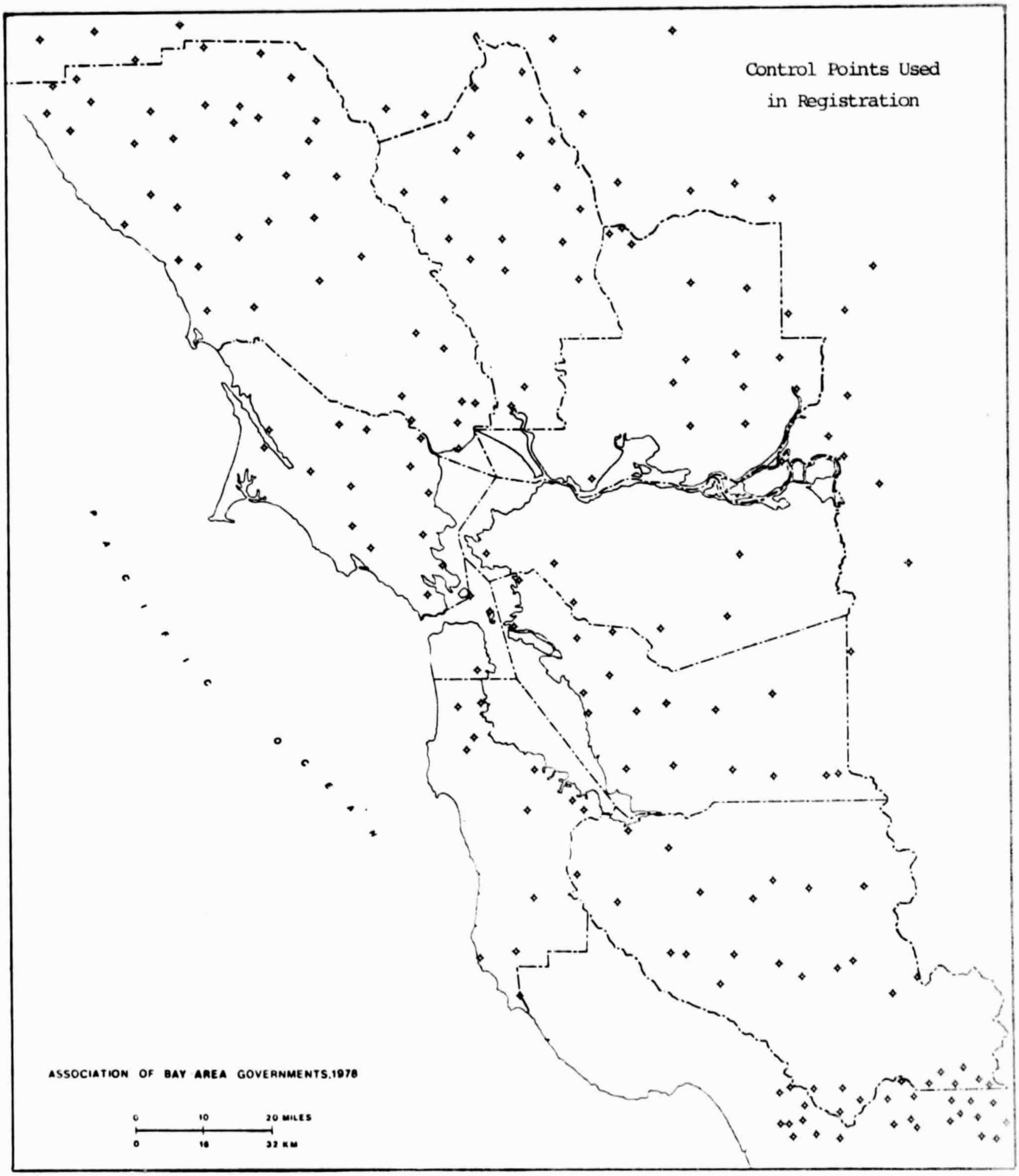
Control Points Used
in Registration
ASSOCIATION OF BAY AREA GOVERNMENTS,1978
0 10 20 MILES
0 16 32 KM

Figure 7

Section 7 -- Transfer of Land Cover Data to ABAG

The IDIMS system was used to generate tapes of the UTM-registered land cover data, which were transmitted to ABAG on 12 September 1980. ABAG encountered parity errors on these TRANSFER tapes for all six quads. The SEL 32/77 at Ames was then used to generate new copies of each tape. This second group of tapes was transmitted to ABAG and entered into BASIS without further difficulty. The source of the parity errors on the HP 3000/IDIMS system was not identified with certainty, but hardware malfunction was suspected.

Section 8 -- Integration of the Land Cover Data into BASIS

The land cover data set was transferred to ABAG in the form of six separate files, each of which corresponded to one of the six 1-degree quads. It had previously been determined that a combined data set -- that is, with the areas for the six quads mosaicked into a single data layer -- would be more useful to ABAG. It was therefore necessary to mosaic the separate data sets together. The mosaicking was performed as the quads were entered into BASIS.

Necessary starting point offsets were calculated by determining the line/sample coordinates of specific locations on 1:70,000 grey maps of the Landsat classified data and computing the difference between these coordinates and the row/column numbers of the same points within the BASIS Coastline File. Each quad was then entered into BASIS in its correct location respective to that of adjacent quads. Small gaps, which were usually one to two BASIS cells (hectares) wide, were present between several of the 1-degree quads. The existence of these gaps was partially attributable to the use of second-order equations during registration, which tends to create curved quad boundaries that inhibit one-to-one matching of quad edges during later mosaicking. In most cases these gaps were easily filled in by editing, because the land cover classes were similar on either side of the gaps.

The Landsat data set was then overlayed with the BASIS Coastline File to verify the registration. All water features registered very well, demonstrating that the registration was adequate.

Section 9 -- Urban Modeling Performed at ABAG

After the Landsat data set was registered within BASIS, a determination was made that some edge problems resulting from the CDF ecozone boundaries were too severe to be acceptable for this project. The CDF ecozone boundaries which outlined urbanized areas were very generalized, and only roughly approximated the true edge of such areas. Since the ABAG/NASA project focused only upon the Bay Area, more detail was required in delineation of urbanized areas.

Two tasks aimed toward achievement of this greater detail were undertaken at ABAG with NASA/TGS assistance during October, 1980: a new urban boundary was digitized using 1:250,000 and 1:100,000 USGS Land Use / Land Cover (LUDA) Maps for the Bay Area, and a model was developed which would effect required class-labeling changes. The newly-digitized urban boundary was treated as a mask within this model, similar to the polygons or masks defined within the IDIMS program ZIP for the earlier stratifications.

Two basic types of changes were required. First, urban classes that were confused with vegetation classes within the urban mask required changing to the appropriate urban class. Second, non-urban classes (largely within the San Francisco Bay North and South ecozones) that were confused with urban classes outside the urban mask needed to be changed to the appropriate vegetation classes.

These changes were achieved through modeling within BASIS using the land cover data file, the newly-digitized ecozone boundaries, and the Urban Mask data file. Data for the verification and evaluation phase of the project (see Section 10), which was concurrently underway, provided a factual basis for the modeling changes. Table 8 summarizes these changes. Non-urbanized areas within the urban mask in the San Francisco Bay South ecozone, which were confused with the urban classes, had already been stratified at NASA/Ames and hence were not considered in the BASIS modeling effort. Within the model, those areas outside of the urban mask which were confused with the urban classes were assigned to the associated vegetation class. For example, Grass was frequently confused with Low Vegetation Residential that was primarily residential areas of grass cover only. Hence, those areas outside of the urban mask with Low Vegetation Residential land use were designated Grasslands. Conversely those areas inside the urban mask (except in the San Francisco Bay South Ecozone) which were classified as grasslands were then designated Low Vegetation Residential.

This urban modeling, although not considered in the original project plan, was completed in November 1980 and added greatly to the quality of the information contained in the land cover data set. The urban modeling increased the subjective confidence level of the final ABAG classification scheme. A listing of this scheme follows as Table 9.

Table 8

CHANGES MADE THROUGH URBAN MODELING

Ecozone	Urban Mask	Original Landsat Classification	Final Landsat Classification
All	Out	Commercial, Services, & Industrial	Barren
All	Out	Mixed Urban	Grass
All	Out	Low Vegetation Residential	Grass
All	Out	Moderate Vegetation Residential	Brush
All	Out	High Vegetation Residential	Conifer/Brush
All but SF Bay S	In	Hardwood	High Vegetation Residential
" " " " "	In	Hardwood/Brush	High Vegetation Residential
" " " " "	In	Conifer	High Vegetation Residential
" " " " "	In	Conifer/Brush	High Vegetation Residential
" " " " "	In	Hardwood Conifer	High Vegetation Residential
" " " " "	In	Conifer Hardwood	High Vegetation Residential
" " " " "	In	Grass	Low Vegetation Residential
" " " " "	In	Open Shrub	Low Vegetation Residential
" " " " "	In	Brush	Moderate Vegetation Residential
" " " " "	In	Mixed Agricultural	Grass
" " " " "	In	Barren	Mixed Urban

"Original Landsat Classification" refers to initial ABAG information class labels

"Final Landsat Classification" refers to final ABAG information class labels

Table 9

ABAG Final Classification Scheme

1. Hardwood Forest -- 30-100% tree canopy closure of primarily hardwood species; less than 15% conifer species intermixed.

2. Hardwood Brush -- <30% tree canopy closure of primarily hardwood species; 70-90% brush cover understory.

3. Coniferous Forest -- 30-100% tree canopy closure of primarily coniferous species; less than 15% of hardwood species intermixed.

4. Conifer Brush -- 5-30% canopy closure of primarily coniferous species; 70-95% brush cover understory.

5. Hardwood Conifer Forest -- 30-100% tree canopy closure with 50-85% of the species present hardwoods and 15-49% conifers.

6. Conifer Hardwood Forest -- 30-100% tree canopy closure with 50-85% of the species present conifers and 15-49% hardwoods.

7. Grassland -- Vegetative cover comprised of grasses; less than 5% tree or shrub species cover.

8. Open Shrub -- Light brush of 5-20% brush cover with remaining cover composed of grasses; less than 5% tree intermixed.

9. Brush -- 20-100% shrub and brush cover; less than 5% tree intermixed.

10. Mixed Agricultural Lands -- Vegetative cover including cropland, pasture, vineyards, and orchards.

11. Commercial, Services, and Industrial -- Urban land uses, including urban central business districts, shopping centers, commercial strip development, institutional land uses, light and heavy industrial areas, and industrial parks.

12. Mixed Urban -- More than 1/3 intermixture of an urban use with another urban use; includes transportation and associated land uses.

13. Low Vegetation Residential -- Housing and apartment complexes having very little vegetation on surrounding property; approximately 0-10% tree canopy cover.

14. Moderate Vegetation Residential -- Housing and apartment complexes having a moderate amount of vegetation on surrounding property; approximately 10-25% tree canopy cover.

15. <u>High Vegetation Residential</u> -- Housing and apartment complexes having heavy vegetation on surrounding property; 25-100% tree canopy cover.

16. <u>Urban Open Space</u> -- Parks, cemetaries and golf courses.

17. <u>Non-Forested Wetlands</u> -- Tidal marshes with primarily grass vegetation.

18. <u>Water</u> -- Streams, canals, lakes, reservoirs, bays, estuaries and ocean.

19. <u>Shallow or Turbid Water</u> -- Shallow streams, canals, lakes, reservoirs, bay and estuaries.

20. <u>Salt Evaporation Ponds</u> -- Tidal areas used for salt evaporation ponds.

21. <u>Mixed Barren</u> -- Various barren lands including bare rocks, mines, gravels pits, quarries, transitional areas, and areas of mixed barren use.

22. <u>Cloud</u> -- Cloud cover.

Section 10 -- Verification and Evaluation of Land Use/Land Cover Data Set

The reliability of the biogenic hydrocarbon emissions inventory to be performed was dependent upon the accuracy of both inputs to that inventory: the land use/land cover data set, and the emissions factors for the land cover classes. In order to evaluate the accuracy of the land cover classes, a verification and evaluation (V & E) procedure was established and implemented. Verification and evaluation of the land cover data set was conducted concurrently with two other phases of the project: stratification and registration to UTM. These processes could be conducted simultaneously because in their initial phases they were relatively independent of one another. Selection and photointerpretation (PI) of the test sites (the initial phases of V & E) were not dependent upon the completion of stratification, while registration of the classified data set did not depend upon completion of the V & E. The sampling design to be used for V & E was finalized in the summer of 1980, at which time the size and sampling rate were established, as well as the target number of samples to be obtained for each land cover class. The test sites were selected randomly and were then extracted from the entire classified data set, using the SEL 32/77.

All of the test sites for which photography existed were photointerpreted (see Figure 9) by two of the project participants. Each interpreted different sites, working largely from color infrared (CIR) U-2 photography at a scale of 1:130,000. Areas not covered by U-2 flights (see Figure 8 for a map of U-2 photo coverage) were photointerpreted from 1:30,000 scale photography. The PI information was recorded in a 12-pixel-square matrix format that mimicked the organization of the test sites as extracted from the digital data, facilitating subsequent manual comparison between the PI and Landsat-based data sets. A random sampling of the photointerpreted sites then identified sites to be field checked. (See Figure 10 for a map of the sites that were visited.)

Field work for verification and evaluation purposes was conducted largely in August of 1980. A meeting of ABAG and NASA/TGS participants was held August 14-15 in preparation for the field work, at which time plans for that work were finalized and ground truth packets were organized for each site; among the products (which had been generated at Ames) in the packets were the following:

* 1:32,000 stereo-pair U-2 photography covering most of the test sites

* 50 x 50 (pixels) Band 5 plots of the raw Landsat data at 1:24,000 scale

* 12 x 12 (pixels) maps of the test sites, extracted from the classified data set

* orthophoto and topographic quad sheet maps at 1:24,000 scale, with the test sites plotted on them

The first part of the field work itself was conducted in mid-August using standardized data collection forms, a sample of which appears as Figure 11. Several sites were inaccessible due to excessive slope, locked gates, or complete lack of access roads. Many 35mm photos were taken of nearly all sites, using both color infrared (CIR) and natural-color film. The inaccessible sites were photographed as thoroughly as possible from overlooking adjoining properties. Ground cover of totally inaccessible sites, when photography was impossible, was estimated from characteristics of adjoining areas and from orthophoto quad maps and aerial photography. Several sites were not visited during these initial field trips due to insufficient time and ensuing darkness, but those were field checked at a later date. The participants met again on August 28th for evaluation of the field work and organization of the ground truth information obtained.

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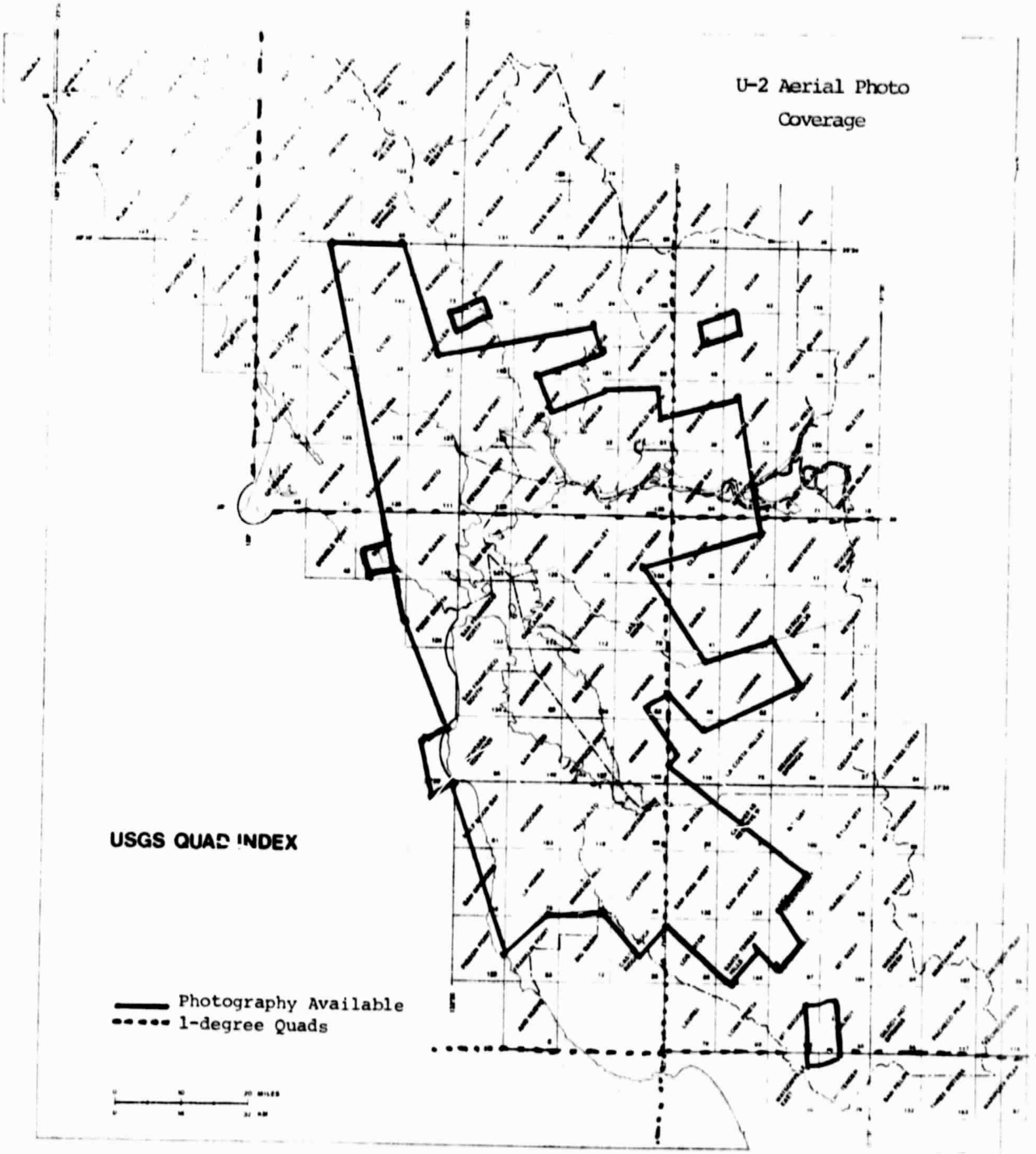

Figure 8

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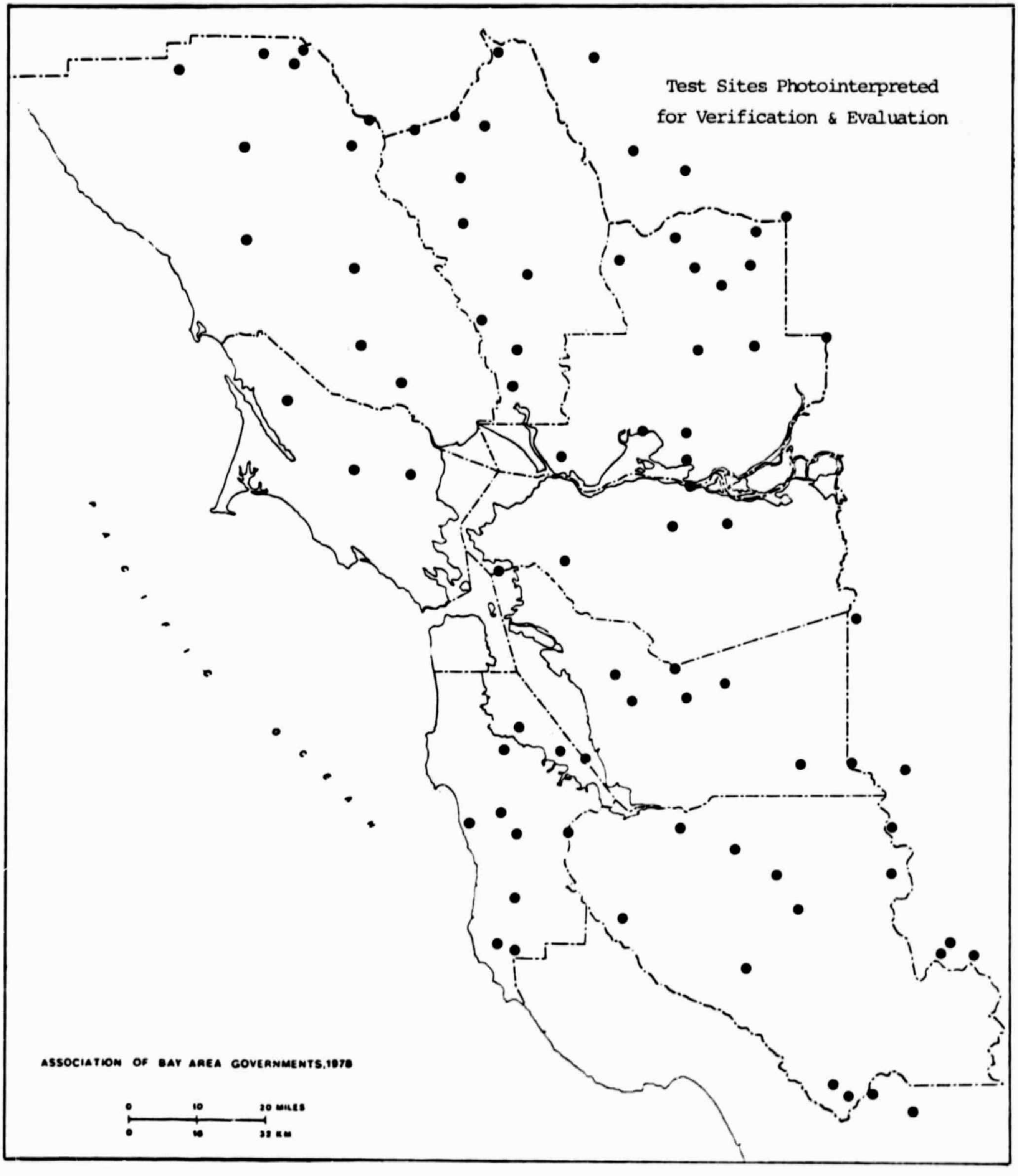

Figure 9

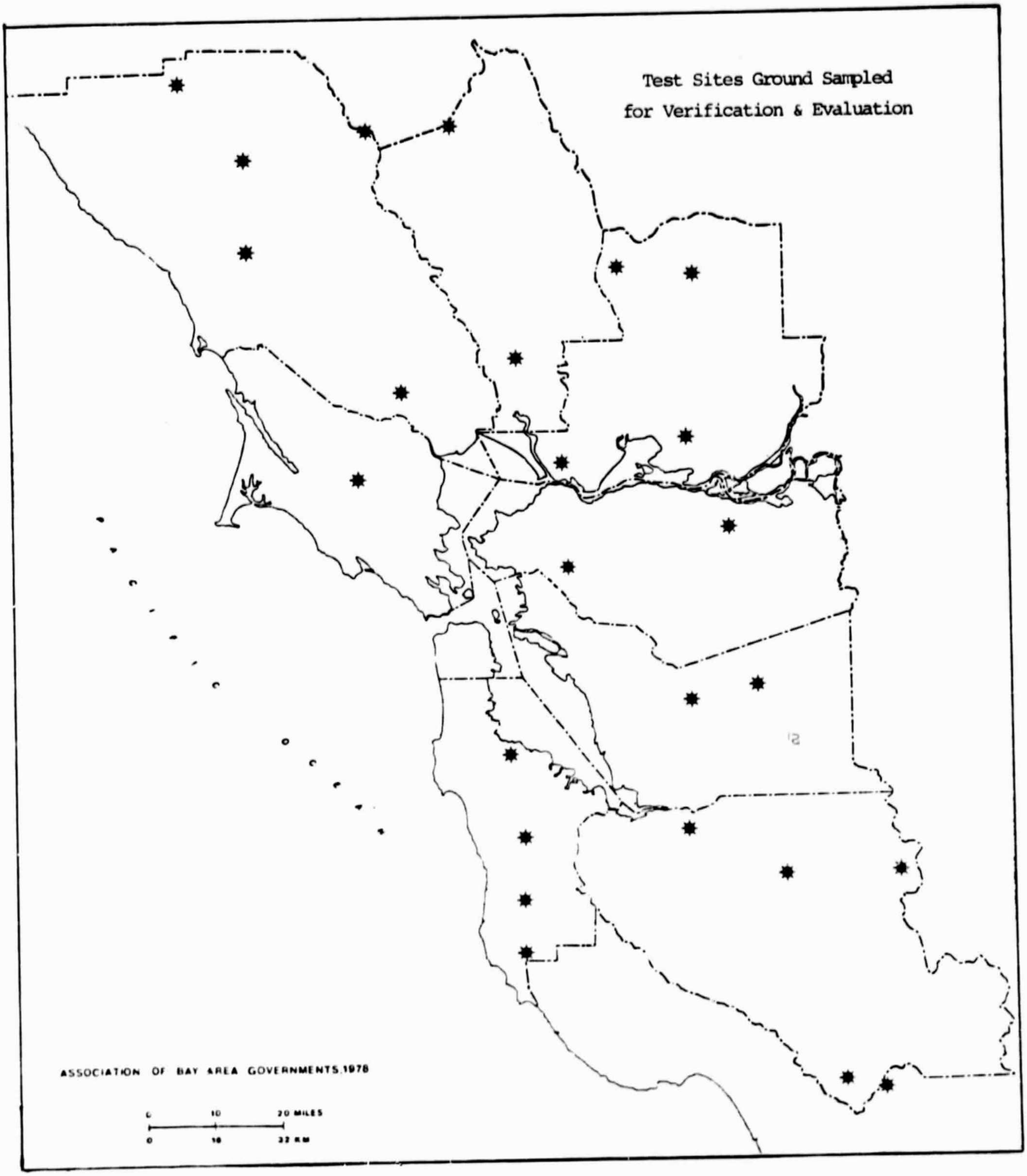
Test Sites Ground Sampled
for Verification & Evaluation
ASSOCIATION OF BAY AREA GOVERNMENTS 1978
0 10 20 MILES
0 16 32 KM

Figure 10

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Field No.______________

GENERAL

Observer______________________ Date______________________

Quadrangle______________________ Latitude/Longitude______________________

Locality____

Photos Roll__________ Frame__________ CIR Photo Date__________

Road Access to Site?____

PHYSIOGRAPHY

Elevation______________ Slope______________ Aspect N S E W

Position on Slope (Toe, Mid, Upper, Ridge)______________________

Macrorelief L T M Landform______________________

VEGETATION (circle)

Level I Forest Woodland Riparian-Shrub Chaparal Sage Grassland

Level II______________________ Level III______________________

Height

_____ Overstory ______________ 1.________ 2.________ 3________

_____ Intermediate ______________ 1.________ 2.________ 3.________

_____ Ground Layer ______________ 1.________ 2.________ 3.________

_____ Surface Layer ______________ 1.________ 2.________ 3.________

Cumulative Vegetative Cover

1. 95 - 100% 4. 25 - 49%

2. 75 - 94% 5. 10 - 25%

3. 50 - 74% 6. - 10%

Forest Crown Cover ______________

______________ Uniform

______________ not uniform

Percentage Cover		Species
________	Coniferous Trees	______________
________	Deciduous Trees	______________
________	Tall Shrubs (> 2 m)	______________
________	Medium Ht. Shrubs (.5-2 m)	______________
________	Dwarf Shrubs (10-50 cm)	______________
________	Prostrate Shrubs (< 10 cm)	______________
________	Grass Sedges	______________
________	Forbs	______________
________	Brush	______________
________	Bare Soil	______________
________	Rock	______________
________	Water	______________
________	Litter	______________

FIGURE 11

GROUND SAMPLING FORM

LAND USE

Level I ______________ Level II ______________ Level III ______________

Soils Sand Silt Clay Gravel Loam Stones Bedrock Peat

Moisture: Dry________ Moist________ Saturated________ Standing Water________

COMMENTS

Once field work and photointerpretation had been completed for most of the test sites, confusion matrices were constructed for those sites to identify the differences between PI and the classified data. Besides helping to determine the reliability of given classes, the construction of these confusion matrices served to identify specific class confusions -- information which was subsequently utilized to further improve the classification through additional stratifications. The fact that the stratification and V & E processes were conducted concurrently thus provided valuable information for both.

It was, in fact, the juxtaposition of these two processes that precipitated recognition of the fact that confusion between urban and spectrally-associated non-urban classes was unacceptably extensive, and resulted in the decision to conduct the urban modeling described in Section 9 of this chapter.

After the urban modeling/stratification was completed at ABAG, a computer tape of the modeled data set was transmitted to Ames. The modeled data was considered the final land cover inventory for the project, and as such was slated to be compared to the PI data for verification and evaluation. Consequently, the V & E test sites were extracted from this modeled data set to provide one portion of the V & E data set.

Meanwhile, the photointerpretation (PI) results had been compared with data gathered during the field work. Further verification of the information recorded for the test sites during PI was performed, using slides taken at the test sites and aerial photography. In this way the PI data set was corrected for those sites in which participants felt that the PI data could be made more accurate. The decision to correct the information gleaned from PI was founded on several aspects of the PI process itself. The two photointerpreters involved were not accustomed to translating information from such a wide variety of scales as those of the materials from which they were working. Neither photointerpreter was experienced in relating photointerpreted information to the kind of generalized land cover reflectance information represented by Landsat pixels. In addition, only one photointerpreter was a local vegetation specialist. In order to avoid adding unnecessary errors into the V & E analysis, they therefore attempted to insure that the PI data was as accurate as possible. Once they felt that maximum accuracy, given available materials, had been attained for the PI data, statistical evaluation procedures were initiated.

In preparation for computer-aided statistical analyses, a file was constructed using the ELAS software at Ames. This file contained three channels of information: PI data for the test sites, unmodeled classified Landsat data for the same sites, and the post-urban-modeling test sites that had recently been extracted. It was determined at that time that the highest priority for V & E was a statistical comparison of the post-modeling land cover with the PI data. The post-modeling data was chosen for V & E because it was the final product and because it appeared to be more accurate in urban areas than the pre-modeling data, based on observations made at the test sites during field work. The participants intended to statistically compare the pre-modeling land cover data with the PI information at a later date, on a time-available basis, in order to objectively measure the effect of the urban modeling that had been performed. Unfortunately, this second statistical comparison could not be conducted due to budgetary constraints.

Although other types of statistical V & E analyses would perhaps have been more desirable, simple linear regression was considered to provide the most time-effective option. The input data set to be used for regression consisted of two channels of the ELAS file: one channel each for the corrected PI data and for the post-modeling classified data. Each of these channels consisted of 84 contiguous 12-pixel by 12-pixel sample boxes or test sites. Each of the two channels therefore contained 12,096 pixels. Rather than perform manual data entry of more than 24,000 points, a technique was devised whereby an IDIMS program could be used to generate the required files on which the regressions could be run. The two channels of data were transferred from ELAS to IDIMS via magnetic tape.

The SAMPLET program on IDIMS, which is normally used to locate and extract verification samples from an entire data set according to sample size dictated by the analyst, was instructed to select 12-pixel by 12-pixel test sites from the ELAS test sites file and to output those sites to ERIS files. (ERIS [Earth Resources Inventory System] is a software package installed on the HP 3000 as a companion to IDIMS. It includes a modified version of the MINITAB software and various data manipulation utilities, which were to be used in statistical analyses of the V & E data.) ERIS requires that input files be in a format specifically adapted for its use; SAMPLET generated files that mimicked the content of the original ELAS V & E files but were organized for ERIS compatibility.

Before the regressions were run, a comparison was made between the original verification and evaluation data set on ELAS and the IDIMS/ERIS version of the same data. (The comparison was done to ensure that SAMPLET had correctly extracted the test sites, since this was an experimental use of SAMPLET.) Toward this end, the DUMP program on ELAS was employed in generating line printer output of the sample boxes and the process was duplicated by the LPMAP program on the IDIMS system. These two sets of line printer maps were then manually compared to assure that the data sets were identical. Once their exact correspondence was confirmed, statistical analyses proceeded.

Examination of the sample data indicated that not all of the 22 land use/land cover classes were present in each of the 84 test sites. Since regressions were to be run on a class-by-class basis, it was therefore necessary in the interests of expediency to exclude those sites in which a particular land cover class was absent in both the PI and the Landsat data before regressions were run for that class. This was accomplished by performing a logical OR on corresponding test sites from the PI and Landsat sample data, using an ERIS utility program.

Regressions were then run on a class-by-class basis, using MINITAB to regress Landsat against PI. The resulting coefficients of determination (r2 values) appear in Table 10.

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Table 10

REGRESSION RESULTS FOR
VERIFICATION AND EVALUATION TEST SITES

Class Number	Land Cover Class Name	No. of Test Sites Containing Class	r^2 * Value	Percentage of Total Land Cover Data Set Comprised by Class
1	Hardwood Forest	19	.002	1.19
2	Hardwood/Brush	47	.371	7.76
3	Coniferous Forest	11	.083	1.12
4	Conifer/Brush	13	.102	1.53
5	Hardwood/Conifer Forest	23	.705	6.35
6	Conifer/Hardwood Forest	15	.253	2.27
7	Grassland	66	.649	29.73
8	Open Shrub	50	.290	12.91
9	Brush	49	.579	12.45
10	Mixed Agricultural Land	27	.500	6.53
11	Commercial/Services/Industrial	7	.055	0.41
12	Mixed Urban	5	.996	1.35
13	Low Vegetation Residential	16	.892	8.07
14	Moderate Vegetation Residential	12	.085	0.79
15	High Vegetation Residential	6	.697	0.89
16	Urban Green	2	**	0.35
17	Non-forested Wetland	5	.850	2.66
18	Deep, Clear Water	14	.868	0.24
19	Shallow, Turbid Water	4	**	0.62
20	Salt Evaporation Ponds	1	**	0.21
21	Mixed Barren	15	.618	0.60
22	Clouds	0	**	1.97

* r^2 values reported have not been adjusted for degrees of freedom

** Regressions could not be computed for these classes because representation in test sites was insufficient -- in either the PI or the Landsat data, or both.

Percentage of Total Land Cover Data Set Comprised by Class computed by BASIS.

Verification/Evaluation Conclusions

An examination of Table 10 demonstrates that the regression results were not encouraging. Upon examination and discussion, however, multiple factors that had influenced these results were identified and the role of each in contributing to the results can be hypothesized. The factors are:

1) The color infrared photography used in photointerpretation varied in scale, making location of V & E sites more difficult.

2) Most of the photos were at 1:32,500 scale, but some were at 1:130,000 scale, which is not amenable to accurate identification of vegetation types.

3) The method used in plotting the test sites on the orthophoto and topographic quad sheets for V & E work was a manual transfer from 1:32,500 and 1:130,000 scale color infrared photography, and was assisted by a zoom stereoscope rather than a zoom transfer scope, as is usually employed. The photography was not in the form of Cibachrome prints; the 1:32,500 photos were color positive transparencies, while the 1:130,000 and some 1:69,000 scale photography was on rolls, making location of the appropriate frames awkward.

4) The field information was gathered primarily <u>after</u> the PI was done. More accurate PI may have been possible had field work preceded PI.

5) As previously mentioned, two persons performed the PI, each working on separate test sites. Optimal results are obtained from a single person doing all of the required PI, or from comparison of duplicate photointerpretation of all PI sites.

6) The backgrounds and areas of expertise of the two photointerpreters varied widely. This nearly ensured that they would identify the same land cover type differently, when photointerpreting an area of such wide-ranging land cover types -- such as large tracts of natural vegetation, vs. large and varied urban areas. Although as much care as possible was exercised to ensure that clear definitions existed for the land cover types being photointerpreted, variability in the results could not be avoided given the circumstances outlined above.

7) A wide spread in the acquisition dates of the data used in the project jeapordizes the ability to place any confidence in a comparison between the

Landsat data, the photography, and the field work. The Landsat data was acquired in 1976, the aerial photography was acquired between 1972 and 1978, and the field work was done in 1980. In an area of such variability of land use and land cover, that degree of variance in data acquisition times is unacceptable.

Ground inspection of the test sites indicated that the urban categories were overall very good in the post-modeling data set. Intuitive feeling of the project participants led to the conclusion that the land cover categories on the whole were more accurate than the V & E indicated. Some vegetation categories, however, were virtually untested with regard to V & E, such as Hardwood Forest, because no test site fell on a homogeneous stand of hardwood forest.

The location/registration of the test sites, in each of the V & E data sets and on the ground, was checked as carefully as possible in order to avoid compounding differences between the data sets and thus influencing regression results. While there had been some temporary confusion with regard to location of one test site on the ground, the test sites within the PI and Landsat data sets appeared to be accurately registered to one another. This was not, however, verified with any statistical analysis technique and may have also contributed to the overall poorness of the V & E results.

In summary, while the obvious conclusion to be drawn solely on the basis of the coefficients of determination (r2 values) is that the Landsat classes poorly predicted what was on the ground, that conclusion may be predicated upon two false assumptions: that the PI data is truly accurate, and that the PI data is correctly registered to the Landsat data and maps. If the PI information is in error, the Landsat-based land cover classes may be more accurate than the regressions make them appear. Since no opportunity exists -- within the confines of the project budget, deadlines, and staffing -- to pursue the source of the differences between the PI and Landsat data, it can only be stated that the land cover categories represent the best land cover inventory achievable under the circumstances. ABAG has used the land cover data set for applications unrelated to this project -- for example, for fire modeling -- and the results have demonstrated that the land cover data set is much more accurate than the V & E results indicate.

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CHAPTER 2

Chapter 2

SELECTION OF BIOGENIC HYDROCARBON EMISSION FACTORS

Two further major activities were required in order to prepare the biogenic hydrocarbon emissions inventory: determination of emission factors (micrograms emission/square meter/hour) for the vegetation classes identified in the Landsat data, and compilation of the inventory based on those vegetative emission factors and the spatial distribution of those vegetative cover types. This chapter describes the process used to select emission factors for the various vegetation types found in the Bay Area; compilation of the emissions inventory is detailed in Chapter 3.

This chapter first provides background pertaining to emissions inventories and their role with regard to air quality planning. The second section details the technique employed in calculating emission factors. A review of potential sources of emission factor data comprises the third section, and the selection of the Delphi Survey technique is related, along with a general outline of the Delphi approach in Section 4. The fifth section covers the computation of area-based emission factors for the ABAG land cover classes. The final section summarizes the major assumptions employed in emission factor selection and presents conclusions regarding that selection process. References conclude the chapter.

Section 1 -- Background

As stated in the Introduction, previous air pollution control strategies have considered man-made (anthropogenic) sources of hydrocarbon emissions, but have virtually ignored the role played by biogenic sources in contributing to overall hydrocarbon emissions. Biogenic hydrocarbon emissions are organic gases emitted by living vegetation, bodies of water, wetlands, and decaying vegetative and animal tissue. These emissions are composed of three basic hydrocarbon types: alkanes (mostly paraffins), alkenes, and aromatics. (Biogenic alkenes are usually subdivided into isoprene and monoterpenes -- substances referred to specifically in later portions of this chapter.)

EMISSIONS ESTIMATION

The assessment of biogenic contributions to ozone levels in the Bay Area required consideration of three factors:

* the total amount of biogenic hydrocarbons emitted in the Region;

* the photochemical reactivity of the emissions -- how well they react with nitrogen oxides to produce ozone;

* the capability of the Region's geography and meteorology to mix biogenic hydrocarbons with man-made hydrocarbons and nitrogen oxides in biogenic source/receptor relationships.

Previous regional biogenic hydrocarbon emission inventories have been based on hydrocarbon emission rates measured using one of the following techniques:

* Bag enclosure -- a branch of living vegetation in the field is enclosed in a Teflon bag; after a specified time period, the bag is evacuated and the amount of hydrocarbons given off is measured (Zimmerman, 1979 a and b).

* Environmental chambers -- entire plants are enclosed in chambers and the hydrocarbon levels in the chambers are closely monitored as a function of time (Tingey, et al., 1978 a and b).

* Energy balance -- meteorological instruments are installed in the field adjacent to biogenic sources; the meteorological data collected (carbon dioxide levels, temperature, wind speed, and incident radiation) are used as input to an energy balance model that estimates biogenic emission rates (Knoerr, 1980).

Emission rates derived from these studies usually are expressed as grams of emission per unit time. Biogenic hydrocarbon emission rates have been observed to vary with a number of parameters, including light intensity (Rasmussen, 1972; Zimmerman 1979a; Tingey, et al., 1978a and 1978b), relative humidity (Tyson, et al., 1975), soil fertility, plant moisture and pathological conditions of vegetation. Only the first three parameters listed have been studied in any detail.

Using one or more of the above three techniques, biogenic hydrocarbon inventories have been compiled for various regions in the United States, including Tampa/St. Petersburg, Florida [Zimmerman, 1979a], Pennsylvania (statewide inventory) [Flyckt, et al., 1980], Houston, Texas [Zimmerman, 1979c], and the California South Coast Air Basin [Taback, et. al., 1978]. Although none of these inventories have yet been incorporated into hydrocarbon inventories for use in non-attainment air quality planning activities, these inventories found that biogenic hydrocarbons represented significant fractions of regional non-methane hydrocarbon (NMHC) inventories: 68% in the Tampa area [Zimmerman, 1979 a], 40-50% in the Houston area [Zimmerman, 1979 c], and 50% in Pennsylvania [Flyckt, et al., 1980].

The second pertinent factor in assessing biogenic contributions to ozone production is photochemical reactivity. Biogenic emissions, even if they are of comparable magnitudes to anthropogenic emissions, could not contribute to ozone production unless they were photochemically reactive. Smog chamber studies conducted under EPA funding have found that biogenic hydrocarbons are moderately to extremely photochemically reactive [Arnts, et al., 1979]. In ozone-producing reactions, isoprene (a type of biogenic alkene) has been shown to be slightly more reactive than propylene (a "typical" man-made hydrocarbon used for comparison purposes), while monoterpenes (another type of biogenic alkenes) were found to be slightly less reactive than propylene [Arnts, et al., 1979]. Outdoor smog chamber studies conducted at the University of North Carolina found that replacing 20% of a "typical" urban hydrocarbon mix with the monoterpene "x - pinene" had marginal impacts on the ozone-producing ability of the smog chamber chemistry [Kamens, et al., 1980]. The results of these studies suggest that biogenic hydrocarbons can contribute to ozone production, provided a source of nitrogen oxides is available. Studies of biogenic hydrocarbon photochemistry have also determined that monoterpenes are efficient ozone scavengers; in other words, these hydrocarbons would deplete existing ozone levels [Arnts, et al., 1979].

The third factor governing the contribution of biogenic emissions to ozone levels -- the capability of a region to mix biogenic hydrocarbons with urban hydrocarbon and nitrogen oxide emissions -- depends on biogenic source/receptor relationships determined by the geography and meteorology of the region in question. A mixing of biogenic and anthropogenic emissions is possible if biogenic emission sources are located upwind of urban areas. Although this factor is best analyzed with a photochemical dispersion model, some subjective comments regarding its importance in the Bay Area can be made here.

Wind flow in the Bay Area during high ozone episodes is typically from the west or northwest [MacKay, 1977]. The Bay Region's geography therefore appears to be conducive to ozone formation from biogenic sources because heavily vegetated areas (Marin and Sonoma Counties and Western San Mateo County) are located upwind of urban areas. However, another geographic factor -- the altitude of the vegetated areas -- may play an important role in determining the magnitude of the biogenic source contribution to ozone levels.

The light winds that exist in the Bay Area during high ozone levels tend to flow around the high altitude parts of the Region (hills and mountains). For example, westerly winds flow through the Golden Gate Bridge and through low passes in San Mateo County, and northerly winds flow through valleys in Marin and Sonoma Counties [MacKay, 1977]. As a result, winds are not likely to entrain biogenic emissions from sources at altitudes of 500m - 1000m and higher, under typical conditions [MacKay, 1977]. The majority of the forests in Marin, Sonoma and Western San

Mateo Counties may be at altitudes that preclude the contribution of their emissions to high ozone levels.

The altitude of forested areas may also be an important factor in determining biogenic contributions to ozone levels from the standpoint of the height of the base of the inversion (the depth of the mixed layer). The average inversion base height in the Bay Area during episodes of high ozone levels is approximately 300m [MacKay, 1977]; consequently, where biogenic emissions from any sources at altitudes above this height will enter the inversion layer, on the average, is difficult to discern. One possibility is that the monoterpene fraction of the emissions will react with ozone to form aerosols, based on photochemical reactivity data of Arnts, et al., (1979) and measured ozone levels in the inversion layer over the Bay Area [MacKay, 1977]. Biogenic compounds emitted into the inversion layer will not likely have significant impact on high ozone levels in the South Bay.

On days of low ozone levels, winds tend to be stronger and the inversion base higher, and biogenic compounds could play a more significant role in ozone production in the Region. On such days, biogenic sources would be contributing to ozone levels, but not to the high levels on which air quality planning activities are based.

The preceding subjective discussion of the potential of the Bay Area's biogenic sources to contribute to ozone levels was based on average data and "typical" conditions. In reality, wind speed and direction and inversion base height all vary with space and time, and the importance of biogenic emissions in determining the Region's air quality can be expected to vary accordingly. For this reason, the final quantitative assessments of the contribution of biogenic emissions to ambient air quality can be best done with a photochemical dispersion model.

Statistical analyses of air quality and meteorological data done by Sandberg, et al., (1978) suggested that biogenic hydrocarbon emissions do influence ozone levels in the Bay Area. In June 1978 Sandberg, et al., reported a strong correlation between the number of times per year that ambient ozone levels in the Region exceeded 80 parts per billion (ppb) (.08 parts per million [ppm]) and the total amount of precipitation during the two previous winters (rainy seasons). In order to explain this correlation, they hypothesized that winter rain contributes to vegetation growth in the spring, which in turn results in biogenic emissions in the summer and fall (seasons of high ozone levels). Because hydrocarbons are an ozone precursor, increased hydrocarbon emissions lead to increased ozone levels in the air. In 1978, the winter rain / summer ozone relationship was used to successfully predict the number of times the 1978 ozone standard of 80 ppb (.08 ppm) was exceeded in the Bay Area [DeMandel, et al., 1979; Sandberg, et al., 1979]. On the other hand, preliminary results of an ambient hydrocarbon measurements study conducted recently by the Bay Area Air Quality Management District (BAAQMD) suggest that biogenic compounds may not have a major influence on the Region's air quality. One day of hydrocarbon sampling in a rural location in Sonoma County found no measurable levels of the isoprene and monoterpene fractions of biogenic compounds [Levaggi, 1980]. Bufalini (1980) suggests that ambient levels of biogenic hydrocarbon compounds are not high enough to significantly affect air quality in urban or rural areas.

The discrepancy between high biogenic emission rates (implied by Sandberg, et al., 1978) and low measured ambient levels is not unique to the Bay Area. For example, natural organic emissions account for 68% of the total hydrocarbon emissions in the Tampa/St. Petersburg area, and yet measured ambient biogenic hydrocarbon concentrations represent less than 10% of the total ambient hydrocarbon level [Dimitriades, 1980].

Possible explanations for this discrepancy include the following [Dimitriades, 1980; Budiansky, 1980; Flyckt,et al., 1980]:

* natural emission rates are overestimated, due in part to uncertainties resulting from the extrapolation of emission factor data to specific regions of the country;

* anthropogenic emission rates are underestimated;

* ambient levels of biogenic hydrocarbons are underestimated because some biogenic hydrocarbons, e.g., alcohols, escape field sampling and detection.

Westberg (1977) used dispersion modeling techniques to show that an ambient terpene concentration of 1.6 ppb within a forest canopy can result from estimated terpene emission rates of 3000 ug/m2-hour; in other words, normal dilution processes within a forest canopy can account for low ambient terpene concentrations. More recently, studies in Pennsylvania have shown that measured ambient biogenic hydrocarbon levels are comparable in magnitude to those estimated with a Gaussian dispersion model and a biogenic emissions inventory [Flyckt, et al., 1980].

AIR QUALITY PLANNING

Gaseous hydrocarbons, whether biogenic or anthropogenic, can react with nitrogen oxides in the presence of sunlight to form ozone. To protect public health, the Federal government has established a 1-hour average ambient ozone standard of 0.12 ppm (120 ppb).

The Bay Area has an ozone problem because hydrocarbons and nitrogen oxides react to produce ambient ozone levels that violate the Federal ozone standard. The 1979 Bay Area Air Quality Plan was prepared in response to this problem; it discusses control measures that will reduce ambient ozone concentrations to levels below the standard by 1987.

Reducing ambient ozone levels can be accomplished by controlling emissions of hydrocarbons or nitrogen oxides, or both. Emission inventories of both hydrocarbons and nitrogen oxides were compiled for the 1979 Plan. These inventories were then fed into a photochemical dispersion model to determine the best control scenario for attaining the ozone standard. The modeling results indicated that, for the Bay Area, controlling hydrocarbon emissions alone is the most effective way to reduce ambient ozone levels. The total hydrocarbon emissions inventory for the Bay Area is a critical element of air quality planning activities, because it determines the amount of emission control needed to attain and maintain the Federal ozone standard.

The control strategies presented in the 1979 Plan were based on the assumption that biogenic sources contribute an insignificant fraction to the Region's total hydrocarbon inventory. The validity of this assumption, and others on which the Plan is based, affects whether or not the Plan will achieve its goal -- attainment of the ozone standard before 1987. The preparation of a biogenic hydrocarbon emissions inventory and subsequent photochemical modeling would, it was hoped, provide a technical basis for either proving or disproving this assumption, and therefore reduce the uncertainty as to whether or not the Plan was likely to succeed.

The definition of ambient standards in the Clean Air Act Amendments implies that only the worst-case or maximum possible ozone levels must be used in determining the amount of control needed to attain the standard. Specifically, in the Bay Area, the 1979 Plan was based on meeting the standard on a particular day (or days) in recent years that experienced high ozone levels (usually summer or early fall) and for which meteorological parameters were measured. After this day was selected, the corresponding seasonal emissions inventory was adjusted to a daily level and fed, together with meteorological data, into the photochemical computer model. Thus the biogenic hydrocarbon emissions inventory was expected to be representative of the particular day(s) in summer or early fall selected for the photochemical modeling in the 1982 revised Plan.

Although ozone is formed from both hydrocarbons and nitrogen oxides, this study did not address the contribution of biogenic nitrogen oxide emissions to regional ozone levels for two reasons:

* studies have shown that emissions of nitrogen oxides from living vegetation, decomposing plant and animal tissue, oceans and fresh water are insignificant (Ratsch, et al., 1977);

* photochemical modeling studies in the San Francisco Bay Area have shown that ambient ozone levels are more sensitive to hydrocarbon emissions than to emissions of nitrogen oxides (ABAG, et al., 1979a).

This project did not consider biogenic emissions from vegetation located outside the boundaries of the nine-county Bay Area because available evidence suggests that such emissions would not significantly influence ozone maxima in the South Bay, for the following reasons. Firstly, the predominant wind flow in the Region during the peak ozone season would not result in transport of biogenic hydrocarbons from outside the Region into the South Bay. Secondly, even if winds were blowing from outside the Region into the South Bay, the biogenic compounds would not likely exist in the atmosphere as ozone precursors long enough to contribute to maximum ozone levels. Atmospheric residence times (daytime) for monoterpenes have been estimated to range from less than one hour to a few hours, and residence times for isoprene have been estimated to range from one hour to one day [Westberg, 1977; Bufalini, 1980; Peterson, et al., 1980]. Biogenic compounds emitted from sources that exist outside the northern and eastern boundaries of the Region would likely have been oxidized (in photolysis or ozonolysis reactions) before they could significantly affect ozone maxima in the South Bay, based on wind speeds observed during elevated ozone levels [MacKay, 1977]. Furthermore, biogenic hydrocarbons, once oxidized in the atmosphere, are not thought to participate further in ozone-producing reactions [personal communication, Bruce Gay, Environmental Sciences Research Laboratory, Research Triangle Park, North Carolina, December, 1980].

Section 2 -- Emission Factor Calculation Technique

In order to use the Landsat-based vegetation inventory (or any spatially-oriented vegetation data) in a photochemical dispersion model, the emission factors had to be expressed as emission rate (e.g., micrograms/hour [ug/hr]) per unit area. The classified Landsat data, as modified by ABAG, provided information describing both the location of the 22 land cover classes and the area encompassed by those classes, on the hectare (approximately 100 meter square) level. Multiplying the area of a particular class within a specific 1-km x 1-km grid by the area-based emission factor produced emission rates as required by LIRAQ. This practice is equivalent to the estimation of anthropogenic hydrocarbon emissions, in which some source activity level is multiplied by an emission factor to arrive at an emission rate.

The major sources of biogenic emissions from trees, bushes, and shrubs are leaves for broadleaf species and needles for coniferous species [Rasmussen, 1972]. Biogenic emissions are therefore proportional to the amount of leaves and needles (foliage) present in an area of interest. A convenient measure of the quantity of foliage in a given area is dry foliar biomass density, usually expressed as grams of dry foliar biomass per square-meter ground area. Dry biomass densities are used to minimize fluctuations in foliar biomass resulting from variable water content in the foliage.

Foliar biomass density can vary with vegetation type and geographic location. For example, conifers are expected to have a different foliar biomass density than hardwoods located in the same area; alternatively, conifers located on the coast are expected to have a different foliar biomass density than conifers located in inland areas. The ecozone classification developed by CDF, as modified by ABAG, was used to define the foliar biomass density data requirments for the project.

Biogenic hydrocarbon emission rates from brush and from broadleaf and coniferous trees, as measured in the laboratory and in the field with state-of-the-art techniques, are usually expressed as micrograms (ug) emissions per gram(g) of dry foliar biomass per hour. Multiplying the emission factors by the biomass densities produces the mass emission rates per area, as shown below:

$$\underset{\text{(EMISSION FACTOR)}}{\left(\frac{\textit{ug emission}}{\textit{hr-g biomass}}\right)} \quad \text{X} \quad \underset{\text{(BIOMASS DENSITY)}}{\left(\frac{\textit{g biomass}}{m^2 \textit{ area}}\right)} \quad = \quad \underset{\text{(AREA-BASED EMISSION FACTOR)}}{\left(\frac{\textit{ug emission}}{\textit{hr-}m^2 \textit{ area}}\right)}$$

The emission rate per unit area for each vegetation type can then be combined with vegetation distribution data to arrive at a biogenic emissions rate for each 1-km by 1-km grid in the nine county Bay Area:

$$\underset{\text{(VEGETATION DISTRIBUTION)}}{\left(m^2 \textit{ area of vegetation type}\right)} \quad \text{X} \quad \underset{\text{(AREA-BASED EMISSION FACTOR)}}{\left(\frac{\textit{ug emission}}{\textit{hr-}m^2 \textit{ area}}\right)} \quad = \quad \underset{\text{(EMISSION RATE)}}{\left(\frac{\textit{ug emission}}{\textit{hour}}\right)}$$

These data can then be converted from ug/hr to the appropriate units for photochemical modeling (grams/second).

Section 3 -- Potential Sources of Emission Factor Data

ABAG considered three potential data sources for the emission factor and biomass density data: original research, published literature, and expert knowledge. Original research incorporates laboratory and field work aimed at measuring emission factors and biomass densities for each vegetation type. Typically, emission factors are measured using one of the three techniques described earlier in this chapter (bag enclosure, environmental chamber, and energy balance).

Determination of biomass densities can be performed using field survey techniques involving ground area measurement, vegetation sampling, dehydration, and measurement of the dried foliar biomass. Original research work such as this, while capable of providing the most accurate data for the Bay Area, was definitely beyond the funding, scope, and time frame of the ABAG project. Hopefully the results of this project will prompt funding of such research work in the Bay Area.

Having eliminated the possibility of pure research work, published literature sources were the next potential data source considered. A number of papers and reports on biogenic hydrocarbon emissions appear in the literature. Most of the reports are based on work done outside the Bay Area, and by using the published data it is therefore assumed that the nature of biogenic emissions from each vegetation class does not change with geographic location. Table 11 is a representative sample of the best available biogenic emission factor and biomass density data found in the literature, together with the appropriate references.

In spite of the volume of information on biogenic emission factors in the literature, the original research work upon which many papers are based is rather limited. Zimmerman and co-workers (1979a, 1979b and 1979c) and Flyckt et al. (1980) have measured biogenic emission rates in the field in various parts of the country, using the bag enclosure technique developed by Zimmerman (1979b). Tingey and co-workers (1978a and 1978b) have measured biogenic emission rates using a technique that involves enclosing an entire living specimen in a dynamic gas exchange chamber. Arnts, et al., (1978) have measured biogenic emission fluxes (ug emission/m2-minute) from a pine forest using energy balance/Bowen ratio techniques (see also Knoerr, 1980). Thus, the state-of-the-art in biogenic emission factors depends to a large extent on the work done by this relatively small group of scientists.

Table 11

BEST DATA AVAILABLE FROM LITERATURE

EMISSION FACTORS

Vegetation Species	Emission Factor		Reference
Coast Live Oak	28.7	(ug/g-hr)	Zimmerman, 1979(b)
Scrub Oak	4	"	Taback, et al., 1978*
Live Oak	33	"	Tingey, et al., 1978(a)
Laurel Oak	12.6	"	Zimmerman, 1979(a)
Live Oak	10.8	"	Zimmerman, 1979(a)
Bluejack Oak	56.4	"	Zimmerman, 1979(a)
Myrtle Oak	17.2	"	Zimmerman, 1979(a)
Maple	1	"	Taback, et al., 1978*
Orange	9.3	"	Zimmerman, 1979(a)
Grapefruit	4.3	"-53900uu965	Zimmerman, 1979(a)
General Conifers	8.9	"	Zimmerman, 1979(b)
Pinjon Juniper	3	"	Taback, et al., 1979*
Redwood	3	"	Kamiyama, et al., 1978
Slash Pine	6.6	"	Tingey, et al., 1978
White Pine	1.20	"	DeSanto, et al., 1976**
Ponderosa Pine	0.72	"	DeSanto, et al., 1976**
White Fir	0.90	"	DeSanto, et al., 1976**
Monterey Pine	3.13	"	DeSanto, et al., 1976**
Sand Pine	13.6	"	Zimmerman, 1979(a)
Sagebrush	54	ug/m^2-hr	Tyson, et al., 1974
Sawgrass	392	"	Zimmerman, 1979(a)
Grassy Mudflat, Marine	206	"	Zimmerman, 1979(a)
Fresh Water Marsh	120	"	Zimmerman, 1979(a)
Marine	129	"	Zimmerman, 1979(b)
Aquatic	102	"	Zimmerman, 1979(b)
Tomatoes	48.1	"	Zimmerman, 1979(a)
Beans	1565	"	Zimmerman, 1979(a)

*Primary reference for emission factor data used by Taback, et al., is personal communication with P.R. Zimmerman.

**Primary reference for emission factor data used by DeSanto, et al., is not available.

Table 11

(continued)

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BEST DATA AVAILABLE FROM LITERATURE

FOLIAR BIOMASS DENSITIES* (g/m^2)

	Bay Area Biomes	
Vegetation Type	Temperate Forest	Coniferous Forest
Conifer	990	559
Oak	55	39
Non-Conifer, Non-Isoprene	22	26
Non-Oak, Isoprene	22	26
Total	1100	650

*The best available data on foliar biomass density (g/m^2) are on the biome level, as published in Zimmerman (1979b). Biomes are large geographical regions ranging in size from approximately 150,000 km^2 to over 300,000 km^2. They are defined according to the composition of potential vegetation, the physiography and physiognomy of the land, and the climate of the area. Most of the nine county Bay Area is classified as "Coniferous Forest"; Marin County and part of Sonoma County are classified as "Temperate Forest" [Zimmerman, 1979b].

The biomass densities shown in Table 11 reflect a very broad spatial resolution, having been developed on the biome level (biomes are defined in the Table) under the auspices of the International Biological Program (Lieth, et al., 1975); consequently, they were not ideally representative of the range in biomass densities expected to be found in the Bay Area. A more accurate estimate of the biomass density of trees in the Bay Area can be gleaned from the literature using biomass estimation techniques such as those discussed by Well [1980]. For example, empirical algorithms relating tree diameter at breast height (DBH) and foliar biomass have been published [Baskerville, 1972; Hanson, 1975; Crow, 1971]. Similar algorithms have been developed for brush and shrubs [Brown, 1976]. Sources of the DBH and related data in the Bay Area include timber stand vegetation maps [U.S. Department of Agriculture, 1979], timber stand surveys conducted by various counties, and information resources at the Forestry Department of the University of California at Berkeley, and at the Pacific Southwest and Range Experiment Station in Berkeley. Therefore, reasonably accurate biomass densities could have been computed, but only after the expenditure of considerable resources that were beyond the scope of this project. For this reason, the biomass density data in Table 11 were considered to be the best information available from the biogenic emissions literature.

Three discrepancies become apparent when comparing Table 12, which presents the vegetation types for which emission factors and biomass densities were required, with Table 11, which presents vegetation types for which data were available. First of all, most of the available data were on a species- specific level, whereas this project required data for broadly-defined land cover classes. Second, the available emission factor data for a particular species, such as oak, can vary considerably in magnitude, e.g., from 4 to 56 ug/g-hour. Third, the available biomass density data were too broadly defined to be used in assigning biomass densities to the 22 ABAG land cover classes. Therefore, these discrepancies had to be resolved in order to use the literature data for this project.

One particularly useful piece of information that was obtained from the literature was the recognition that emission factors on a per unit biomass basis are not measured for all vegetation types. In general, only emission factors for trees and shrubs are measured as ug/g biomass-hour. For the other classes, such as water, agricultural land, grassland, etc., the emission factors are measured in the field on a per unit area basis; the measurement of biomass density is built into the sampling process.

By comparing Tables 11 and 12, one can see that published literature did not contain the specific emission factors or biomass density data needed for the ABAG project, and thus could not be readily used as a data source. Having exhausted the conventional sources of data, the project participants focused upon an alternative source of data -- expert knowledge.

Table 12

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PERCENT
COMPOSITION OF LAND COVER CLASSES

LAND COVER CLASS	VEGETATION TYPE						
	Hardwood	Conifer	Grass	Brush	Aquatic/ Marine	Crop Cover	Barren
Hardwood Forest	80	5	5	5	--	--	5
Hardwood/Brush	15	--	10	75	--	--	--
Conifer Forest	5	80	5	5	--	--	5
Conifer/Brush	--	15	10	75	--	--	--
Hardwood/Conifer	55	25	5	5	--	--	--
Conifer/Hardwood	32.5	47.5	10	10	--	--	--
Grassland	--	--	97.5	2.5	--	--	--
Open Shrub	--	--	80	20	--	--	--
Brush	--	--	15	85	--	--	--
Mixed Agricultural Commercial	--	--	--	--	--	90	10
Services and Industrial	2.5	2.5	5	--	--	--	90
Mixed Urban	5	5	7.5	2.5	--	--	80
Low Vegetation Residential	5	5	7.5	2.5	--	--	80
Moderate Vegetation Residential	15	7.5	30	5	--	--	42.5
High Vegetation Residential	27.5	10	10	10	--	--	42.5
Urban Open Space	30	20	45	5	--	--	--
Non-Forested Wetlands	--	--	90	--	7.5	--	2.5
Water	--	--	--	--	100	--	--
Shallow or Turbid Water	--	--	--	--	100	--	--
Salt Evaporation Ponds	--	--	--	--	95	--	5
Mixed Barren	--	--	--	--	--	--	100
Clouds	--	--	--	--	--	--	--

Section 4 -- Obtaining Expert Knowledge: The Delphi Approach

At the outset of the project a Biogenic Hydrocarbon Emissions Inventory Advisory Committee had been formed to provide technical guidance pertaining to emissions. The Committee consisted of representatives from state and regional air pollution control agencies, academia, private consultants, and national research laboratories. The Committee was appointed by ABAG staff; individuals were selected because of their position, affiliation, interest in and knowledge of the subject, and proximity to the Bay Area. At the first Advisory Committee meeting the gaps apparent from comparison of Tables 11 and 12 were identified and discussed. The Committee recommended using the Delphi approach to obtain the data required for the study.

Delphi Surveys

The Delphi approach can be generally described as a systematic technique for soliciting group opinion. Delphi surveys involve concise communication, e.g., filling out a questionnaire, and as a result the participants must be highly familiar with the subject matter. A Delphi survey is most effective when the participants are all experts in the sense that they are knowledgeable and can communicate an entire body of thought with few words, often by reference to relevant literature. The essential features of a Delphi survey are (Linstone, et al., 1975):

* Iteration with controlled feedback -- the panel interaction is carried out through responses to a series of questionnaires. Extracted from the responses is that information relevant to the issues; this information is then fed back to the panel. Both majority and minority views are represented, but not in such a way as to overwhelm opposition by weight of repetition.

* Statistical group response -- the group response to specific questions is fed back to the panelists in statistical terms so that the degree to which differences of opinion exist is accurately portrayed, in addition to the median response; in this way, all responses are considered.

* Anonymity -- the identity of panelists and their interactions are handled in an anonymous fashion through the use of questionnaires; specific opinions or responses are not identified with a particular person.

From the standpoint of resolving the data gaps in this project, the concept of a Delphi survey was useful because the people who had measured the emission factors that appeared in the literature were the experts assigning emission factors and biomass densities to the ABAG vegetation classes. Intuitively, the data so derived could be expected to be more accurate than if a "non-expert" had made the assignments. Use of the Delphi approach was based on the reasonable assumption that the professional judgement of scientists familiar with biogenic emission rates was a more valuable information resource than the use of available literature by non-experts.

Three basic tasks comprised the Biogenic Delphi survey:

* Selection of participants;

* Preparation and mailing of two rounds of questionnaires;

* Processing of results for both rounds.

Selection of Participants

The participants in the survey were selected from authors of current research papers and reports, and from a list of participants in an EPA Symposium entitled, "Atmospheric Biogenic Hydrocarbons, Emission Rates, Concentrations, and Fates," held at the EPA Environmental Research Center, Research Triangle Park, North Carolina, January 8-9, 1980. Additional names were obtained by conversations with other participants.

Initially a list of over twenty experts in biogenic emissions was compiled, reflecting a nationwide distribution of scientists in many fields. Each person on the list was contacted by telephone; the interviewer explained the study to them, described the data gaps, and asked their participation in the Delphi survey to resolve those gaps. Out of the original list of twenty experts, only eleven persons considered themselves sufficiently knowledgeable of biogenic emissions to participate in the Delphi survey. Of these eleven, only eight participated in both rounds of Delphi questionnaires (three panel members asked to be removed after receiving the first questionnaire). Table 13 presents a list of the panel members participating in both rounds of the survey.

Table 13

BIOGENIC DELPHI SURVEY PANEL OF EXPERTS

Elgene Box Department of Geography University of Georgia Athens, GA 30602	Specialty: biomass quantification
Ken Knoerr School of Forestry and Environmental Studies Duke University Durham, NC 27706	Specialty: emission factors
David Lincoln Department of Biological Sciences Stanford University Stanford, CA 94305	Specialty: emission factors; local vegetation
Harold Mooney Department of Biological Sciences Stanford University Stanford, CA 94305	Specialty: emission factors; local vegetation
Reinhold Rasmussen Environmental Technology Department Oregon Graduate Center Beaverton, OR 97005	Specialty: emission factors
David Tingey Corvallis Environmental Research Terrestrial Division, Air Pollution Effects U.S. Environmental Protection Agency 200 S.W. 35th Street Corvallis, OR 97330	Specialty: emission factors
Hal Westberg Air Pollution Department Washington State University Pullman, Washington 99163	Specialty: ambient concentrations of biogenic hydrocarbons; emission factors
Patrick Zimmerman National Center for Atmospheric Research P.O. Box 3000 Boulder, CO 80307	Specialty: emission factors

March 21, 1980; updated April 10, 1980

Participants confirmed by telephone conversation.

Questionnaire Design

The goal of the Delphi survey was to obtain area-based emission factors for the 22 land cover classes. These factors were to be derived from emission factors based on grams of biomass and biomass densities (g/m2) for specified geographic areas. Because the remote sensing data set was organized into ecozones, it was decided to request biomass densities on the ecozone level.

Although the resource of a Delphi Panel should be used as much as possible in meeting the goal of a Delphi survey, caution must be exercised so as not to ask for a great deal of information on the questionnaires. The Delphi questionnaires must be simply designed so as not to give the panel members the impression that tremendous amounts of their time would be required to complete the questionnaire. With that limitation in mind, asking the Panel members for 22 emission rates for each ecozone under different light and temperature conditions was obviously not advisable. The information required from the Delphi Panel therefore had to be simplified.

The complicating factor of varying emission rates with changing environmental conditions such as light and temperature was avoided by limiting the scope of the biogenic inventory to one day. The biogenic inventory thus represented a "snapshot" in time of the annual emission rates. Aside from a desire to simplify the questionnaire, another important reason for focusing the inventory on only one day was that photochemical modeling used in air quality planning is based on the concept of a prototype day, i.e., a day (or days) in a recent base year on which high ozone levels were observed and for which extensive meteorological data have been collected [ABAG, et al., 1979b].

Once the decison was made to focus the biogenic inventory on one day, the question of which day had to be resolved. Because the ultimate purpose of preparing the biogenic inventory was to select the optimum emission control strategy for attaining and maintaining the ozone standard, and because high ozone levels are observed in the Bay Area during summer and fall [Sandberg, et al., 1980; MacKay, et al., 1977], the Delphi questionnaire asked for summertime emission rates (total non-methane hydrocarbon [TNMHC]) and biomass densities. The selection of a summer day also corresponded with the Landsat vegetation data file, which represented the vegetation distribution existing in the Bay area on August 6, 1976. Ideally, the biogenic inventory should have represented the same prototype day as was used in the photochemical modeling; however, for this project, such day-to-day correspondence was not possible because the vegetation data file was fixed; ABAG staff did not have the option of selecting Landsat imagery for a particular day of their choice. Although vegetation distribution is generally not dynamic, two vegetative types predominant in the Bay Area do tend to be dynamic -- grasses and wetlands, both of which are significant sources of biogenic emissions.

In order to further reduce the informational requirements of the questionnaire, it was decided that the questionnaire would ask for emission factors and biomass densities for the seven vegetation types; the 22 land cover classes were composed of varying percentages of these types (see Table 12). Therefore, an area-based emission factor for a land cover class could be computed by taking a weighted average of the area-based vegetation type factors, according to the percent composition of that class.

Although it was known at the start of the survey that emission factors for the vegetation types Grass, Aquatic, Marine, and Crops were measured on a per-unit-area basis -- and therefore were independent of biomass densities on the ecozone level -- the Round One questionnaire asked for emission factors for all seven vegetation types on a per-unit biomass basis, and for biomass densities on the ecozone level, to determine if the panelists could provide data that were more spatially refined than those appearing in the literature. The Round One questionnaire also asked for the participants' estimates of uncertainty in emission factors and biomass densities. Figure 12 presents the questionnaire used in Round One of the Delphi survey. The Round Two questionnaire was modified slightly from its predecessor based on the results of Round One.

Results of the Biogenic Emissions Delphi Survey

Round One of the Delphi Survey was conducted from April 23, 1980 to May 22, 1980. Approximately two weeks after mailing the first round of questionnaires, all the panelists were contacted by telephone to confirm their receipt of the Delphi Pamphlet and to insure a timely return of their responses. Of the eleven questionnaires mailed out, seven responses were received. On the average, the "emission factor" side of the questionnaire was about sixty percent complete, and the "biomass density" side was fifty percent complete.

Round Two questionnaires were sent out on June 6, 1980. Of the eight questionnaires distributed (three panelists of the original eleven withdrew), six were returned by the July 18, 1980 deadline. The emission factor side was about fifty percent complete on these.

The goal of the Delphi Survey was to produce a consensus of opinion on biogenic emission factors and foliar biomass densities for land cover classes in the Bay Area. It is important to note at this point that the numbers derived from this study represent a consensus of opinion, and may not represent the actual emission rates and biomass densities found in the Bay Area.

After two rounds of the Delphi Survey were completed, it was apparent that the responses of the panelists had clustered together; i.e., a consensus of opinion had developed. A typical Round Two response from the Delphi Panel was that the Round One results represented the best available data. For this reason, it was decided to cancel a planned Third Round of the Delphi Survey; only marginal improvements in the data could be expected from the investment of the considerable resources required to conduct another iteration of the Delphi Survey.

Table 14 summarizes the results of the ABAG Delphi Survey. The mean emission rates and biomass densities presented in Table 14 represent weighted averages based on the percent uncertainties assigned by the participants to their estimates, using statistical techniques described in Meyer (1975). In general, estimates with low percent uncertainties received greater weight in the averaging process. Because of the small sample sizes resulting from the Delphi Survey, any statistical treatment of the data should not be viewed as a rigorous analysis.

The percent uncertainties of emission rates and biomass densities given in Table 14 represent the standard error of the Delphi responses. It should be noted that the uncertainties in Table 14 are not the final estimates of uncertainty for the biogenic inventory: uncertainty changes when uncertain emission rates are combined with uncertain biomass densities.

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Example of Completed Questionnaire

Emission Factors

Vegetation Type	Your Best Estimate Of Summer Day Emission Factors (ug emission/hr-g leaf biomass)	Your Uncertainty In Estimate (± %)	References and Supporting Data for Your Estimate. If Applicable*
1. HARDWOOD	28.7	±50	EPA 1975, RTP
2. CONIFER	9.0	±25	Zimmerman, 1979
3. GRASS	etc.	etc.	etc.
4. BRUSH			
5. AQUATIC			
6. MARINE			
7. CROPS			

* Please use additional sheets if necessary.

Foliar Biomass Density by Ecozone

Vegetation Type	Your Best Estimate Of Foliar Biomass by Ecozone ± %Uncertainty (g leaf biomass/meter² area) Coast	Bay	Coastal Interior	Valley	Precipitation Correction (Specify units)	References And Supporting Data, If Applicable*
1. HARDWOOD	110 ± 8%	120 ± 15%	116 ± 30%	85 ± 10%	+25 %	[illegible] data base
2. CONIFER	23[illegible] ± 20%	136 ± 20%	110 ± 10%	95 ± 15%	0 %	Calif Dept. Forestry, 1974
3. GRASS	etc.	etc.	etc.	etc.	etc.	etc.
4. BRUSH						
5. AQUATIC						
6. MARINE						
7. CROPS						

* Please use additional sheets if necessary.

Figure 12

Table 14

SUMMARY OF BIOGENIC HYDROCARBON DELPHI SURVEY RESULTS

Vegetation Type	Emission Factor ±% Uncertainty	Foliar Biomass Density (g/m^2) ±% Uncertainty by Ecozone			
		Coast	Bay	Coast Int.	Valley
Hardwood	30 ug/g-hr ±20%	580±25%	500±25%	370±30%	260± 30%
Conifer	7 ug/g-hr ±10%	1000±25%	320±70%	350±20%	100±100%
Brush	6 ug/g-hr ±50%	275±60%	325±70%	250±80%	200± 60%
Grass	170 ug/m^2-hr ±50%	----	----	----	----
Aquatic	100 ug/m^2-hr ±25%	----	----	----	----
Marine	140 ug/m^2-hr ±20%	----	----	----	----
Crops	510 ug/m^2-hr ±40%	----	----	----	----

Section 5 -- Computation of Area-Based Emission Factors

Area-based emission factors and percent uncertainties were calculated for the vegetation types hardwood, conifer, and brush by multiplying the emission rates per gram biomass by the biomass densities. Emission rates for the remaining four vegetation types were already expressed in terms of area. The Delphi results summarized in Table 14 were used in these calculations. The percent uncertainties of the area-based emission factcrs were calculated using statistical techniques described in Meyer (1975).

The area-based emission factors for the 22 land cover classes were calculated by taking weighted averages of the area-based factors for the vegetation types, according to the percent composition of each land cover class as given in Table 12. Three sets of emission factors were prepared in this manner, according to the percent uncertainties in the area-based factors: low, medium and high. In other words, the percent uncertainty of each factor was used to compute absolute uncertainty, which was then added to the mean to get the "high" estimate, and subtracted from the mean to get the "low" estimate. After the three sets of factors were computed for the land cover classes, the difference between the medium and low, (or medium and high) values was divided by the median to arrive at percent uncertainty of the factors for the land cover classes.

Table 15 summarizes the daytime area-based emission factors and corresponding percent uncertainties by ecozone for the 22 land cover classes. The uncertainties in the factors ranged from 25% to 80%. Although the biogenic emissions inventory appears to be highly uncertain, it is not significantly less certain than a regional anthropogenic emissions inventory, the <u>minimum</u> uncertainty of which has been estimated as $\pm 25\%$ [National Academy of Sciences, 1974].

The data in Table 15 were found to be comparable in magnitude with area-based daytime total non-methane hydrocarbon (TNMHC) emission factors developed for broad land use categories by Zimmerman(1979a). Biogenic hydrocarbon emission rates have been observed to vary with a wide number of environmental parameters; in particular, temperature and light intensity have been shown to exert a strong influence on biogenic emission rates [Tingey, et al., 1978a and 1978b]. Consequently, in the literature, biogenic hydrocarbon emission rates are refined on a temporal scale of "day" and "night", reflecting different sets of light and temperature conditions.

Therefore it was decided that at least two sets of biogenic factors would be used in the 1982 Plan control strategy evaluation: "day" and "night." Because the Delphi Survey only provided "day" factors, the "night" factors were derived from Zimmerman's data (1979a), which report "day" and "night" emission factors for Land Use and Land Cover Data Analysis (LUDA) categories in terms of total non-methane hydrocarbons, paraffins, olefins and aromatics. These data were used to derive nighttime emission factors for the ABAG land cover classes in the following manner.

First of all, the ABAG land cover classes were correlated with the LUDA categories studied by Zimmerman. In many cases, the ABAG land cover classes were not uniquely identified by LUDA categories; e.g., the LUDA category entitled Deciduous Forest was assigned to the ABAG classes Hardwood Forest and Hardwood/Brush. Dividing the "night" TNMHC emission factor by the "day" TNMHC factor for each LUDA category computed the fraction of daytime emissions represented by the nighttime emissions. Multiplying this fraction by the daytime TNMHC factors obtained from the Delphi Survey produced nighttime TNMHC factors for the ABAG land cover classes. These data are shown in Table 16. In general, nighttime emissions are lower than daytime emissions because isoprene emissions are negligible at night and because monoterpene emissions are reduced at night due to lower air temperatures.

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Table 15

DAYTIME EMISSION FACTORS (ug/m2-hr) AND CORRESPONDING

PERCENT UNCERTAINTIES BY ECOZONE FOR LAND COVER CLASSES

E C O Z O N E

Land Cover Class	Coast		Bay		Coastal Interior		Valley	
Hardwood Forest	12400(ug/m2-hr)	±30%	12200(ug/m2-hr)	±30%	9000(ug/m2-hr)	±40%	6500(ug/m2-hr)	±40%
Hardwood Brush	3100 "	±40%	3200 "	±40%	2400 "	±50%	1900 "	±50%
Conifer Forest	6400 "	±30%	2400 "	±60%	3000 "	±30%	1000 "	±75%
Conifer Brush	1900 "	±50%	1300 "	±70%	1200 "	±60%	800 "	±60%
Hardwood/Conifer	10100 "	±30%	8800 "	±35%	6900 "	±40%	4600 "	±40%
Conifer/Hardwood	8300 "	±40%	6000 "	±35%	5100 "	±40%	3000 "	±50%
Grassland	190 "	±50%	200 "	±55%	190 "	±50%	190 "	±50%
Open Shrub	360 "	±60%	400 "	±60%	340 "	±70%	320 "	±60%
Brush	960 "	±60%	1100 "	±70%	880 "	±80%	790 "	±55%
Mixed Agricultural	460 "	±40%	460 "	±40%	460 "	±40%	460 "	±40%
Commercial Services & Industrial	560 "	±30%	430 "	±35%	360 "	±40%	230 "	±50%
Mixed Urban	1100 "	±30%	900 "	±40%	740 "	±40%	470 "	±45%
Low Vegetation Residential	1100 "	±30%	900 "	±40%	740 "	±40%	470 "	±45%
Moderate Vegetation Residential	2900 "	±30%	2500 "	±30%	2000 "	±40%	1400 "	±45%
High Vegetation Residential	5000 "	±30%	4500 "	±30%	3400 "	±40%	2400 "	±40%
Urban Open Space	6000 "	±30%	5000 "	±35%	4000 "	±40%	2700 "	±45%
Non-Forested Wetlands	160 "	±50%	160 "	±50%	160 "	±50%	160 "	±50%
Water	120 "	±25%	120 "	±25%	120 "	±25%	120 "	±25%
Shallow or Turbid Water	120 "	±25%	120 "	±25%	120 "	±25%	120 "	±25%
Salt Evaporation Ponds	130 "	±30%	130 "	±30%	130 "	±30%	130 "	±30%
Sand and Beaches	-0-		-0-		-0-		-0-	
Mixed Barren	-0-		-0-		-0-		-0-	
Clouds	-0-		-0-		-0-		-0-	

Table 16

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NIGHTTIME EMISSION FACTORS (ug/m2-hr) AND CORRESPONDING
PERCENT UNCERTAINTIES BY ECOZONE FOR LAND COVER CLASSES

	E C O Z O N E							
Land Cover Class	Coast		Bay		Coastal Interior		Valley	
Hardwood Forest	2800(ug/m2-hr)	±30%	2800(ug/m2-hr)	±30%	2100(ug/m2-hr)	±40%	1500(ug/m2-hr)	±40%
Hardwood/Brush	710 "	±40%	730 "	±40%	550 "	±50%	440 "	±50%
Conifer Forest	2400 "	±30%	890 "	±60%	1100 "	±30%	370 "	±75%
Conifer/Brush	700 "	±50%	480 "	±70%	440 "	±60%	300 "	±60%
Hardwood/Conifer	3000 "	±30%	2600 "	±35%	2100 "	±40%	1400 "	±40%
Conifer/Hardwood	2500 "	±40%	1800 "	±35%	1500 "	±40%	900 "	±50%
Grassland	95 "	±50%	100 "	±55%	95 "	±50%	95 "	±50%
Open Shrub	80 "	±60%	90 "	±60%	80 "	±70%	70 "	±60%
Brush	220 "	±60%	250 "	±70%	200 "	±80%	180 "	±55%
Mixed Agricultural	230 "	±40%	230 "	±40%	230 "	±40%	230 "	±40%
Services & Industrial	250 "	±30%	190 "	±35%	160 "	±40%	100 "	±50%
Mixed Urban	500 "	±30%	400 "	±40%	330 "	±40%	200 "	±45%
Low Vegetation Residential	500 "	±30%	400 "	±40%	330 "	±40%	200 "	±45%
Moderate Vegetation Residential	1300 "	±30%	1100 "	±40%	900 "	±40%	900 "	±45%
High Vegetation Residential	2200 "	±30%	2000 "	±30%	1500 "	±40%	1100 "	±40%
Urban Open Space	3000 "	±30%	2500 "	±35%	2000 "	±40%	1400 "	±45%
Non-Forested Wetlands	160 "	±50%	160 "	±50%	160 "	±50%	160 "	±50%
Water	120 "	±25%	120 "	±25%	120 "	±25%	120 "	±25%
Shallow or Turbid Water	120 "	±25%	120 "	±25%	120 "	±25%	120 "	±25%
Salt Evaporation Ponds	130 "	±30%	130 "	±30%	130 "	±30%	130 "	±30%
Sand and Beaches	-0-		-0-		-0-		-0-	
Mixed Barren	-0-		-0-		-0-		-0-	
Clouds	-0-		-0-		-0-		-0-	

Section 6 -- Summary of Major Assumptions and Conclusions

The data presented in Tables 15 and 16 represent area-based emission factors for the 22 land cover classes. It is appropriate to discuss the major assumptions on which these factors were based. First of all, it was assumed that the emission factors obtained from the Delphi Survey were representative of emission rates in the Bay Area. The Delphi results were provided by scientists who had directly measured emission rates in areas other than the Bay Area. The emission factors derived from the Delphi Survey were undoubtedly influenced by emission factors measured in other areas of the country, so whether they adequately represent real emission rates in the Bay area is unknown.

At least one scientist who has studied biogenic emission rates cautions against extrapolating his emission rate data to other areas of the country [Zimmerman, 1979b]. Unique species composition, soil fertility, moisture, and other environmental and meteorological conditions can cause local or regional emission factors to differ significantly from those found in the literature (or obtained from the Delphi Survey). On the other hand, some consistency in measured emission rates has been documented; for example, emission rates measured from oak trees in Florida (Tampa/St. Petersburg) were found to be approximately the same as those measured in California (Santa Barbara), using the bag-enclosure technique [Zimmerman, 1979b].

A second assumption was that the biomass densities obtained from the Delphi Survey were representative of those existing in the Bay Area. Some Delphi Panelists may not have been familiar enough with the Bay Area's climate and geography to accurately describe dry foliar biomass densities for different ecozones.

A third assumption was that the vegetation distribution derived from the remotely-sensed data accurately represented the vegetation distribution for the time period selected for the ozone control strategy evaluation. In other words, the vegetation distribution in the Region was assumed to have remained unchanged from 1976 to 1980.

Lastly, the emission factor assignment process was based on the assumption that the "day" and "night" emission factors derived from the Delphi Survey were representative of the temperatures and light intensities actually existing during the time period selected for ozone control strategy evaluation.

One currently unresolved issue is the behavior of LIRAQ when using biogenic hydrocarbon emissions as part of the input data. The photochemical reactivity of biogenic hydrocarbons is considerably different from that of the anthropogenic hydrocarbons upon which LIRAQ is based [Duewer, 1977]. Assigning biogenic hydrocarbons to LIRAQ input classes, which were developed for anthropogenic hydrocarbons, could be expected to have a significant impact on simulated ozone levels.

The principal recommendation for increasing the accuracy of the biogenic hydrocarbon emission factors is to embark on an extensive field program aimed at:

* measuring biogenic emission rates for the vegetation types identified from the remote sensing data

* measuring ambient levels of biogenic hydrocarbons at locations representative of the ABAG land cover classes

The purpose of the ambient monitoring would be to obtain data for comparing ambient biogenic levels with emission rates. Furthermore, in order to distinguish anthropogenic hydrocarbons from biogenic hydrocarbons in ambient samples, the ratio of carbon-14 to carbon-12 in the ambient samples should be measured. Because anthropogenic hydrocarbons result from combustion of fossil fuels, the ratio of carbon-14 to carbon-12 in anthropogenic emissions should be different from that found in hydrocarbons emitted by living vegetation.

The biogenic emission factors were perhaps the least accurate of the two major data bases used to prepare the ABAG biogenic hydrocarbon emissions inventory. This project has attempted to develop, in an open manner, a methodology for estimating biogenic hydrocarbon emission rates using the best available technical information. As better emission factor data become available, perhaps from future field studies in the Bay Area, they can be readily incorporated with ABAG's vegetation file to update the biogenic inventory. At best the project will produce an order of magnitude estimate of biogenic emissions; such an estimate was the best that could be made at the time, as alluded to in the following statement made by Hal Westberg (1977):

> "The lack of data on emissions of organic gases from various plants and the concentrations of organics in the atmosphere, while inadequate for determining the annual rate of such emissions for the world, are even less adequate for determining biogenic emissions from a particular region. Yet, it is precisely because of this lack of data that we must rely on crude approximations to provide information on the magnitude of biogenic hydrocarbon emissions."

The next chapter will detail the procedure used in compiling the biogenic hydrocarbon emissions inventory, using the emission factors whose derivation has been described above.

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CHAPTER 3

Chapter 3

COMPILATION OF THE BIOGENIC HYDROCARBON EMISSIONS INVENTORY AND PREPARATION FOR AIR QUALITY MODELING

Having modified the CDF classification and having derived emission factors for the land cover types in that modified classification scheme, the emissions inventory could be compiled. This chapter describes how these two data sets were integrated to produce a biogenic hydrocarbon emissions inventory for the Bay Area, and how that inventory was made compatible with input data requirements for the LIRAQ model so that the biogenic emissions could be employed in the evaluation of ozone control strategies for the Bay Area.

The first section of this chapter describes an emissions intensity map that was generated prior to compilation of the actual emissions inventory. Creation of the biogenic hydrocarbon emissions inventory is detailed in the second section. LIRAQ input data format requirements and the process that was employed in making the biogenic hydrocarbon emissions inventory compatible with LIRAQ are the subject of the third section. Results and conclusions regarding these topics are presented in the final section, followed by references for the chapter.

Section 1 -- ABAG Region Emission Intensity Map

Before the biogenic hydrocarbon emissions inventory was compiled, the vegetation file and emission factors were used to prepare Figure 13, a regional map of biogenic hydrocarbon emission intensities per unit area. The area-based daytime TNMHC (total non-methane hydrocarbons) biogenic emission factors assigned to the land cover classes were grouped into eight categories, each category representing one of eight shade codes on ABAG's computer. (While numerous shade codes were available, only eight were individually distinguishable on a small scale map such as the Emissions Intensity map.) Each category was assigned a shade representative of emission intensity. The darkest shade was used for the highest emission rate per unit area, and the lightest shade was used for the lowest emission rate per unit area. Two factors regarding the map are important to note:

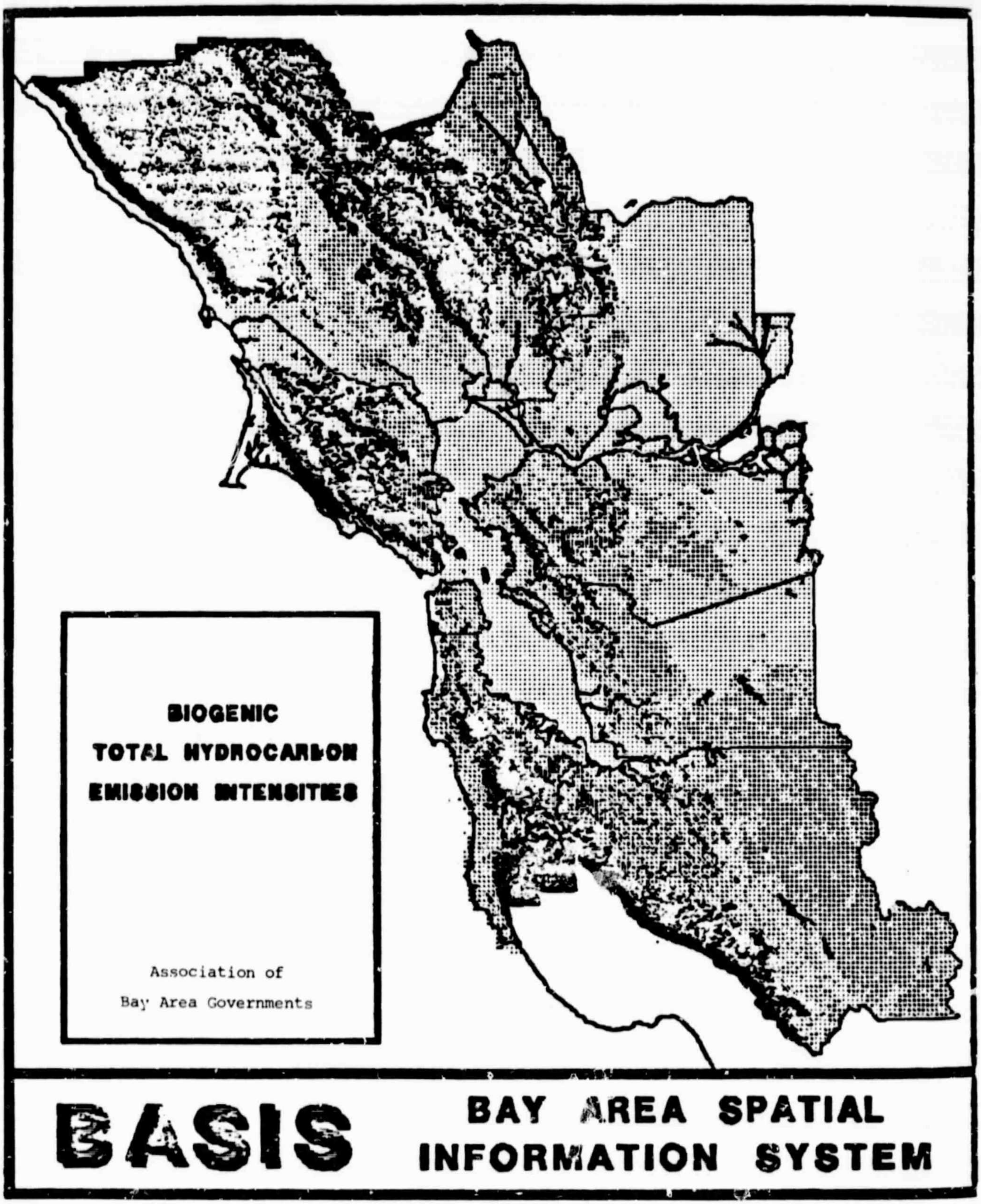

BIOGENIC
TOTAL HYDROCARBON
EMISSION INTENSITIES
Association of
Bay Area Governments
BASIS
BAY AREA SPATIAL
INFORMATION SYSTEM

Figure 13

* it does not represent the biogenic hydrocarbon emissions inventory because no emission rates (g/s) had yet been computed;

* no quantitative information on emission rates is presented in the map; i.e., the intensities of the shades are not directly proportional to the magnitudes of the emission factors.

The map is, however, useful in illustrating the geographic variation of relative biogenic hydrocarbon emission rates per unit area in the Region. For example, one point of interest is the large dark area in northern Sonoma County, where the land cover is primarily oak and coniferous forests. This particular section of the Region was expected to emit larger amounts of biogenic hydrocarbons than the lighter areas, such as the urbanized sections ·ound the Bay. One question that hopefully can be addressed in future LIRAQ modeling efforts is whether or not biogenic compounds emitted in northern Sonoma County can remain in the atmosphere long enough to react with nitrogen oxides in the San Francisco/Oakland area, and eventually form ozone. (This type of information will be generated when LIRAQ treats the entire region on a county-by-county basis.) Other strongly emitting areas, such as the Santa Cruz mountains, also exist in the Region but the Sonoma County area is perhaps the largest concentration of strong biogenic hydrocarbon emitters. A map such as Figure 13 is useful in trying to formulate a qualitative picture of biogenic hydrocarbon emission rates and in trying to understand their role in regional ozone production.

Section 2 -- Compilation of ABAG Emissions Inventory

Producing an emissions inventory, in terms of mass per unit time, from the two data sets -- land cover and emission factors -- was straightforward. The process involved direct multiplication of the area-based TNMHC emission factor for a particular land cover class in a particular location in the Region (ug/m2-hr) by the area covered by that class (m2), within a given hectare grid cell. A total emission rate for each hectare grid cell was calculated for each land cover class represented in that grid cell, and a running total was kept until the entire kilometer cell had been tabulated. (The use of 1-km cells was convenient for BASIS because although data sets were stored in hectare units, the Region was organized in BASIS by kilometer cells -- 100 hectares x 80 data levels for each 1-km storage cell.) The calculation was performed for both daytime and nighttime emission factors.

Additional calculations were required to prepare the inventory for input to LIRAQ; the remainder of this chapter describes that work.

C-2

Section 3 -- LIRAQ Requirements

The format of input data for LIRAQ varied, depending upon how the model was to be used. For the purposes of simulating daily ozone production on the regional level, the biogenic hydrocarbon emissions were disaggregated into LIRAQ hydrocarbon classes, and were expressed in terms of grams/second (g/s) for each 1-km x 1-km grid in the Region. Gridding emissions into 1-km x 1-km cells was possible because the vegetation file in BASIS was on a hectare (0.1-km x 0.1-km) level, and the data had only to be aggregated to represent the larger 1-km x 1-km cells. Presenting the emission rates in terms of grams/second represented only a unit conversion from ug/hr. The disaggregation of the emissions into the LIRAQ hydrocarbon classes was somewhat more difficult, and will now be discussed in detail.

At least two techniques for disaggregating the biogenic emissions were available. One method was to calculate a total non-methane hydrocarbon (TNMHC) emission rate for each 1-km x 1-km grid in the region, and then to split each grid's emissions into the LIRAQ input classes. A second available technique was to split the area-based emission factors (ug/m2-hr) into the LIRAQ hydrocarbon classes, and to calculate disaggregated emissions for each grid. The second method was selected because it involved fewer calculations. The current version of LIRAQ (LIRAQ 2S) required hydrocarbon emissions to be broken down into the following three hydrocarbon classes: HC 1 (mostly alkenes and some highly reactive aromatics); HC 2 (alkanes, simple aromatics, ethers, alchohols, etc.); and HC 4 (aldehydes and some ketones). (While an HC 3 class had initially been part of LIRAQ 2S, that class was no longer in use during the ABAG effort.)

Another version of LIRAQ (LIRAQ 4HC) was concurrently under consideration for use in the 1982 Plan; it required TNMHC emissions to be disaggregated into four classes:

* HC 1 (alkenes)
* HC 2 (alkanes, ethers, and alcohols)
* HC 3 (aromatics)
* HC 4 (mainly aldehydes and some ketones).

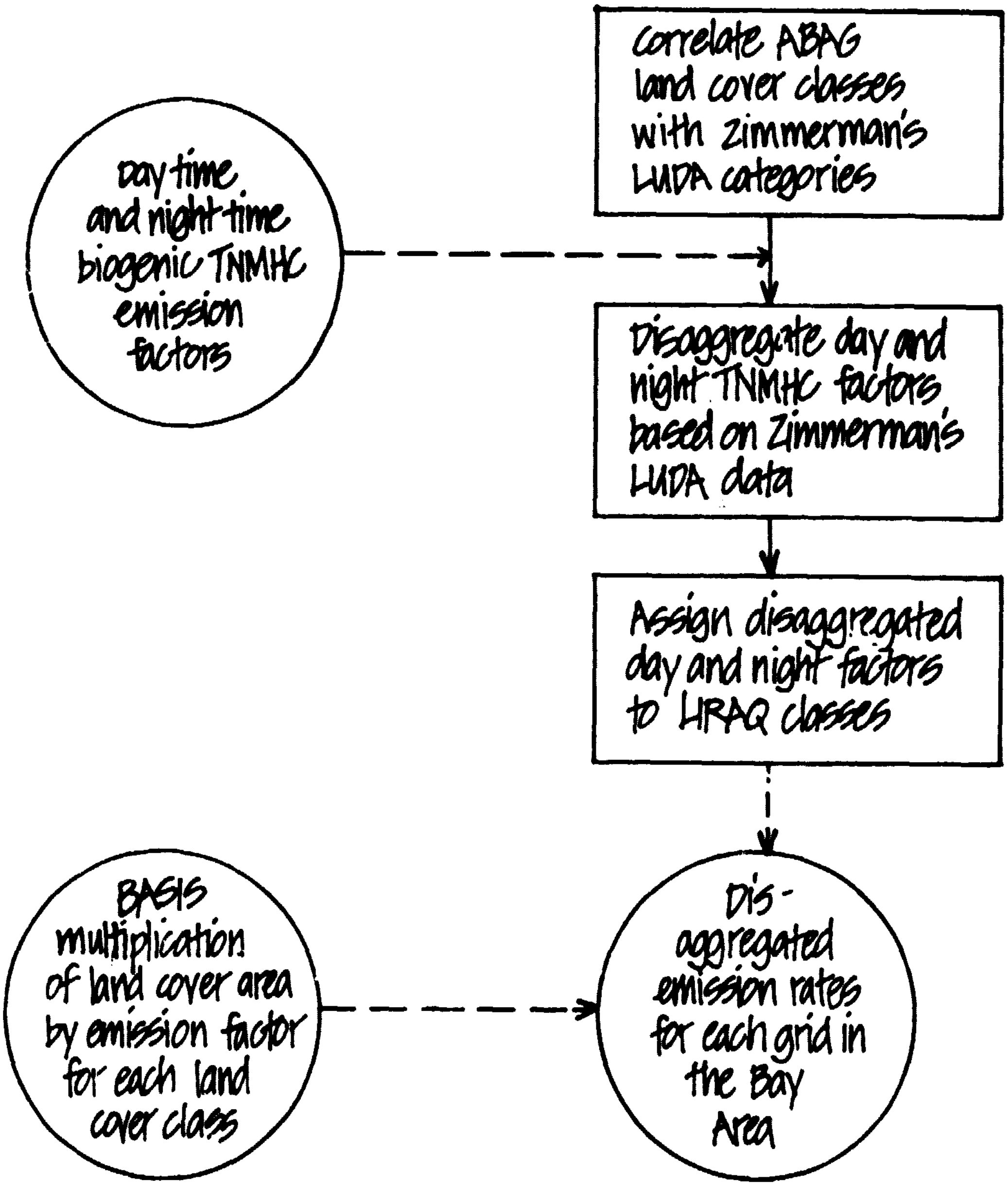
Note that the major difference between the two versions was the addition of a fourth hydrocarbon class consisting of pooled aromatics from the classes HC 1 and HC 2 of LIRAQ 2S. This chapter discusses the disaggregation of emissions as performed for both LIRAQ 2S and LIRAQ 4HC. Because no significant aldehyde and ketone emissions have yet been detected from biogenic sources, all the biogenic TNMHC emissions were disaggregated into the hydrocarbon classes HC 1 and HC 2 for LIRAQ 2S and into HC 1, HC 2, and HC 3 for LIRAQ 4HC.

LIRAQ requires twenty-four gridded one-hour hydrocarbon emission inventories in order to perform diurnal simulations of ozone production. Typically, the anthropogenic hydrocarbon emissions that are input to LIRAQ are varied on an hourly basis; however, the best available data on biogenic emissions rates are refined on a temporal scale of "day" and "night". Although a diurnal profile of biogenic emissions levels could be produced by using temperature/emission rate algorithms developed by Tingey, et al., (1978 a,b), such computer simulations were clearly beyond the scope of this project. Therefore, two sets of biogenic emission factors were used to prepare two biogenic inventories: day and night. The TNMHC emission factors for each had to be disaggregated into the LIRAQ hydrocarbon classes.

Zimmerman (1979) had measured day and night biogenic hydrocarbon emission factors for Land Use and Land Cover Data Analysis (LUDA) categories, which are broad-based land use classes similar to the ABAG land cover classes developed from the Landsat data. Zimmerman (1979) reported day and night emission factors for the LUDA categories in terms of TNMHC, paraffins, olefins (isoprene and terpenes) and aromatics. Zimmerman's data did not present emission rates for different compounds within each of these hydrocarbon classes, with the exception of the terpenes. Zimmerman's data for LUDA classes were used to disaggregate the ABAG daytime and nighttime TNMHC biogenic emission factors into hydrocarbon classes (paraffins, olefins and aromatics), as described in the following paragraphs.

Figure 14 presents a diagram of the process used in assigning the factors obtained from the Delphi Survey to LIRAQ hydrocarbon classes. The first step in the assignment scheme was to correlate the twenty-two ABAG land cover classes with the LUDA categories studied by Zimmerman. In many cases, the ABAG classes were not uniquely identified by LUDA categories. For example, the LUDA category entitled Deciduous Forest was assigned to the ABAG classes labeled Hardwood Forest and Hardwood/Brush.

Logic flow diagram for disaggregating TNMHC biogenic hydrocarbon emissions into LIRAQ hydrocarbon classes



Source: ABAG

Figure 14

The second step was disaggregating the TNMHC emission factors for day and night into paraffins, olefins and aromatics, based on the percent composition of the TNMHC factors for the LUDA classes. For example, the daytime THMNC emission factor for the LUDA Deciduous Forest category was composed of 9% paraffins, 68% isoprene, 16% terpenes, and 7% aromatics. The daytime TNMHC emission factors for the ABAG land cover classes labeled Hardwood Forest and Hardwood/Brush were multiplied by these percentages to produce the respective disaggregated emission factors.

The final step was to assign the paraffin, olefin, and aromatic emission factors to the appropriate LIRAQ hydrocarbon classes, and in so doing, to adjust the mass emission rates of each type of hydrocarbon to account for their photochemical reactivity. The following scheme was used to assign the daytime emission factors.

The paraffin emission factors were all assigned to the hydrocarbon class HC 2 for both versions of LIRAQ. The model assigns a photochemical reactivity representative of a "typical" alkane; i.e., the paraffin mass emission rate factors were not adjusted for photochemical reactivity. The olefin emission factors, expressed as isoprene and terpenes, were adjusted for their respective photochemical reactivities before assigning them to the HC 1 class. The adjustment was based on the maximum level of ozone produced by isoprene and terpenes at HC/NOx ratios in the 2.0 to 6.0 range [Personal communication, Joyce Penner, Lawrence Livermore Laboratory, November 26, 1980]. These data, collected by Gay, et al., (1977), were used because the ambient HC/NOx ratios used in the smog chamber studies of Gay, et al., are representative of the ambient HC/NOx ratios observed in the Bay Area [DeMandel, et al., 1979]. The more recent biogenic hydrocarbon photochemical reactivity data collected by Arnts, et al., (1979) were not used because they were collected at ambient HC/NOx ratios in the 30-200 range, which is much higher than those measured in the Bay Area. Propylene, which produced a maximum ozone level of 556 ppb, was chosen as the reference compound in the adjustment procedure. Isoprene emission factors were multiplied by 642/556 before assigning them to the HC 1 class (isoprene produced a maximum ozone level of 642 ppb). Terpene emission factors were multiplied by 303/556 before assigning them to the HC 1 class, where 303 is the average maximum ozone level in ppb produced by the terpenes p-cymene, myrcene, D-limonene, delta-carene, alpha-pinene, beta-pinene, and terpinolene.

For LIRAQ 2S, the aromatic emission factors were apportioned in the following manner: 90% were assigned to the LIRAQ Class HC 2 and 10% were assigned to the LIRAQ Class HC 1 [Personal communication, Joyce Penner, Lawrence Livermore Laboratory, November 26, 1980]. The mass emission rate factors were not adjusted for photochemical reactivity. For LIRAQ 4HC, all the aromatic emissions were assigned to the class HC 3.

The same general schemes were used to disaggregate nighttime emission factors except that terpene emission factors were reduced by an additional 15%, based on outdoor smog chamber data collected by Kamens (1980) [Personal communication, Joyce Penner, Lawrence Livermore Laboratory, November 26, 1980].

Once the disaggregated day and night emission factors (g/m2-sec) for each of the ABAG land cover classes were obtained, an ABAG computer program, described in the following paragraphs, was used to calculate the emission rates (g/s) of compounds in the LIRAQ classes for each 1-km x 1-km grid in the Bay Area.

Figure 15 presents the flowchart upon which the emission model is based. LIRAQ 2S requires four input vaues for each 1-km x 1-km UTM grid cell: HC 1 daytime, HC 2 daytime, HC 1 nighttime, and HC 2 nighttime (HC 4 emissions were assigned a value of zero). LIRAQ 4HC requires six input values for each grid cell: HC 1 daytime, HC 2 daytime, HC 3 daytime, HC 1 nighttime, HC 2 nighttime, and HC 3 nighttime (HC 4 emissions were again zero). For each hectare grid in the nine-county Bay Area, the model computed the required data by identifying the land cover classes in the grid, computing their area in the grid, and multiplying the appropriate emission factor by that area. The model then totaled the hectare emissions by square kilometer and entered them on magnetic tape along with the UTM coordinates of the kilometer grid cell. The magnetic tape was then forwarded to Lawrence Livermore Laboratory for input to LIRAQ.

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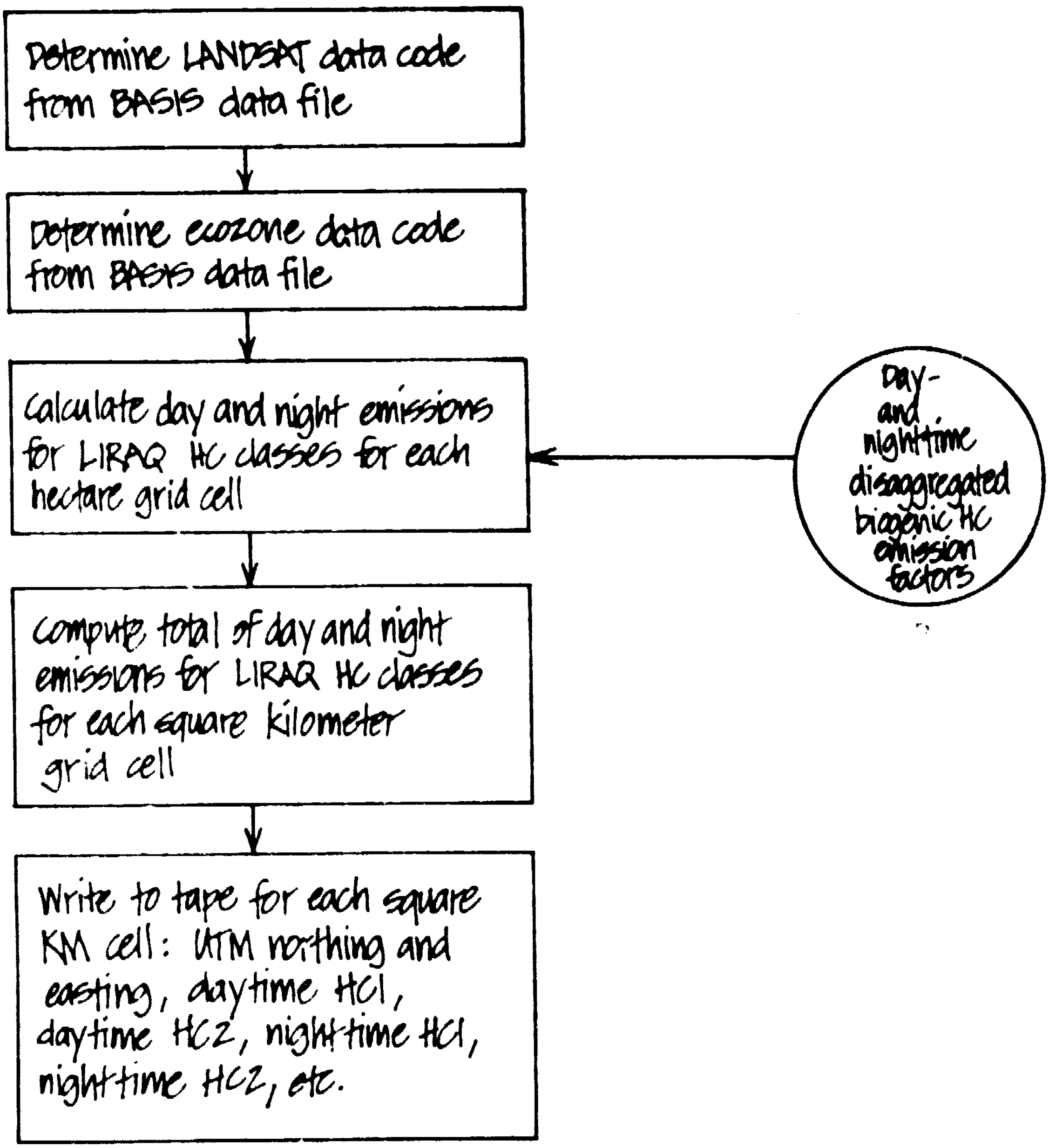
Development of Biogenic Emission Tape



Source: ABAG

Figure 15

Section 4 -- Results and Conclusions

Total non-methane hydrocarbon biogenic emissions in the nine county Bay Area for a 24-hour period of twelve hours of darkness and twelve hours of light were calculated to be 463 tons/day. For the LIRAQ input, approximately 30 percent of the total emissions were in the HC 2 class, and about 70 percent were in the more reactive HC 1 class.

As shown in Figure 3 (page 9), the air quality planning boundary of the BAAQMD defines a smaller region than the nine-county Bay Area. Therefore, the anthropogenic hydrocarbon inventory reported by the Bay Area Air Quality Management District represents a geographic region that is smaller than the nine-county Bay Area. Before comparing the magnitude of the biogenic inventory with that of the anthropogenic inventory, it must be established that the two inventories represent the same geographic area. Putting the biogenic inventory on the same spatial scale as the anthropogenic can best be done by summing emission rates from all the grid squares in the air quality planning region. Performing this calculation on a computer is straightforward, provided that a digitized map of the air quality planning region is available.

The uncertainty in the nine-county biogenic hydrocarbon emissions inventory has been calculated to be ± 50 percent. This calculation was founded on the uncertainties in the emission factors. The vegetation data also contributed a fixed, but unknown, fraction to the total uncertainty of the inventory. The value is unknown because the uncertainty of the land cover data could not be translated into emission rate uncertainties in a straightforward manner.

The true uncertainty, which reflects relative error, could be determined by physically measuring emission rates in the Region, and comparing them with those values used in this study. Alternatively, the uncertainty in the biogenic emission rates could be gauged by comparing the magnitude of the inventory with the total amount of fixed carbon in the Region [Personal communication, P.R. Zimmerman, National Center for Atmospheric Research, January, 1981].

The overall goal of this project was to assess the contribution of biogenic hydrocarbon emissions to regional ozone levels. This chapter described how the major piece of information needed to perform that task -- a regional, disaggregated and gridded biogenic hydrocarbon emissions inventory -- was prepared. The magnitude of the biogenic hydrocarbon emissions inventory is in itself insufficient information to assess the contribution of biogenic emissions to excesses of the ambient ozone standard. Ozone formation from hydrocarbons and nitrogen oxides is a highly complex process involving chemistry, meteorology, and geography. An initial LIRAQ inventory, however, showed that biogenic sources contributed .02 parts per million (ppm) of ozone. While biogenic sources comprised 38% of the total hydrocarbon emissions in the area, the geographic location of the biogenic sources prevented their contributing more than the .02 ppm cited above. ABAG investigations have recently reported a simulated ozone maximum of .17 ppm of ozone in the Bay Area, while the current Federal standard is a maximum of .12 ppm. Consequently, it is imperative that additional photochemical modeling of the biogenic inventory occur in the future, using either LIRAQ 2S or LIRAQ 4HC. The results of these modeling efforts will provide the information needed to develop ozone control strategies in a technically sound manner.

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CHAPTER 4

Chapter 4

CONCLUSIONS

Introduction

The purpose of this final chapter is to present conclusions drawn by the participants of this project. In it, the objectives will be reiterated and the ways in which those objectives were addressed will be examined. Both positive and negative aspects of each topic will be discussed, and conclusions will be presented which identify modifications that the participants would have made to the project design, having viewed it retrospectively.

It is important to note that no final results regarding the role played by biogenic hydrocarbon emissions in contributing to overall ozone production in the Bay Area can be presented because air quality modeling with LIRAQ is on-going at this time. ABAG air quality planners can provide additional information to interested parties. These conclusions will therefore address the primary objectives with regard to the processes preparatory to running LIRAQ on the biogenic inventory data, but can present only preliminary results regarding the outcome of that modeling effort.

ATTAINMENT OF PRIMARY OBJECTIVES

The project's primary objectives were twofold, the first being to investigate the role of biogenic hydrocarbon emissions in contributing to overall ozone production in the Bay Area and attempt to identify the significance of that role. This objective was to be addressed by first generating a land cover inventory for the area, then by assigning emissions factors to the land cover types identified in that inventory, followed by compiling a biogenic hydrocarbon emissions inventory based on the land cover and emissions data, and lastly by submitting that emissions inventory to an existing air quality model.

The decision to use a pre-existing Landsat classification was guided by the need to explore the utility of this concept within the context of overall CIRSS goals. Those goals are addressed in the section pertaining to secondary objectives. The second primary objective, which related to training, is addressed in Section 2.

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Section 1 -- Attainment of First Primary Objective

A. CREATION OF LAND COVER DATA SET

The decision to use a pre-existing Landsat classification as the basis of the project's required land cover inventory was predicated on the need for expediency. This need was dictated by impending deadlines and requirements related to ABAG's participation in air quality planning efforts. The use of a pre-existing data set also satisfied the CIRSS objective of investigating the vertical data integration concept. The fact that the classification selected had been developed as part of an unrelated project imposed several limitations (due to the nature of the data set) on the land cover inventory generated by ABAG, but provided two benefits as well.

The first of these benefits accrued from the preservation of the original CDF spectral clusters in digital form. Had these original clusters not been preserved, the ABAG project would have been dependent upon a classification grouped into information categories and those categories would have been at some variance from the land cover types comprising the ABAG classification scheme. The second of these benefits accrued from the fact that comparisons between ABAG identification of a spectral class and CDF identificaton of the same class were possible; this provided participants with a means of cross-checking their class identifications which would normally would have been based solely on photointerpretation and ancillary data -- a cross-checking capability that does not exist when an original classification is being generated.

On the other hand, several characteristics of the CDF classification made adaptation of that data to the needs of the ABAG project more difficult. A discussion of these characteristics follows.

A four-year time lag existed between conditions represented in the satellite data and conditions observed on the ground during the ABAG field work, because the Landsat data used in the CDF classification was acquired (by the satellite) in 1976 while the ABAG project was conducted largely in 1980. The passage of those four years saw land use and land cover changes in the Bay Area, particularly in areas of urban expansion. The ABAG land cover inventory needed to reflect those changes. Stratification and urban modeling were able to effect some improvement in the classification but were time-consuming processes. Future investigation may demonstrate that projects, particularly those focused on urban areas, will show more accurate and cost-effective results when the acquisition date of the remotely-sensed data employed is in close proximity to project start-up and field work dates.

The CDF land cover inventory, being a statewide classification, contained less detail than was needed by the ABAG project, which focused upon a much smaller geographic area. While a single urban category sufficed for the CDF effort, the intended use of the land cover data by ABAG for additional projects required a minimum of five urban categories. A relatively small proportion of these categories, over the entire ABAG study area, were obtained during re-identification (relabeling) of the CDF spectral clusters, and stratification and urban modeling were required to develop most of the needed urban detail.

In addition, the digitized ecozone boundaries utilized in the CDF project were generalized during delineation and digitization, and ABAG discovered that this generalization was too extreme given the size of their study area and their objectives. Urban classes appeared in mountains, while vegetation types associated with higher elevations appeared in the urban areas due to imprecision in the digitized ecozone boundaries. Due to the statewide nature of the CDF project, and due to time and cost constraints in that project, the more generalized boundaries may have been acceptable for CDF objectives, but were insufficiently precise for the more localized ABAG project. ABAG therefore re-digitized the ecozone boundaries for purposes of the BHEI compilation, and digitized boundaries for the urban area prior to performing urban modeling on the land cover data set.

A third characteristic of the CDF classification that required ABAG modification was the confusion that had been left unresolved between some of the CDF spectral classes. This factor also relates to the respective level of detail required by the two projects: when dealing with millions of acres, confusion between two spectrally-similar cover types or confusion that appears in spatially-scattered areas may be attributed little or no importance in the overall classification, whereas that same confusion can be much more obvious and extensive (proportionally) when a smaller geographic area is treated. While every effort had been undertaken to minimize confusion of this sort in the CDF classification process, these class conflicts had to be resolved before the data could be employed in generating a biogenic hydrocarbon emissions inventory. This confusion was resolved by ABAG through stratification.

A major factor, however, that made the CDF classification difficult to adapt to the ABAG objectives pertained to the respective focus or nature of the two projects -- particularly with respect to the clustering that had been performed. The process of developing spectral clusters from Landsat data involves decisions on the part of the digital analyst, and those decisions are guided by the information classes being sought. The fact that the spectral clusters developed during the CDF project were aimed at identification of forest cover types -- with very little emphasis on urban areas -- dictated that major modifications be performed in the ABAG project to make the classification more suitable to ABAG objectives. This approach has limitations because the analyst is constrained by the amount of information inherent in the pre-existing clusters; there is greater latitude (in information class development) during clustering than in relabeling or in stratification. While the use of a pre-existing classification saved a great deal of time for the ABAG project, there was a marked trade-off between this expediency and the achievement of urban and vegetation classes suited to the assignment of emission factors.

Another major factor was the result of constraints imposed on the CDF classification: due to deadlines, the CDF project was unable to select optimized dates or to employ multi-temporal classification techniques. These limitations were reflected in the accuracy of the classification.

Once the land cover data had been modified, the resulting data set did provide a satisfactory input to the biogenic hydrocarbon emissions inventory and to other environmental planning efforts. ABAG has used the land cover data, within BASIS, for several other applications to date. Experience in these modeling efforts has demonstrated that the land cover data set is more accurate than the verification and evaluation (V & E) results indicate, which has further strengthened the conclusions that were drawn regarding the reliability of the V & E results as represented by the regression table.

When viewing the project retrospectively, several project design alternatives that would have provided a more timely and cost-effective method for creating the required land cover inventory were identified. First, field work should have been completed before any digital processing, particularly the relabeling of spectral classes, was performed so that PI keys could have been generated, and so that familiarity with the data and the area could have been gained. Secondly, registration to the UTM map base should have been the first digital process undertaken, followed by spectral class identification and stratification of clouds. Re-digitized ecozone boundaries and ungrouped spectral classes should then have been sent to ABAG for integration into BASIS, where all stratifications should have been conducted using urban modeling techniques. Only then should the data have been grouped. The fact that grouped data was transferred to ABAG severely limited the classification improvements made by the urban modeling that was performed on BASIS and further limited ABAG's ability to provide an accurate, proven site-specific data set for spin-off uses. In addition, two sets of test sites should have been used: one for PI and field work, and a second set for verification and evaluation.

B. EMISSION FACTOR ASSIGNMENT

The assignment of emission factors to the land cover types was performed by conducting a Delphi Survey of ABAG-identified experts in the biogenic hydrocarbon emissions field, when a review of available literature on the subject yielded no suitable data pertinent to Bay Area land cover types. The specific combination of conditions (vegetation, climate, etc.) governing emission of biogenic hydrocarbons prevent the use of generalized, i.e. nationwide, emission factors. While the Delphi approach proved to be the most satisfactory technique for identifying appropriate emission factors for Bay Area cover types (given project constraints), the Survey should have included a larger number of participants. Additional participants were, however, not available because there were too few people who considered themselves experts in the field of Bay Area Biogenic Hydrocarbons. The procedure of choice, as previously stated, would have been to gather emissions data using field techniques described in Chapter 2, but that procedure was judged to be too time-consuming and costly to have been a viable option within the context of the project. The emission factors rendered by the Delphi Survey were, nonetheless, superior to anything available to ABAG at the time and provided information that can be used in the future to refine the technique of emissions assignment. In addition, the emission factors comprised two data base layers (daytime factors and nighttime factors) that could be updated and revised at any time.

C. COMPILATION OF BIOGENIC HYDROCARBON EMISSIONS INVENTORY

The emissions inventory was compiled on ABAG's geographic information system, BASIS, which is a UTM-based system with 100-meter grid cells. As a consequence the modified CDF land cover data, which was comprised of nominal 80-meter cells registered to a Lambert Conic Conformal projection, had to undergo registration to the UTM map base and resampling to 100-meter grid cells. A significant expenditure of time and computer resources was required to perform this registration. The process, although lengthly, was accomplished with satisfactory results. There is, however, a loss of precision that occurs whenever resampling is performed. Control points employed in the ABAG registration effort were selected from the unclassified registered CDF data, which had undergone resampling from the original Landsat 57- x 79-meter pixels to 80-meter square pixels during registration. A better registration for the ABAG project could probably have been achieved using the JPL control points (employed in the registration to Lambert) and a piecewise transformation. To do so would have required the used of VICAR, however, and in addition the control points were poorly documented because no follow-on use for the data was anticipated. These factors precluded the use of this registration method.

The biogenic hydrocarbon emissions inventory that was compiled on BASIS used the land cover data for determination of the areal or spatial extent of emissions, whose degree was dictated by the emission factors assigned to each land cover type. The accuracy of the emissions inventory was therefore dependent upon the accuracy of the land cover data set. No quantitative accuracy assessment has been performed on the emissions inventory, since no "control" is available. The only statement that can be made, therefore, is necessarily qualitative in nature and based on the subjective, observed accuracy of the land cover data and the uncertainties defined for the emission factors by the Delphi panel. The emission factors are perhaps less accurate than the land cover data set, but represent the best data available at the time.

D. INPUT OF BIOGENIC HYDROCARBON EMISSIONS INVENTORY TO LIRAQ

As described in Chapter 3, the emissions inventory underwent modification in order to make it compatible with LIRAQ input data requirements. Those modifications involved translation from the ABAG 100-meter grid cells to the LIRAQ 1-km grid cells. As previously described, that translation was accomplished by a process termed disaggregation. This process was straightforward and no problems were encountered. The disaggregation resulted in emission rates by percent composition of each square kilometer and as such effectively performed a smoothing of the land cover data. Due to project time constraints, no accuracy assessment was performed to evaluate whether the smoothing was beneficial or detrimental to accuracy. It should be noted, however, that if two classes confused with one another in the land cover inventory were assigned the same emission factor, there effectively would remain no confusion in the emissions data set for the areas of those classes -- an issue regarding which further investigation could prove fruitful.

Section 2 -- Attainment of Second Primary Objective

The second of the two primary objectives was to train ABAG personnel in the remote sensing analysis techniques involved in generating and using the land cover inventory. This objective was to be addressed by ensuring full ABAG participation in all aspects of the land cover inventory creation, the ultimate goal being to provide ABAG with that land cover data for use in future applications.

ABAG's involvement in the creation of the land cover data set took the form of participation in workshops for each phase of the processing. ABAG personnel, after introductory sessions on the basics of digital image processing and photointerpretation, did participate in all phases of the data set creation. ABAG personnel, along with TGS staff, re-identified and relabeled the CDF spectral clusters, performed stratification to eliminate confusion between information classes, selected and digitized control points for registering the data to UTM, did field checking of verification and evaluation test sites, and created photo products. In addition, ABAG personnel performed all of the photointerpretation of test sites for the V & E phase. With minimal technical assistance from NASA and TGS personnel, ABAG staff performed the urban modeling that was done on BASIS.

The level of ABAG participation in the project was facilitated by the proximity of the ABAG and NASA/Ames offices/facilities. Conducting the necessary field work was also simplified by that proximity and by the location of both agencies within the study area, making multiple field trips feasible and cost-effective.

The fact that the land cover data has successfully been integrated into BASIS and employed by ABAG in other environmental planning efforts -- without the assistance of NASA and TGS personnel -- provides additional evidence that the project's training objective was met. Another objective relative to training, however, emerged during the project. An effort was made to acquire and install ELAS (which had previously been brought up on a Varian computer) at ABAG, but technical difficulties and budgetary constraints arose. The intent was for NASA and TGS to train ABAG personnel in Landsat data analysis using ELAS, to provide ABAG with operational capability. Although the effort was abandoned when ABAG acquired a microcomputer (smaller than the Varian) upon which ELAS installation had never been implemented, Geogroup (a private consultant to ABAG) has recently acquired both BASIS and hardware capable of supporting ELAS. Geogroup consequently re-initiated inquiries concerning acquisition of ELAS in April of 1982.

ATTAINMENT OF SECONDARY OBJECTIVES

The secondary objectives of the project were of a more general nature and addressed concerns of the CIRSS Task Force, under whose auspices the project was conducted. The first of these objectives involved investigation of the concept of vertical data integration, which was defined by the CIRSS Task Force as follows:

> Vertical Data Integration refers to the general compatibility of data formats, classification methods, and encoding routines whereby data collected within a geographical area by one level of government and its associated agencies can be selectively incorporated into the geo-based information systems of many other levels of government and their associated agencies with minimal data manipulation or reformatting.

This concept was tested both by integration of the Landsat-based land cover data into BASIS, and by integration of the biogenic hydrocarbon emissions inventory data into LIRAQ. Both involved integration of data developed by one level of government into the another agency's GIS: CDF data integrated into BASIS, and BASIS data integrated into Lawrence Livermore's LIRAQ. Both geo-based information systems existed before the land cover data set was generated.

The CIRSS definition of vertical data integration includes the condition "with minimal data manipulation or reformatting". This condition was clearly met with regard to the ease with which the biogenic hydrocarbon emissions inventory was modified for entry into LIRAQ; the integration of the modified CDF data into BASIS met this requirement as well, but the difficulty with which the CDF data was modified to meet the needs of the ABAG project constitutes a deviation from this concept.

Those difficulties were largely attributable to the fact that the CIRSS vertical data integration effort was not considered in the CDF project design. When the CDF project was being conducted, the continued vertical data integration efforts as now visualized by the CIRSS Task Force were not forseen. Had the CDF project been conducted with an eye toward future integration of the classification with other data bases and other applications, the ecozone boundaries could have been more carefully selected and digitized, the classification could have been iteratively refined until information class conflicts had been resolved, and the verification/evaluation efforts could have been more concentrated so that the accuracy of the classified product was better defined. Furthermore, massive quantities of information -- particularly printouts generated during digital processing -- emerged during CDF classification of the entire state, and record-keeping was not geared toward subsequent use of the information in an unrelated project. Consequently, records of digital processing undergone by the CDF data set, such as control point information, proved to be difficult to locate during the ABAG project. Had follow-on use been anticipated, better records could have been kept.

These modifications in CDF project design could have been implemented without changing the focus of the classification -- the project need not have concentrated additional effort on identification of urban classes, for example -- but would have required a greater expenditure of time and money. The difficulties with which ABAG used the CDF classification have therefore demonstrated the value of a coordinated approach to multi-agency or statewide use of common remotely-sensed data sets.

Costs associated with the ABAG project are presented in Table 17.

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Table 17

ESTIMATED RESOURCE UTILIZATION AND COSTS

PERSONNEL

	Hours	Cost (Overhead not included)
ABAG		
R. Moreland	860	
M. Gilmour	300	
D. Hunsaker	150	
P. Wilson	6	
D. Olmstead	55	
ABAG Subtotals:	1371	$24,815.
NASA/Ames		
D. Sinnott	100	
S. Norman	50	
NASA Subtotals:	150	$ 3,300
TGS		
E. Fosnight	700	
C. Carson-Henry	500	
G. Forde	60	
TGS Subtotals:	1260	$17,278

COMPUTER SUPPORT

	CPU Seconds	Connect Minutes	Cost	Software Packages Utilized
ABAG				
Varian V76[1]	72,000	2,040	$2,144	BASIS
NASA/Ames				
IBM 360/67[1]	6,228	-----	$1,400	Utilities
HP 3000/III	.... not available			IDIMS
SEL 32/77	.... not available			CIE[2], ELAS[3], ILEX[4]
BBN[5]				
PDP 10	787	744	$ 140	EDITOR[6]

1 All programs run in batch mode.
2 CIE: Classified Image Editor; software written at Ames.
3 ELAS: Earth Resources Laboratory Applications Software.
4 ILEX: Software package containing program to make Versatec plotter maps.
5 BBN: Bolt, Beranek, and Newman in Boston, Massachusetts.
6 EDITOR: ERTS Data Interpreter and TENEX Operations Recorder; software package supported by USDA.

APPENDIX A

Appendix A

THE ABAG REGISTRATION PROCESS

The purpose of this appendix is to provide detailed documentation of the process used in registering the modified CDF land cover data to the UTM map grid. Several aspects of the registration process are specifically addressed at a level of detail that was inappropriate for inclusion in Chapter 1: criteria for control point selection and the technique used for entering the selected points, criteria and techniques employed during development of the regression equations, and information regarding the application of the regression equations to the registration problem. Listings of the control point coordinates and their root mean square (RMS) errors are also presented for the actual control points used in the the ABAG registration effort.

Selection of Control Points

As discussed in Chapter 1, registration requires the development of a mathematical model which will allow the calculation of coincident pixel positions in the image for every grid cell in the map base. That is, the coincident pixel location in the image must be found for every position, P, in the map base.

The mathematical mapping may be developed from: 1) a mathematical model of the differences between the image and the map space (due to curvature of the earth, variation in scan speed, and the skew which results from the rotation of the earth under the satellite platform during imaging of the scene), from 2) polynomial regression equations or least-square approximations, or from 3) a combination of the the first two methods. The geometry of the CDF data had been modified by JPL's pre-classification processing (addressed in Section 1 of Chapter 1), precluding development of a valid mathematical model as in the first option. Least-squares polynomial regression equations were therefore developed for registering each of the six 1-degree quads to the UTM map base.

The development of least-squares regression equations requires control points that represent coincident locations in the image and on the map base. Several standard criteria for control point selection were applied during the identification of coincident points for the ABAG project. Among these were:

1. The locational accuracy of selected points. The control points must at the very least be selected with the same accuracy as the accuracy desired for the final registered data file.

2. The importance of spatial distribution of control points. An even spatial distribution over the entire area to be registered, particularly near the edges, greatly enhances the chance of obtaining a good registration. Ideally control points will even be selected outside the study area.

3. The minimum number of points. The number of control points must always be greater than the number of coefficients in the polynomial equation. (For example, a first-order equation requires a minimum of three control points, and a second-order equation requires a minimum of six.)

4. "Overselection" of points. Selection of a large number of points usually improves the quality of the registration. Overselection also allows for point deletion without that deletion having an adverse effect on overall distribution.

In order to provide a well-distributed set of control points, less-than-optimally located points may need to be included. Generally, given a well-distributed set of control points and a set which contains a sufficient number of extra points, the root mean square (RMS) errors generated during computation of the equations will either be negligible or their source will be detectable.

Three types of features normally provide good control points: water bodies, agricultural fields, and cultural features such as road intersections. The use of water bodies, however, can provide inaccurate control points if the Landsat data represents a drought year while the map information does not, as was the case in the ABAG project. Agricultural fields must be used with caution in control point selection because although they can provide sharp high-contrast points, variation in field patterns due to seasonal or annual crop changes can be the source of locational confusion. The value of orthophoto quad sheet maps for registration work cannot be emphasized too heavily, particularly when fields are being used for control points.

The ABAG control point selection process was conducted with these considerations in mind. A large number of points were selected to allow for deletion of bad points without adversely affecting the quality of the point distribution.

Control point selection began with the generation of grey scale maps on ILEX; these maps were employed in the identification of potential control points in the image. Originally, grey scale maps of Landsat Band 7 were printed for all the 1-degree by 1-degree quads and the approximate location of potential control points was noted. Those points were then used as center points for 70- x 70-pixel 1:24,000 grey scale maps, a sample of which appears as Figure 1. However, although Band 7 (one of the infrared bands) was excellent for determining water boundaries, it did not compare well with the orthophoto quads being used; features that were recognizable on the Band 7 maps looked very different on the orthophoto quads. The green band (Band 5) proved to be more satisfactory for determining coincident points in regions of natural vegetation. The difference between the Band 7 maps and the orthophoto quads was attributable to the date of the two information sources: the Landsat data represented 1976 conditions, while most of the orthophoto quads represented 1970 conditions. In addition, 1976 was a drought year while 1970 was not, causing very different shorelines for lakes and reservoirs between the two dates. Locating approximate control points on small grey scale maps proved not to be necessary. A sufficiently dependable set of well-distributed control points was able to be located by simply printing an even distribution of 70- x 70-pixel maps and selecting one control point from each.

The control point selection procedure used in the ABAG project can be summarized as follows:

1. Grey scale maps were generated at 1:75,000 for each 1-degree by 1-degree quad, to be used for orientation;

2. An even distribution of center points was selected across the area in which control points were desired;

3. 70- x 70-pixel 1:24,000 grey scale maps of the area surrounding each center point were printed;

4. The area represented by each 1:24,000 map was located on the 1:75,000 grey scale map to aid orientation on the orthophoto quads (this step was aided in several areas by mosaicking several of the orthophoto quads to facilitate recognition of larger features);

5. Sharp high-contrast coincident points were then located on both the 1:24,000 grey scale maps and the orthophoto quads (this step was facilitated by printing the 1:24,000 grey scale maps on translucent paper and by flickering the grey scale maps over the orthophoto quads);

6. Lastly, once the coincident points were located, each point was carefully marked on both the grey scale map and the orthophoto quad, and the line/sample coordinates of that point were recorded.

Figure 2 illustrates the set of control points used in the ABAG registration process.

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Sample of Grey Scale Map Used for Control Point Selection

CATEGORIES	CATEGORY ASSIGNMENTS																			
1- 20	39	39	39	39	39	39	39	39	39	39	39	39	39	39	39	39	39	39	39	39
21- 40	39	39	38	37	35	33	31	29	27	25	23	22	21	20	19	18	17	16	15	14
41- 60	13	13	12	12	11	11	11	10	10	10	9	9	9	9	8	8	8	8	7	7
61- 80	7	7	6	6	6	6	5	5	5	5	5	4	4	4	4	4	3	3	3	3
81- 86	3	2	2	2	2	2														

SCALE = 24000.0, HORZ. PIXEL SIZE = 80.00, VERT. PIXEL SIZE = 80.00

CONTROL POINTS SAN FRANCISCO EAST BAND 5

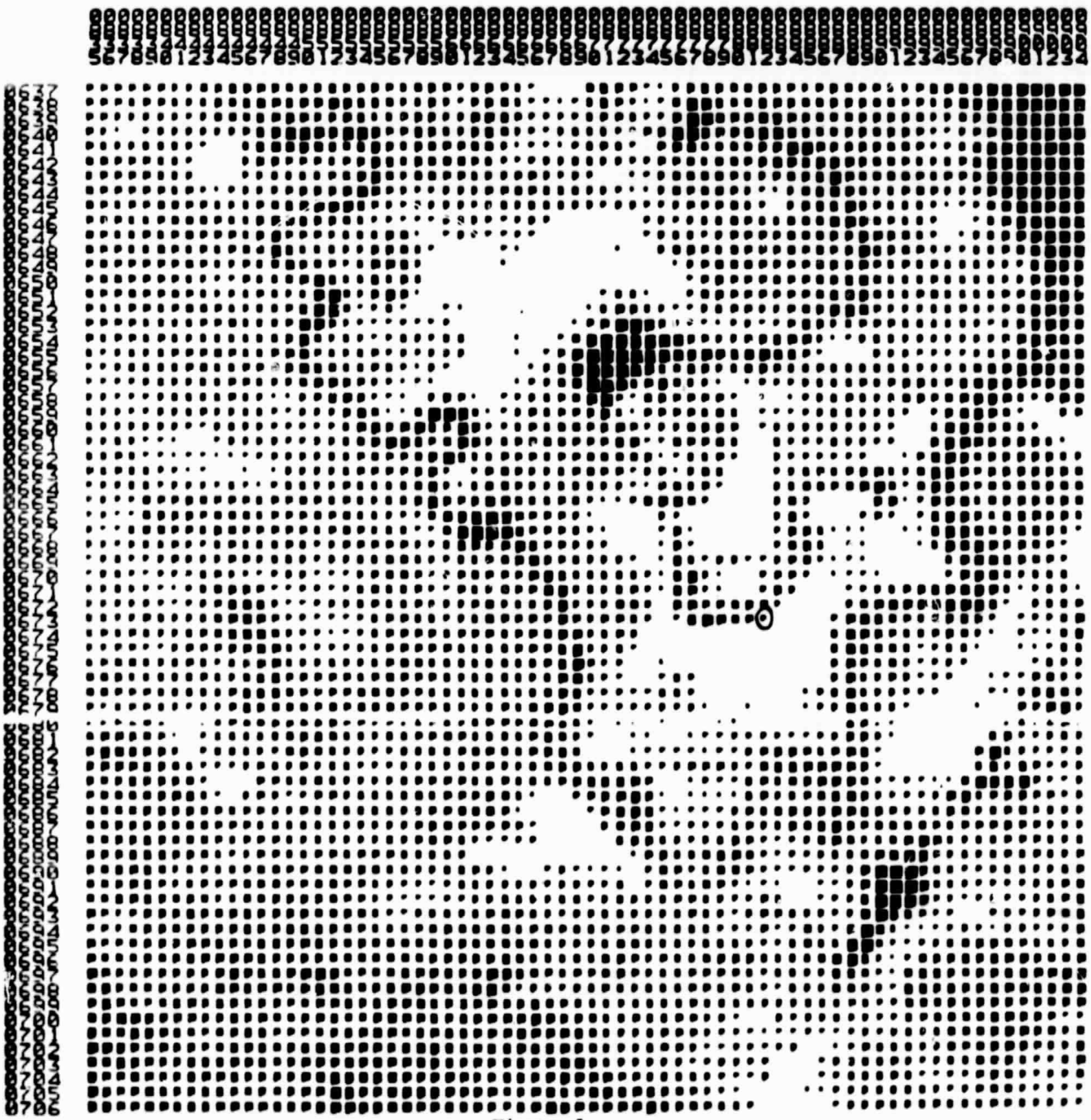

Figure 1

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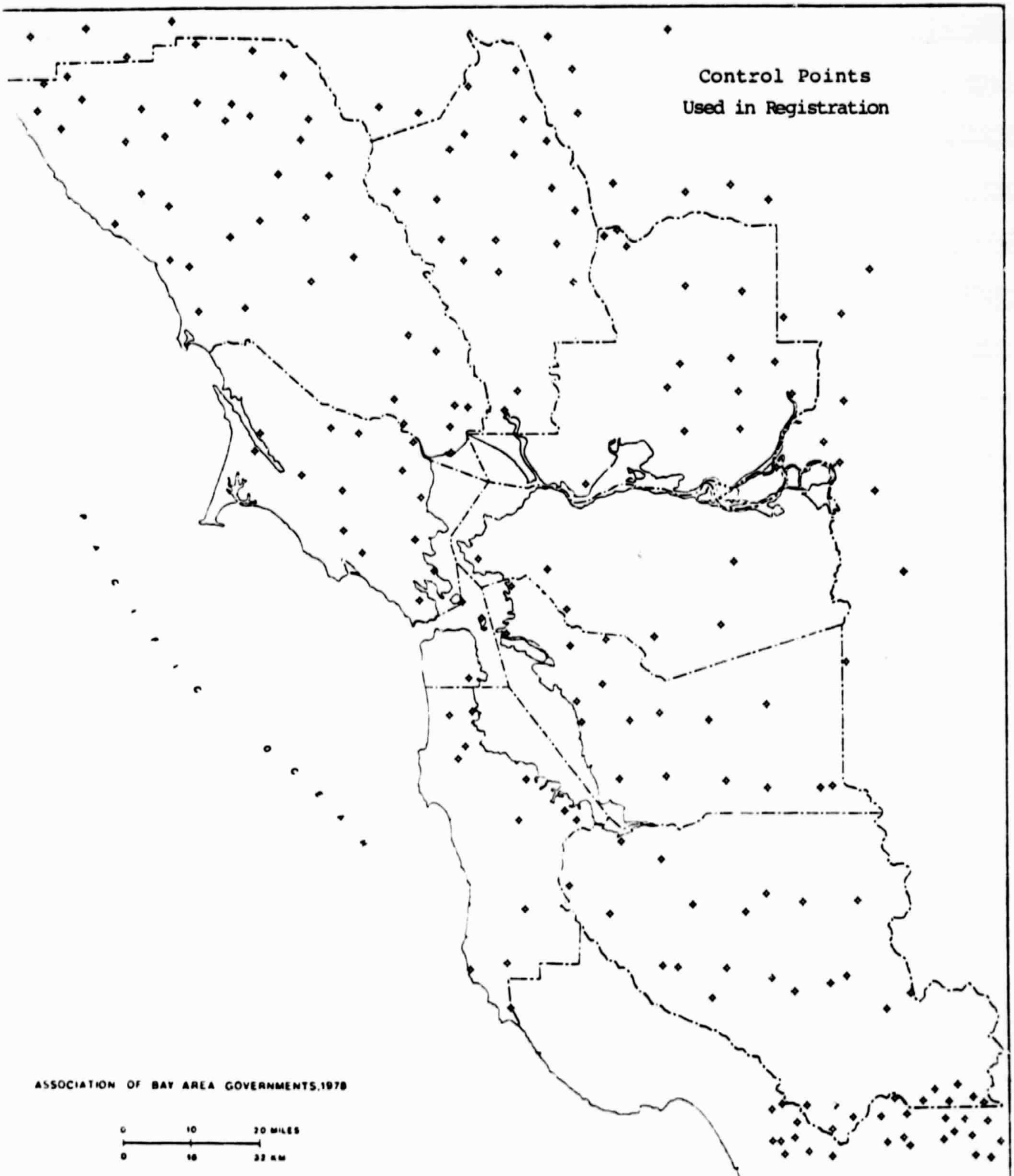

Figure 2

Digitization of Control Points

The EDITOR analysis system was used to enter the control points into the computer. The latitude/longitude coordinates were entered using an X-Y digitizer and the following process:

1. An orthophoto quad was mounted on the digitizier;

2. The four corner points were digitized and latitude/longitude coordinates for the NW and SE corner points were entered to orient the orthophoto quad to the digitizer bed;

3. A control point on the orthophoto quad was digitized with the latitude/longitude being calculated by EDITOR, based on the latitude/longitude entered for the corner points;

4. The line/sample coordinates for the control point were entered on the terminal;

5. Steps 3 and 4 were cycled through until all control points on a given map had been digitized;

6. The map was removed from the digitizer and Steps 1-5 were repeated on another map, until all control points had been entered.

This procedure was followed until control point files had been created for all six 1-degree quads.

Development of Regression Equations

After creating a file of the control points, first-degree regression equations were developed to evaluate the control points. The EDITOR system, employed in generating the ABAG equations, includes control point analysis modules that allow the root mean square (RMS) error for the entire set of points to be calculated. When that RMS error is unsatisfactory, RMS errors for individual control points can be listed. The listing can be generated in the order of the magnitude of the individual RMS errors, simplifying the detection of points with extreme RMS errors. The software then allows modification or deletion of those points, followed by recalculation of the RMS error for the set of remaining points. This capability enables iterative editing until satisfactory RMS errors are obtained.

For the ABAG project, a maximum RMS error of 1 pixel was sought, since errors of less than one pixel represent the accuracy desirable for most applications. When a coordinate varied by several pixels, it was assumed that an erroneous line/sample or latitude/longitude coordinate had been entered for that point. Further evaluation was performed for points with high RMS errors, in an attempt to identify the source of the error.

Control point plots were created, consisting of vectors -- one for each control point -- the tail of which denoted the actual spatial position of the control point in the image, and the head of which marked the spatial position of the same point in the image as calculated by the regression equations based on the latitude/longitude coordinates. The plots served to identify points whose coordinates were suspect. Of even more importance, this technique facilitated detection of patterns among the control points, which in turn indicated the the possible existence of localized distortions that had not been mitigated by the equation. Inspection of RMS errors and creation of control point plots identified erroneous points and suggested the source of error, but point editing decisions were based on manual evaluation of those points -- a discussion of which follows.

Several factors, originating in either the selection process or in entry of the point coordinates into the computer, can be the source of high RMS errors:

* The line/sample coordinates may have been digitized erroneously.

* The line/sample coordinates and latitude/longitude coordinates may not be coincident. This can occur if the points are not identified precisely in the Landsat data or on the map.

* Local distortion may exist in the imagery from which control points were selected.

Erroneous digitizing can be tested for by comparing a listing of the digitized control point coordinates with the line/sample coordinates recorded during control point selection. Comparing these coordinates to the approximate position of the control point on the orthophoto quad may further illuminate the source of error.

Coordinates that are not actually coincident can be identified by comparing the orthophoto quad to the grey scale map from which the point was selected. An inability to correctly locate the selected point in the image, among similar features in its vicinity, can cause this sort of error. An inability to identify well-defined and high-contrast points that allow for the precise determination of both the X and Y coordinates of the point being selected can also result in identification of point coordinates that are not coincident.

Points exhibiting high RMS errors were evaluated with these factors in mind. Errors caused by erroneous digitizing or identification of non-coincident coordinates are attributable to human error and were ameliorated by editing and/or redigitization. When neither of these techniques rectified the inaccuracy, a new control point was selected. Errors due to local distortion in the parent image, on the other hand, are rectifiable only by deletion of the point. It is important to note, however, that even if the "bad" point can be deleted without adversely affecting the overall distribution of points, the source of the error (distortion) will remain intrinsic to the data. It is therefore preferable to retain such points in order to maximize registration in the area of the distortion, even though high RMS errors will appear for the point when regression equations are being developed. This type of distortion appeared in the Santa Rosa East 1-degree quad, generating higher-than-desirable RMS errors. The distortion was probably attributable to the use of inaccurately-located control points in the registration to Lambert Conic Conformal. (ABAG control points were selected from the Lambert-registered image.) After all possible measures had been taken to improve RMS errors for this quad, the overall error remained high because the inherent image distortion could not be modeled by the regression equation. A piecewise re-registration of the distorted area would have been the procedure of choice for rectifying the distortion, but was precluded by project deadlines and budget constraints. While the piecewise re-registration could have been accomplished on VICAR using the original JPL control points, deadlines would have been detrimentally affected by its use due to the complexity of VICAR as installed at Ames.

Listings of the ABAG control point coordinates and RMS errors appear as Tables 1 through 6. Comparison of the RMS errors for the Santa Rosa East quad with those of any other quad will demonstrate the distortion (reflected by the RMS errors) detected in Santa Rosa East.

Once obvious errors had been identified and resolved during control point evaluation and editing, higher-order equations were computed for the control points.

The procedure utilized in the ABAG project can be summarized as follows:

1. A first-degree regression equation was developed for use in an initial evaluation of each control point file;

2. The first-degree regression equation was output to an oblique calibration (OCAL) file to be used as input for calculating higher-degree equations;

3. A second-degree equation was developed for use in registration and final evaluation of control points;

4. The second-degree equation was output to a precision calibration (PCAL) file, which required the input of the OCAL file. (The PCAL file is the calibration file required by EDITOR).

5. The PCAL file was used to create a precision calibration (PRECIS) file which would later be used to transform the modified CDF image to the UTM projection;

6. The PRECIS file -- which contained the coordinates of the input data, the calculated coordinates of the registered output data, and the coefficients of the second-degree equations for each quad -- was transferred to the IBM-360 system at Ames, where the registration program to be utilized resided.

Originally, third-degree regression equations were developed for the ABAG data. The registration program allowed use of only second-degree equations, so the third-degree equations were discarded.

Registration of the Land Cover Data to the UTM Grid

Once the PRECIS file had been created for each quad, the registration procedure was straightforward. The following is a summary of the registration procedure that was employed in the ABAG project:

1. The input land cover data was subsectioned, using the CLIPCAT program on the IBM 360/67, so that it contained only the area defined by the PRECIS file;

2. The clipped land cover data file was then converted into ILLIAC-IV format;

3. The program NINDEX was run on the ILLIAC, using the PRECIS file to create an Index File which contained X and Y shift values for each pixel in the clipped land cover data;

4. The subsectioned land cover data and the Index File were then input to the NREFORM program on the IBM 360. NREFORM created a registered output data set, using the X and Y shift values from the Index File to determine correct placement in the UTM coordinate system for each pixel.

5. The UTM land cover data from NREFORM, which was in ILLIAC format, was converted to byte format (one byte per pixel) for use on IDIMS.

This procedure was followed for each of the six 1-degree quads. Once the land cover data was registered to the UTM map base, it was ready for additional processing and analysis.

SAN FRANCISCO EAST

CONTROL POINTS

PAIR	LAT	LON	ROW	COL
1	37.97836	122.66780	136.0	370.0
2	37.94341	122.64350	181.0	404.0
3	37.96362	122.52160	137.0	530.0
4	37.91675	122.47470	194.0	589.0
5	37.92465	122.36560	168.0	703.0
6	37.88228	122.30760	217.0	772.0
7	37.87118	122.51370	261.0	555.0
8	37.91163	122.20450	163.0	880.0
9	37.77914	122.24550	345.0	857.0
10	37.73156	122.15820	329.0	952.0
11	37.84558	122.17180	248.0	927.0
12	37.80037	122.32150	328.0	770.0
13	37.83048	122.37650	296.0	707.0
14	37.79607	122.07700	299.0	1040.0
15	37.67730	122.15550	470.0	975.0
16	37.64177	122.14670	520.0	993.0
17	37.72297	122.10530	401.0	1022.0
18	37.64503	122.03780	498.0	1110.0
19	37.54305	122.05720	640.0	1105.0
20	37.49391	122.03470	702.0	1139.0
21	37.43536	122.05340	784.0	1128.0
22	37.32280	122.09230	944.0	1106.0
23	37.13115	122.29800	1236.0	910.0
24	37.22688	122.31150	1107.0	885.0
25	37.19270	122.39720	1167.0	799.0
26	37.33207	122.26810	957.0	914.0
27	37.36947	122.18020	892.0	1003.0
28	37.48665	122.15010	729.0	1015.0
29	37.49795	122.17860	719.0	982.0
30	37.46522	122.26740	775.0	892.0
31	37.54104	122.26360	673.0	882.0
32	37.60614	122.40230	605.0	722.0
33	37.58070	122.40980	641.0	718.0
34	37.66805	122.38010	517.0	734.0
35	37.66226	122.44310	535.0	668.0
36	37.75175	122.37540	402.0	723.0
37	37.72714	122.41180	442.0	689.0
38	37.85282	122.41760	271.0	659.0

Table 1

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SAN FRANCISCO EAST

```
                     LINE        SAMPLE        METERS

RMS ERRORS:          0.916       1.238         100.8            38 CTL PTS.
<<S
 PAIR   ROW      COL     RERROR   CERROR   METERS
  23  1236.0    910.0     0.02    -3.62     205.
  12   328.0    770.0    -1.15    -2.85     185.
   9   345.0    857.0    -1.87    -1.82     180.
  16   520.0    993.0     1.64     1.95     170.
  10   329.0    952.0    -1.86    -1.24     163.
  11   248.0    927.0     1.70     0.42     136.
MORE? (Y OR N) N
<<D
MAXIMUM ABSOLUTE ACCEPTABLE ERROR? (>0.0) 2
CPS DELETED... 12 23
  2 PAIRS DELETED,  36 OR  94.7% LEFT.
                     LINE        SAMPLE        METERS

RMS ERRORS:          0.920       0.879         88.1             36 CTL PTS.
```

Table 1

(continued)

SANTA ROSA WEST

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CONTROL POINTS

PAIR	LAT	LON	ROW	COL
1	38.86424	123.53426	266.0	527.0
2	38.85596	123.58605	286.0	473.0
3	38.78431	123.51477	372.0	560.0
4	38.92476	123.47114	175.0	584.0
5	38.91270	123.40520	182.0	656.0
7	38.77879	123.33886	357.0	745.0
8	38.86860	123.07649	199.0	1009.0
9	38.84347	123.04070	228.0	1051.0
10	38.81071	123.18350	292.0	906.0
11	38.84647	123.43848	277.0	631.0
13	38.73465	123.01238	373.0	1099.0
14	38.67860	123.12297	465.0	991.0
15	38.72041	123.15475	413.0	950.0
16	38.65719	123.18068	503.0	933.0
17	38.73840	123.30998	409.0	782.0
18	38.69701	123.34549	470.0	752.0
19	38.54521	123.08201	642.0	1057.0
20	38.44878	123.09371	773.0	1060.0
21	38.43713	123.04344	783.0	1115.0
22	38.57222	123.16859	617.0	960.0
23	38.50838	123.19524	705.0	941.0
24	38.37088	123.01860	868.0	1152.0
25	38.71148	123.40196	455.0	692.0

```
                      LINE        SAMPLE        METERS

RMS ERRORS:           0.800       1.702         115.4            25 CTL PTS.
<<S
 PAIR    ROW      COL     RERROR   CERROR   METERS
   6    237.0    779.0    -1.18     6.73     393.
  25    455.0    692.0    -1.94     2.18     197.
  12    383.0    703.0     0.73    -2.81     169.
  13    373.0   1099.0    -1.35     0.48     110.
   2    286.0    473.0     1.34     0.19     107.
  17    409.0    782.0     0.69    -1.59     105.
MORE? (Y OR N) N
<<D
MAXIMUM ABSOLUTE ACCEPTABLE ERROR? (>0.0) 6
CPS DELETED... 6
  1 PAIRS DELETED,  24 OR  96.0% LEFT.
                      LINE        SAMPLE        METERS

RMS ERRORS:           0.771       0.820          76.6            24 CTL PTS.
```

Table 2

SANTA ROSA EAST

ORIGINAL PAGE IS
OF POOR QUALITY

	LAT	LON	ROW	COL
1	38.51545	122.16578	692.0	980.0
2	38.55848	122.21789	642.0	922.0
3	38.51777	122.13174	684.0	1015.0
4	38.63089	122.28905	553.0	830.0
5	38.70426	122.26348	450.0	844.0
6	38.67052	122.21426	489.0	905.0
7	38.71592	122.15635	419.0	959.0
8	38.50125	122.04653	694.0	1109.0
9	38.58120	122.08354	591.0	1054.0
10	38.76882	122.18575	350.0	917.0
11	38.84261	122.21922	255.0	867.0
12	38.77377	122.28095	357.0	813.0
13	38.67761	122.39210	503.0	709.0
14	38.75101	122.40984	406.0	678.0
15	38.65498	122.45440	542.0	646.0
16	38.58978	122.39721	623.0	719.0
17	38.54149	122.48831	701.0	630.0
18	38.56458	122.57047	681.0	539.0
19	38.15689	122.72601	1256.0	447.0
20	38.15558	122.64086	1247.0	540.0
21	38.49061	122.34761	752.0	792.0
22	38.43066	122.34643	833.0	805.0
23	38.49635	122.09951	708.0	1053.0
24	38.47889	122.02992	722.0	1130.0
25	38.44984	122.43612	819.0	706.0
26	38.49226	122.47564	766.0	653.0
27	38.71744	122.51570	466.0	571.0
28	38.72711	122.62268	468.0	456.0
29	38.46504	122.67190	830.0	449.0
30	38.60858	122.71999	643.0	372.0
31	38.76892	122.84538	442.0	214.0
32	38.49183	122.94689	535.0	151.0
33	38.50933	122.87710	801.0	224.0
34	38.60834	122.84278	662.0	243.0
35	38.51835	122.77300	773.0	333.0
36	38.81054	122.89036	392.0	159.0
37	38.12366	122.88095	1321.0	284.0
38	38.03362	122.50271	1393.0	710.0
39	38.08735	122.53271	1323.0	668.0
40	38.14304	122.87443	1294.0	288.0
41	38.65891	122.78020	583.0	300.0
42	38.69112	122.75964	536.0	317.0
43	38.21045	122.56294	1161.0	614.0
44	38.16914	122.55212	1216.0	633.0
45	38.13480	122.52077	1258.0	671.0

Table 3

ORIGINAL PAGE IS
OF POOR QUALITY

SANTA ROSA EAST

46	38.16601	122.42363	1202.0	770.0
47	38.21272	122.41787	1138.0	768.0
48	38.12753	122.42758	1255.0	771.0
49	38.21453	122.38964	1131.0	797.0
50	38.13273	122.25117	1224.0	959.0
51	38.22916	122.28485	1098.0	909.0
52	38.15423	122.34292	1207.0	856.0
53	38.37558	122.92325	989.0	198.0
54	38.06555	122.13551	1300.0	1095.0
55	38.41418	122.75759	911.0	364.0
56	38.29893	122.47567	1029.0	690.0
57	38.93208	122.61984	190.0	423.0
58	38.33743	122.55935	989.0	593.0
59	38.04336	122.68831	1405.0	509.0
60	38.07429	122.78825	1376.0	395.0
61	38.42975	122.15617	808.0	1005.0
62	38.47798	122.19391	746.0	957.0
63	38.54894	122.96478	539.0	99.0
64	38.68798	122.95014	500.0	109.0
65	38.62729	122.88686	507.0	177.0

Table 3

(continued)

SANTA ROSA EAST

ORIGINAL PAGE IS
OF POOR QUALITY

```
                       LINE       SAMPLE      METERS

RMS ERRORS:           0.759       1.782       117.5            63 CTL PTS.
<<S
 PAIR    ROW      COL     RERROR   CERROR   METERS
   2    642.0    922.0     1.09     4.69     279.
   7    419.0    959.0     0.86     3.91     231.
   6    489.0    905.0     0.96     3.65     221.
  37   1321.0    284.0    -1.37    -2.90     197.
  57    190.0    423.0     0.69    -3.24     192.
  63    539.0     99.0    -0.83     3.11     188.
MORE? (Y OR N) N
<Q
<CI
RANGE? (L,H) 63,63
SOURCE OF IMAGE COORDS? (? FOR LIST) T
ARE IMAGE COORDS OBLIQUE TRANSFORMED? (Y OR N) N
POINT 63...IMAGE ROW COL?
<CI                              500 100
RANGE? (L,H) 51,51
POINT 51...IMAGE ROW COL? 1000 900
<AN
REGISTRATION
<<S
 PAIR    ROW      COL     RERROR   CERROR   METERS
  51   1000.0    900.0   -97.49    -5.93    7715.
  63    500.0    100.0   -39.83     4.11    3158.
   2    642.0    922.0     1.09     4.69     279.
   7    419.0    959.0     0.86     3.91     231.
   6    489.0    905.0     0.96     3.65     221.
  37   1321.0    284.0    -1.37    -2.90     197.
MORE? (Y OR N) N
<<D
MAXIMUM ABSOLUTE ACCEPTABLE ERROR? (>0.0) 30
CPS DELETED... 51 63
  2 PAIRS DELETED,  63 OR  96.9% LEFT.
                       LINE       SAMPLE      METERS

RMS ERRORS:           0.760       1.712       114.1            63 CTL PTS.
<<S
 PAIR    ROW      COL     RERROR   CERROR   METERS
   2    642.0    922.0     1.11     4.71     281.
   7    419.0    959.0     0.86     3.81     227.
   6    489.0    905.0     0.98     3.59     217.
  37   1321.0    284.0    -1.41    -2.93     200.
  55    911.0    364.0    -0.88    -3.01     184.
  57    190.0    423.0     0.63    -3.11     183.
MORE? (Y OR N) Y
  40   1294.0    288.0    -1.28    -2.48     173.
  53    989.0    198.0     1.75     1.42     160.
  15    542.0    646.0    -0.73    -2.56     156.
  32    835.0    151.0     1.94    -0.18     154.
  64    500.0    109.0    -0.20     2.63     150.
   9    591.0   1054.0    -0.31    -2.31     133.
MORE? (Y OR N) Y
  33    801.0    224.0     1.43     1.23     133.
  17    701.0    630.0    -0.63    -2.16     132.
  24    722.0   1130.0    -1.05    -1.76     130.
  10    350.0    917.0    -0.26     2.21     127.
  43   1161.0    614.0    -0.07     2.20     125.
  34    662.0    243.0     1.49     0.52     121.
MORE? (Y OR N) N
```

Table 3

(continued)

SACRAMENTO WEST

ORIGINAL PAGE IS OF POOR QUALITY

CONTROL POINTS

PAIR	LAT	LON	ROW	COL
1	38.85278	121.92274	351.0	120.0
2	38.03955	121.47830	1386.0	746.0
3	38.44362	121.49042	840.0	654.0
4	38.56586	121.91421	737.0	182.0
5	38.57651	121.82136	710.0	278.0
6	38.55568	121.70982	720.0	400.0
7	38.40724	121.91201	952.0	215.0
8	38.36741	121.54055	950.0	615.0
9	38.28691	121.89691	1114.0	252.0
10	38.35365	121.68000	990.0	470.0
11	38.26033	121.69167	1119.0	475.0
12	38.24328	121.95594	1182.0	197.0
13	38.17351	121.90808	1270.0	262.0
14	38.27814	121.79978	1110.0	358.0
15	38.23470	121.78607	1168.0	379.0
16	38.16820	121.78735	1260.0	390.0
17	38.21382	121.66404	1179.0	513.0
18	38.15502	121.66854	1259.0	520.0
19	38.10068	121.69069	1336.0	507.0
20	38.10354	121.56681	1313.0	639.0
21	38.20382	121.54715	1173.0	640.0
22	38.13428	121.59305	1276.0	604.0
23	38.06015	121.82810	1411.0	369.0

	LINE	SAMPLE	METERS	
RMS ERRORS:	.0.729	0.894	76.7	23 CTL PTS.

<<S

PAIR	ROW	COL	RERROR	CERROR	METERS
1	351.0	120.0	1.30	1.55	135.
17	1260.0	390.0	1.43	-1.26	134.
2	1386.0	746.0	-0.38	2.12	124.
7	952.0	215.0	-0.94	1.22	102.
14	1110.0	358.0	-1.20	0.65	101.
18	1179.0	513.0	1.06	-0.70	93.

MORE? (Y OR N) N

Table 4

SAN JOSE WEST

ORIGINAL PAGE IS
OF POOR QUALITY

CONTROL POINTS

PAIR	LAT	LON	ROW	COL
1	37.92685	121.80530	235.0	229.0
2	37.90524	121.35910	198.0	714.0
3	37.80422	121.99600	429.0	57.0
4	37.84118	121.84360	356.0	211.0
5	37.75097	121.54820	437.0	543.0
6	37.66280	121.97060	616.0	111.0
7	37.67810	121.86410	579.0	222.0
8	37.54230	121.95850	778.0	143.0
9	37.50748	121.61940	778.0	513.0
10	37.51720	121.58470	760.0	549.0
11	37.36396	121.89030	1011.0	246.0
12	37.34057	121.64110	1007.0	523.0
13	37.35705	121.73720	999.0	415.0
14	37.20859	121.58940	1174.0	602.0
15	37.21793	121.54860	1156.0	645.0
16	37.22473	121.72790	1179.0	449.0
17	37.20774	121.67890	1193.0	506.0
18	37.19858	121.85050	1233.0	321.0
19	37.23004	121.82650	1186.0	341.0
20	37.22560	121.93360	1207.0	226.0
21	37.23565	121.97470	1199.0	180.0
22	37.35323	121.51310	972.0	658.0
23	37.35006	121.38420	957.0	800.0
24	37.34322	121.77010	1023.0	381.0
25	37.40286	121.98620	971.0	137.0
26	37.52476	121.83280	783.0	282.0
27	37.51150	121.72490	786.0	399.0
28	37.68488	121.72640	552.0	367.0
29	37.16866	121.30580	1189.0	920.0
30	37.13464	121.34668	1242.0	882.0

Table 5

SAN JOSE WEST

ORIGINAL PAGE IS
OF POOR QUALITY

	LINE	SAMPLE	METERS	
RMS ERRORS:	1.478	1.361	140.0	30 CTL PTS.

<<5

PAIR	ROW	COL	RERROR	CERROR	METERS
14	1174.0	602.0	-4.37	-0.07	346.
15	1156.0	645.0	-3.50	0.06	277.
1	235.0	229.0	0.73	-4.22	246.
7	579.0	222.0	-1.57	2.46	187.
25	971.0	137.0	-1.56	-2.08	171.
18	1233.0	321.0	1.99	0.97	167.

MORE? (Y OR N) SA\A\SN

<<SA

PAIR	ROW	COL	RERROR	CERROR	METERS
14	1174.0	602.0	-4.37	-0.07	346.
15	1156.0	645.0	-3.50	0.06	277.
1	235.0	229.0	0.73	-4.22	246.
7	579.0	222.0	-1.57	2.46	187.
25	971.0	137.0	-1.56	-2.08	171.
18	1233.0	321.0	1.99	0.97	167.
11	1011.0	246.0	-0.69	-2.68	162.
23	957.0	600.0	1.83	0.05	144.
16	1179.0	449.0	1.76	0.55	143.
3	429.0	57.0	1.44	1.12	131.
22	972.0	658.0	1.56	-0.69	129.
26	783.0	282.0	-1.59	0.45	128.
2	198.0	714.0	-1.46	0.78	123.
10	760.0	549.0	1.39	-0.83	120.
28	552.0	367.0	0.35	1.90	111.
9	776.0	513.0	1.07	-1.23	110.
19	1188.0	341.0	1.36	0.35	109.
6	616.0	111.0	-0.44	1.77	106.
27	785.0	399.0	-0.96	-0.81	88.
8	778.0	143.0	-0.73	-1.07	84.
17	1193.0	506.0	-0.01	1.31	74.
5	437.0	543.0	0.88	0.24	71.
24	1023.0	381.0	0.66	-0.84	71.
4	356.0	211.0	-0.01	1.20	68.
12	1007.0	523.0	0.17	1.06	62.
20	1207.0	226.0	0.59	0.29	49.
30	1242.0	882.0	0.51	0.21	42.
29	1169.0	920.0	0.01	-0.57	32.
21	1199.0	180.0	0.29	0.24	27.
13	999.0	415.0	0.31	0.09	25.

<<D
MAXIMUM ABSOLUTE ACCEPTABLE ERROR? (>0.0) 4.35
CPS DELETED... 14
1 PAIRS DELETED, 29 OR 96.78 LEFT.

	LINE	SAMPLE	METERS	
RMS ERRORS:	1.225	1.384	124.6	29 CTL PTS.

<<3
ENTER ? FOR COMMANDS.
<<5

PAIR	ROW	COL	RERROR	CERROR	METERS
15	1156.0	645.0	-4.12	0.05	326.
1	235.0	229.0	0.36	-4.22	241.
7	579.0	222.0	-1.51	2.46	184.
11	1011.0	246.0	-0.71	-2.68	162.
25	971.0	137.0	-1.24	-2.08	153.
3	429.0	57.0	1.66	1.13	146.

MORE? (Y OR N) N

Table 5
(continued)

SAN JOSE WEST

ORIGINAL PAGE IS
OF POOR QUALITY

```
<C1
RANGE? (L,H) 15,15
SOURCE OF IMAGE COORDS? (? FOR LIST) T
ARE IMAGE COORDS OBLIQUE TRANSFORMED? (Y OR N) N
POINT 15...IMAGE ROW COL? 1100 624
<AN
REGISTRATION
<<E
                    LINE        SAMPLE       METERS

RMS ERRORS:        10.525       3.870        860.6          29 CTL PTS.
<<S
 PAIR    ROW      COL     RERROR   CERROR   METERS
  15   1100.0    624.0   -52.47   -18.08    4273.
  30   1242.0    882.0     7.97     3.20     656.
  16   1179.0    449.0     7.50     2.91     616.
  17   1193.0    506.0     6.75     4.08     581.
  18   1233.0    321.0     5.76     2.54     478.
  25    971.0    137.0    -4.95    -3.47     438.
MORE? (Y OR N) N
<<S
 PAIR    ROW      COL     RERROR   CERROR   METERS
  15   1100.0    624.0   -52.47   -18.08    4273.
  30   1242.0    882.0     7.97     3.20     656.
  16   1179.0    449.0     7.50     2.91     616.
  17   1193.0    506.0     6.75     4.08     581.
  18   1233.0    321.0     5.76     2.54     478.
  25    971.0    137.0    -4.95    -3.47     438.
MORE? (Y OR N) 25
MORE? (Y OR N) N
<<D
MAXIMUM ABSOLUTE ACCEPTABLE ERROR? (>0.0) 25
CPS DELETED... 15
 1 PAIRS DELETED,  28 OR  93.3% LEFT.
                    LINE        SAMPLE       METERS

RMS ERRORS:         0.923       1.409        108.1          28 CTL PTS.
<<S
 PAIR    ROW      COL     RERROR   CERROR   METERS
   1    235.0    229.0     0.06    -4.22     239.
   7    579.0    222.0    -1.48     2.46     182.
  11   1011.0    246.0    -0.70    -2.68     162.
   3    429.0     57.0     1.86     1.12     160.
  25    971.0    137.0    -0.93    -2.08     139.
  23    957.0    800.0     1.66     0.05     131.
MORE? (Y OR N) N
```

Table 5

(continued)

MONTEREY WEST

ORIGINAL PAGE IS OF POOR QUALITY

CONTROL POINTS

PAIR	LAT	LON	ROW	COL
1	36.92825	121.73920	234.0	308.0
2	36.98313	121.72720	159.0	311.0
3	36.98737	121.67340	147.0	369.0
4	36.89909	121.69480	267.0	362.0
5	36.93031	121.71390	228.0	336.0
6	36.98874	121.62610	138.0	420.0
7	36.96823	121.63770	167.0	411.0
8	36.94696	121.63370	195.0	419.0
9	36.90155	121.63450	255.0	426.0
10	36.95963	121.53330	162.0	528.0
11	36.94689	121.58270	187.0	475.0
12	36.89356	121.58220	258.0	485.0
13	36.99168	121.57560	127.0	473.0
14	36.87594	121.51590	272.0	565.0
15	36.91076	121.48090	219.0	594.0
16	36.96351	121.49080	150.0	574.0
17	36.98998	121.46030	107.0	603.0
18	36.88644	121.39860	235.0	687.0
19	36.91506	121.41220	200.0	668.0
20	36.96720	121.42380	132.0	647.0
21	36.97850	121.38040	109.0	690.0
22	36.98161	121.36220	101.0	710.0
23	36.96102	121.32830	124.0	751.0
24	36.93971	121.34720	157.0	735.0
25	36.90108	121.32570	208.0	766.0
26	36.89675	121.33820	216.0	753.0
27	36.99774	121.29360	69.0	781.0
28	36.96730	121.25370	103.0	830.0
29	36.93819	121.30630	153.0	780.0
30	36.90651	121.28170	193.0	812.0
31	36.87776	121.26240	229.0	838.0
32	36.98884	121.24220	73.0	838.0
33	36.87663	121.24330	228.0	0.0
34	36.89935	121.20170	189.0	899.0
35	36.96949	121.22800	96.0	857.0
36	36.99149	121.17540	58.0	909.0
37	36.94260	121.19300	127.0	900.0
38	36.98334	121.13860	63.0	950.0
39	36.93719	121.15380	128.0	944.0
40	36.88777	121.14860	196.0	958.0

Table 6

MONTEREY WEST

ORIGINAL PAGE IS
OF POOR QUALITY

```
                      LINE       SAMPLE       METERS

RMS ERRORS:           1.099      0.929        101.6            40 CTL PTS.
<<S
 PAIR              COL      RERROR   CERROR   METERS
  18  [illegible]  687.0    -3.01    -1.66    301.
  13   127.0       473.0     1.65    -2.16    191.
   2   159.0       311.0    -2.02     0.97    169.
  14   272.0       565.0     0.71     2.49    152.
  22   101.0       710.0    -1.86     0.16    148.
  17   107.0       603.0    -1.20     1.50    127.
MORE? (Y OR N) N
<<D
MAXIMUM ABSOLUTE ACCEPTABLE ERROR? (>0.0) 3
CPS DELETED... 18
  1 PAIRS DELETED,  39 OR  97.5% LEFT.
                      LINE       SAMPLE       METERS

RMS ERRORS:           0.926      0.897        89.1             39 CTL PTS.
```

Table 6

(continued)

APPENDIX B

Appendix B

OUTPUT PRODUCTS GENERATED

FOR THE ABAG

BIOGENIC HYDROCARBON EMISSIONS INVENTORY PROJECT

Documentation for the ABAG project consists of photographic products as well as working papers and this final report. The photographic products were designed to record significant steps in the analysis flow and to display the final land use/land cover inventory.

This Appendix describes the planning and generation of the project's photographic products. In addition, Table 1 illustrates the distribution and cost of those products.

Selection of Photographic Products

A set of photographic prints was generated to record the status of the data set at each major stage of the analysis. Five significant stages were identified for photographic documentation: 1) the CDF classification scheme, 2) the pre-stratification land cover data, following reassignment of information class labels to CDF spectral clusters, 3) the classification following the cloud, wetland, and urban stratification at NASA/Ames, 4) the final ABAG classification following the urban stratification at ABAG, and 5) the biogenic hydrocarbon emissions inventory following assignment of emission rates to the ABAG information classes. This sequence, in 8 x 10" color photographs, was generated for each 1-degree quad for each analysis stage, with two exceptions. No Stage 3 photograph was generated for the Monterey West quad because no cloud or wetland classes were identified within the quad; for the Stage 4 product, the San Jose West quad and the Monterey West quad were placed on the same photograph. Slides and viewgraphs were also produced of the San Francisco East quad for all documentation stages. In addition, a poster was created illustrating all steps between the CDF data and the biogenic emissions inventory.

The photographic products of the final land use/land cover data consisted of 35mm slides; 8x10-inch viewgraphs; and 1:250,000, 1:500,000, and 8x10-inch color paper prints. The biogenic hydrocarbon emissions inventory was displayed as black/white 8x10-inch viewgraphs, 35mm slides, and 8x10-inch paper prints (see Table 1).

Reproductions of the 8x10-inch sequence of color photo products for each quad appear as Figures 2 through 23, following. The final ABAG land cover information classes for the entire study area are reproduced in Figure 1.

Generation of Photographic Products

Two analysis systems were used in the production of the photographic products. The two systems were IDIMS, which is resident on the HP 3000 Series III, and the Classified Image Editor (CIE), which is resident on the SEL 32/77. The same basic procedure was used on both systems. First a color was selected for each information class. Next, a three-band data file was created, with the three bands composed of intensity values for the three primary colors: red, green, and blue. Finally, a Dicomed D-47 digital color film recorder was used to create a 4x5-inch Vericolor II 4107 negative from the three-band data file.

IDIMS was used for its effective annotation options. In addition, since many of the tasks were performed on the HP 3000 Series III and since the Dicomed is accessed through the HP 3000/IDIMS, the creation of Dicomed files was simplified by using IDIMS for the annotation process. The Dicomed functions available on IDIMS did, however, have limitations which forced use of the CIE for creation of the final-image Dicomed files. The IDIMS function which creates the three-band input to the Dicomed film recorder limits the colors available to a fixed set of 30 standard colors and the IDIMS function DICOMED limits the maximum image size to 4096 x 4096 pixels. The CIE, on the other hand, could be used to create analyst-defined colors by setting the intensities for each of the primary colors, and allowed the creation of a Dicomed image large enough to contain the entire ABAG region at a reasonable resolution. The CIE images were then entered into the IDIMS system, where the Dicomed products were made.

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Table 1

OUTPUT PRODUCTS

VERSATEC Plotter Maps 1:400,000 scale (Generated at ABAG)

Total biogenic hydrocarbon emissions
Land cover/land use with aspect
Land cover/land use

Magnetic Tapes (Computer Tapes)

Land cover/land use data set
Biogenic Hydrocarbon data set

Photographic Products

Product Description/ Distribution	Total # of Copies	Total Cost
Paper Prints		
ABAG Region with county boundaries, 1:250,000 scale 1 copy to ABAG	1	$145.00
ABAG Region with county boundaries, 1:500,000 scale 2 copies to NASA, 3 copies to ABAG (@ $42.95 each)	5	214.75
ABAG Region with county boundaries, 8" x 10" 10 copies to NASA, 20 copies to ABAG (@ $8.00 each)	30	240.00
ABAG Region - Biogenic Hydrocarbon Emissions, 8" x 10" 15 copies to NASA, 25 copies to ABAG (@ $8.00 each)	40	320.00
CDF Classification scheme for each of six 1-degree quads, 8" x 10" 3 sets to NASA, 2 sets to ABAG, Remainder for distribution (@ $8.00 each)	30	240.00
Pre-stratification classification for each of five 1-degree quads, 8" x 10" 3 sets to NASA, 2 sets to ABAG, Remainder for distribution (@ $8.00 each)	25	200.00
Post-stratification for class confusion (prior to urban stratification at ABAG) for each of six 1-degree quads, 8" x 10" 3 sets to NASA, 2 sets to ABAG, Remainder for distribution (@ $8.00 each)	30	240.00

Table 1

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(continued)

Photographic Products, continued

Product Description/ Distribution	Total # of Copies	Total Cost
Final ABAG classification scheme for each of five 1-degree quads, 8" x 10" 3 sets to NASA, 2 sets to ABAG, Remainder for distribution (@ $8.00 each)	25	$200.00

Poster: ABAG Analysis Flow

Viewgraphs (8" x 10")

ABAG Region with county boundaries 1 copy each to NASA and ABAG (@ $16.00 each)	2	32.00
ABAG Region - Biogenic Hydrocarbon Emissions 1 copy each to NASA and ABAG (@ $16.00 each)	2	32.00
ABAG analysis flow, from poster 1 copy each to NASA and ABAG (@ $16.00 each)	2	32.00
San Francisco East 1-degree quad, CDF classification 1 copy each to NASA and ABAG (@ $16.00 each)	2	32.00
San Francisco East 1-degree quad, pre-stratification classification 1 copy each to NASA and ABAG (@ $16.00 each)	2	32.00
San Francisco East 1-degree quad, post-stratification classification (prior to urban stratification performed at ABAG) 1 copy each to NASA and ABAG (@ $16.00 each)	2	32.00
San Francisco East 1-degree quad, final ABAG classification scheme 1 copy each to NASA and ABAG (@ $16.00 each)	2	32.00

Slides (35mm)

ABAG Region with county boundaries 2 copies to NASA, 2 copies to ABAG (@ $1.25 each)	4	5.00
ABAG Region - Biogenic Hydrocarbon Emissions 2 copies to NASA, 2 copies to ABAG (@ $1.25 each)	4	5.00
ABAG analysis flow, from poster 2 copies to NASA, 2 copies to ABAG (@ $1.25 each)	4	5.00

Table 1

(continued)

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Photographic Products, continued

Product Description/ Distribution	Total # of Copies	Total Cost
San Francisco East 1-degree quad, CDF classification 2 copies to NASA, 2 copies to ABAG (@ $1.25 each)	4	$ 5.00
San Francisco East 1-degree quad, pre-stratification classification 2 copies to NASA, 2 copies to ABAG (@ $1.25 each)	4	5.00
San Francisco East 1-degree quad, post-stratification classification (prior to ABAG urban stratification) 2 copies to NASA, 2 copies to ABAG (@ $1.25 each)	4	5.00
San Francisco East 1-degree quad, Final ABAG classification 2 copies to NASA, 2 copies to ABAG (@ $1.25 each)	4	5.00

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Figure 1. ABAG Region/Study Area. Final ABAG information classes.

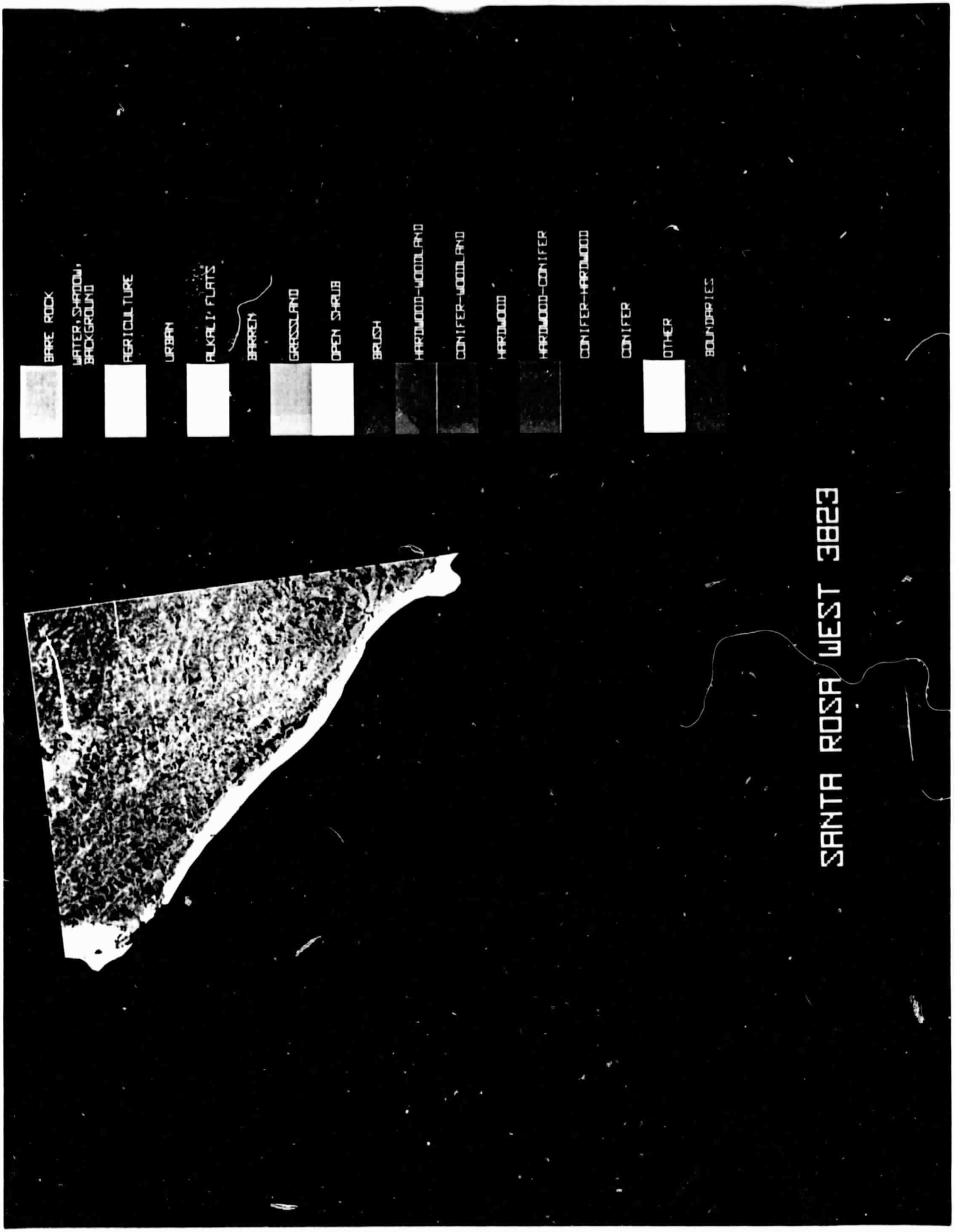

Figure 2. Santa Rosa West quad. Original CDF information classes.

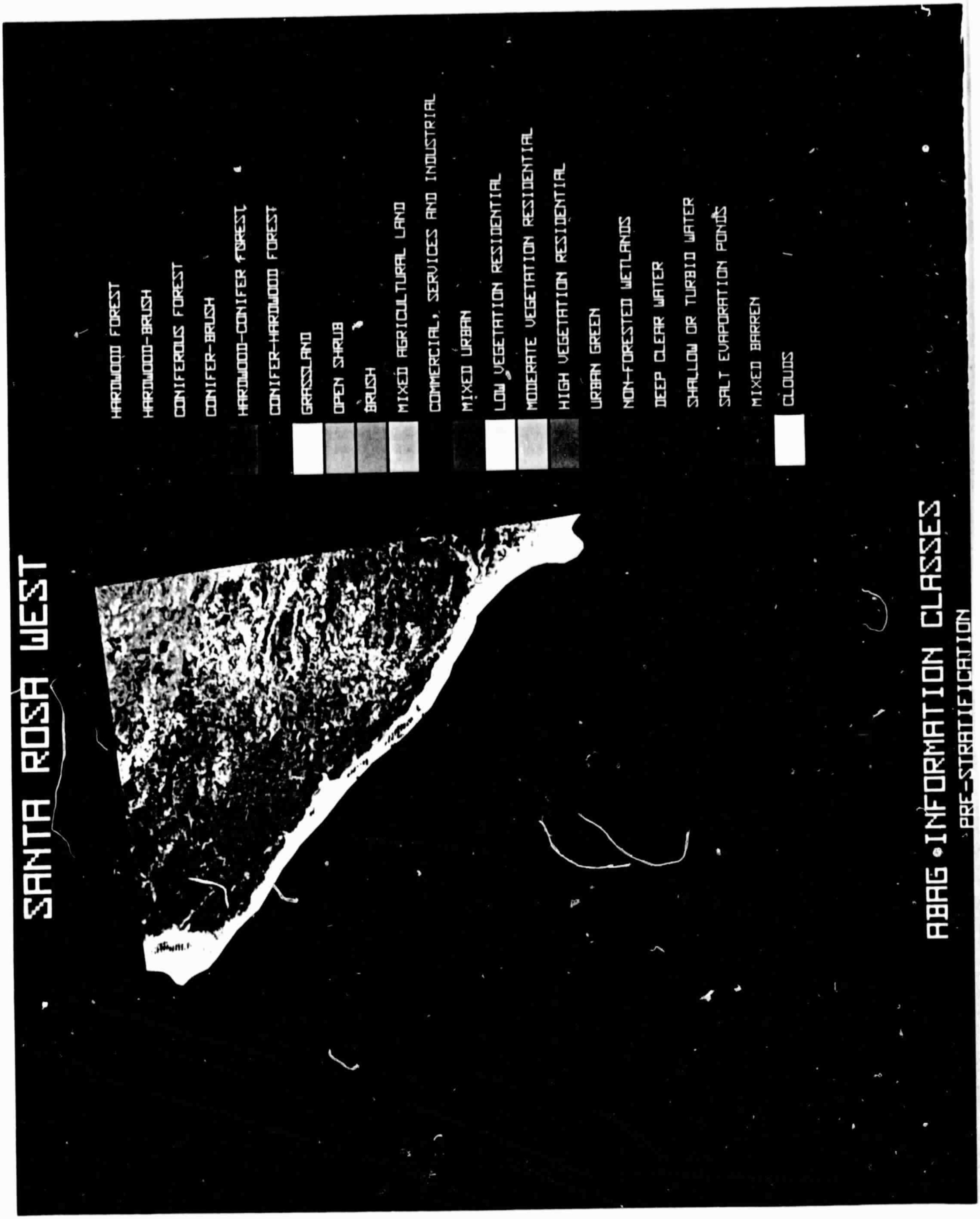

Figure 3. Santa Rosa West quad. ABAG information classes, after identification and regrouping of CDF spectral clusters, prior to stratification.

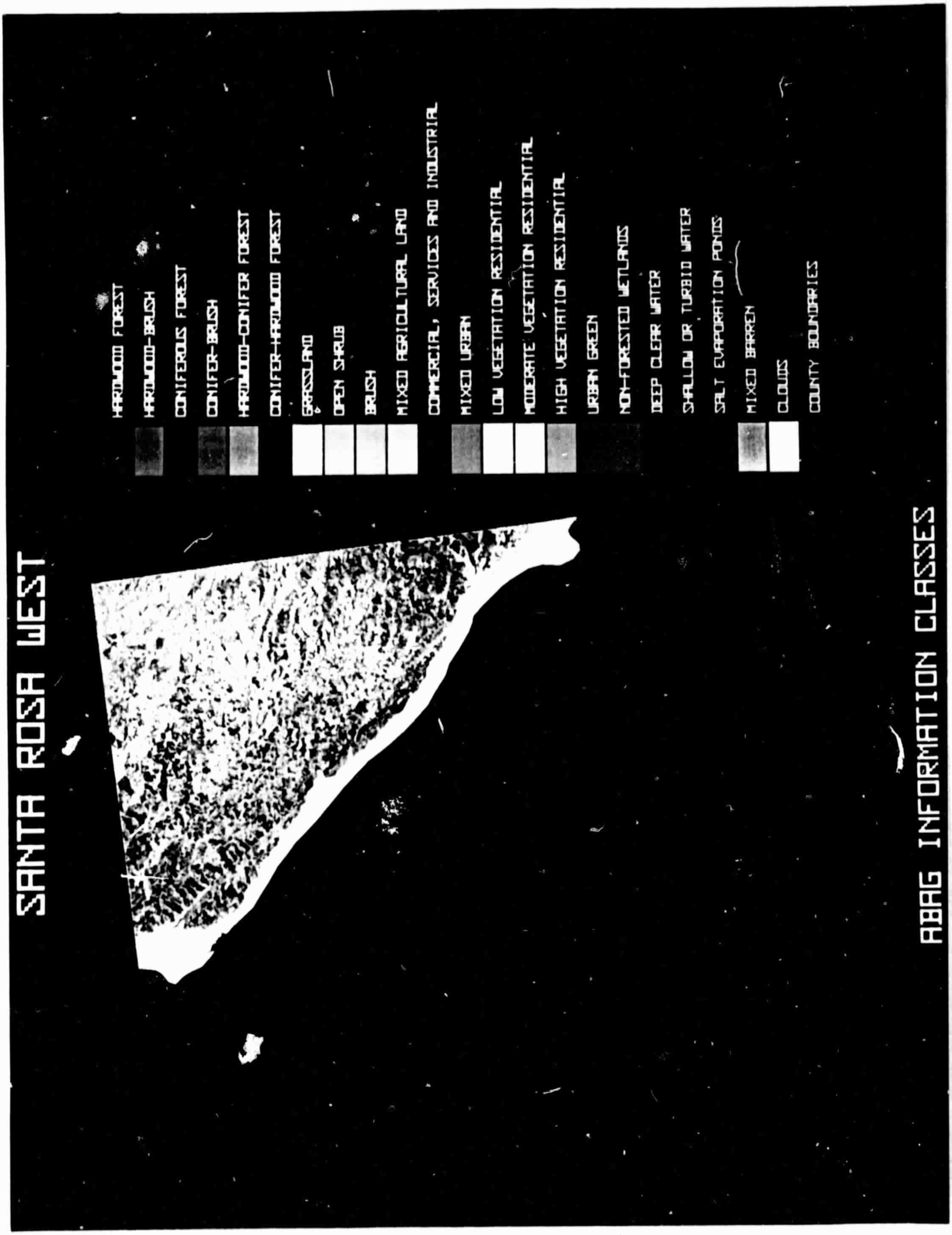

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Figure 4. Santa Rosa West quad. ABAG information classes after stratification performed at Ames.

Figure 5. Santa Rosa West quad. Final ABAG information classes, after urban modeling performed at ABAG.

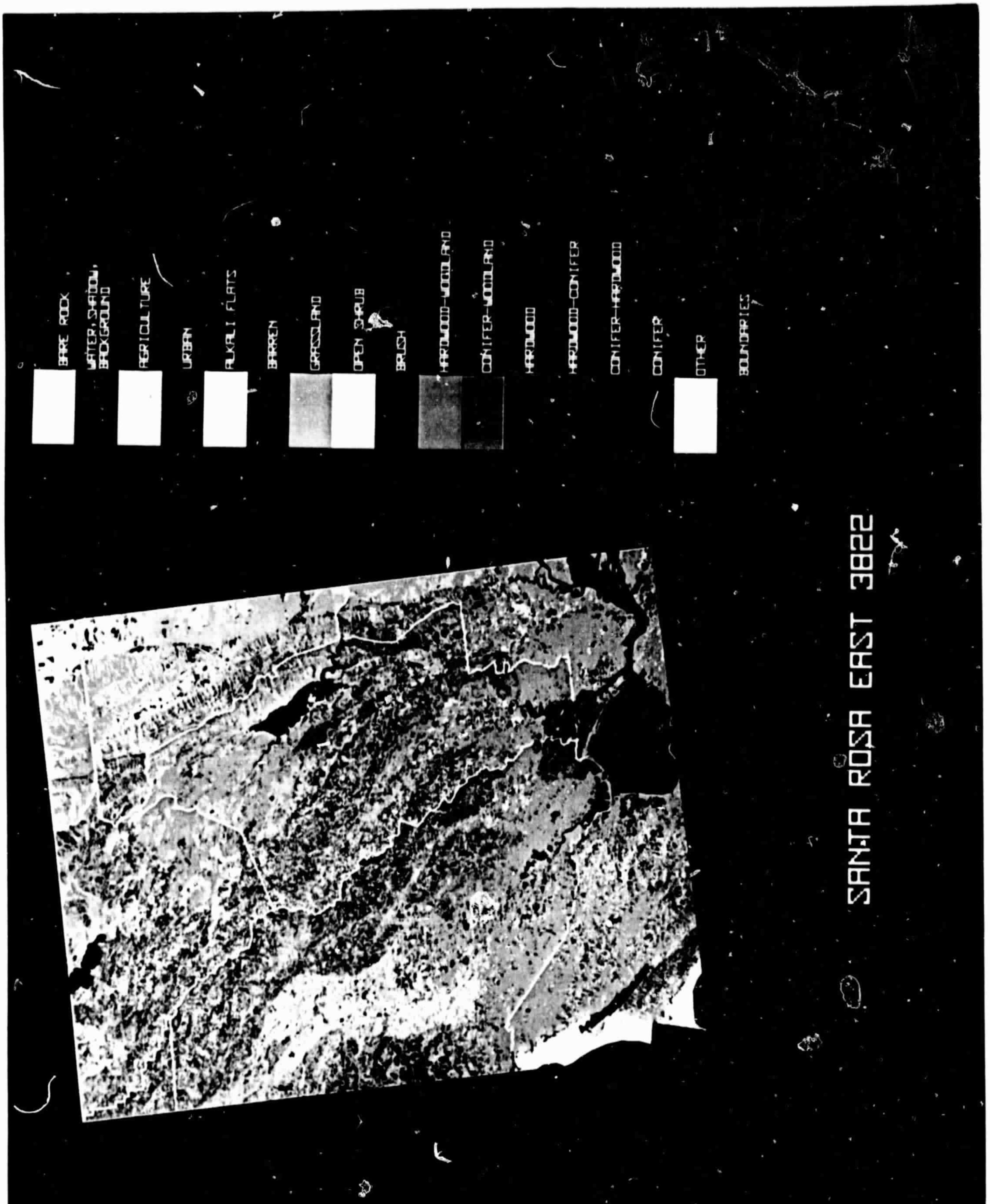

Figure 6. Santa Rosa East quad. Original CDF information classes.

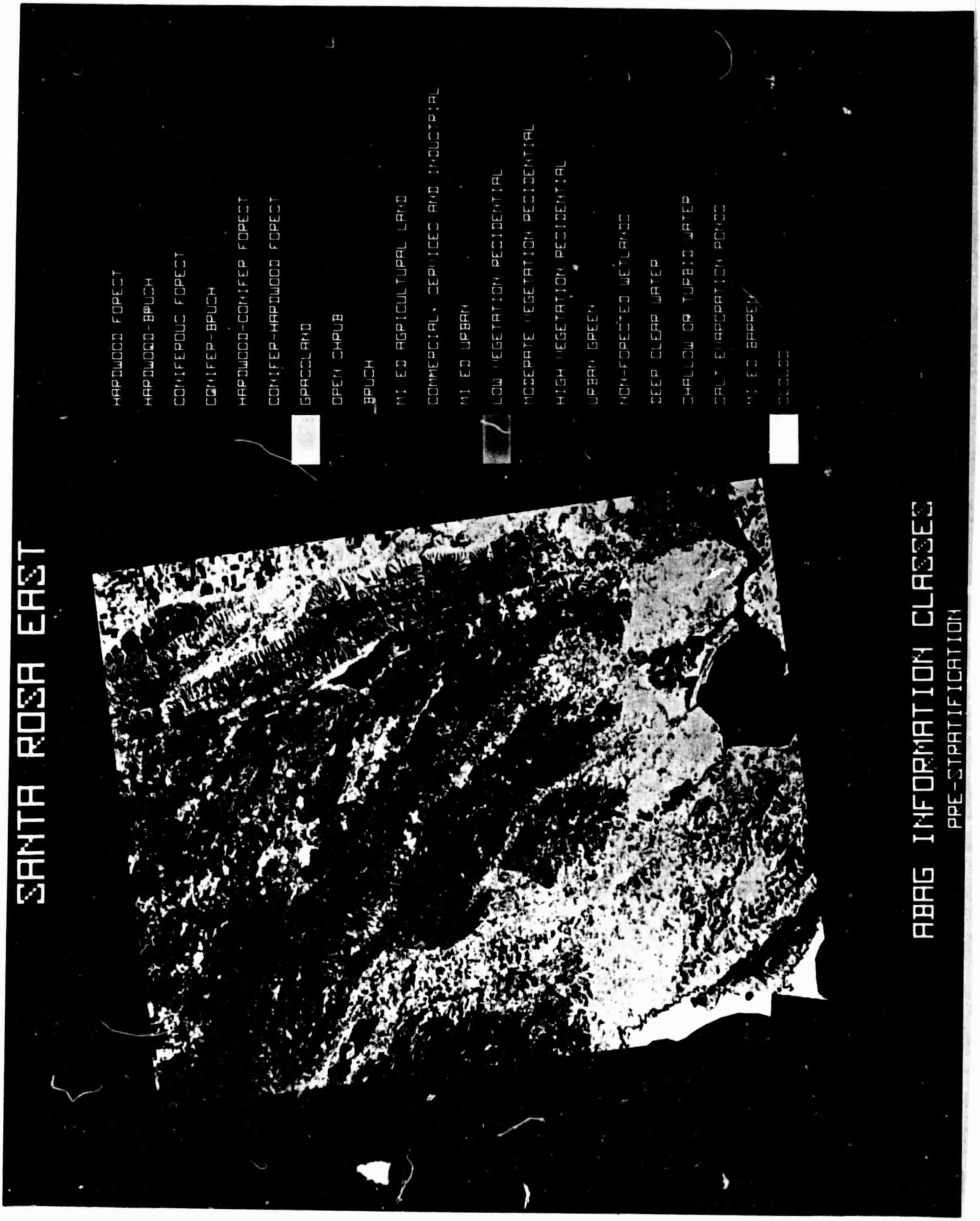

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Figure 7. Santa Rosa East quad. ABAG information classes after identification and regrouping of CDF spectral clusters, prior to stratification.

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Figure 8. Santa Rosa East quad. ABAG information classes after stratification performed at Ames.

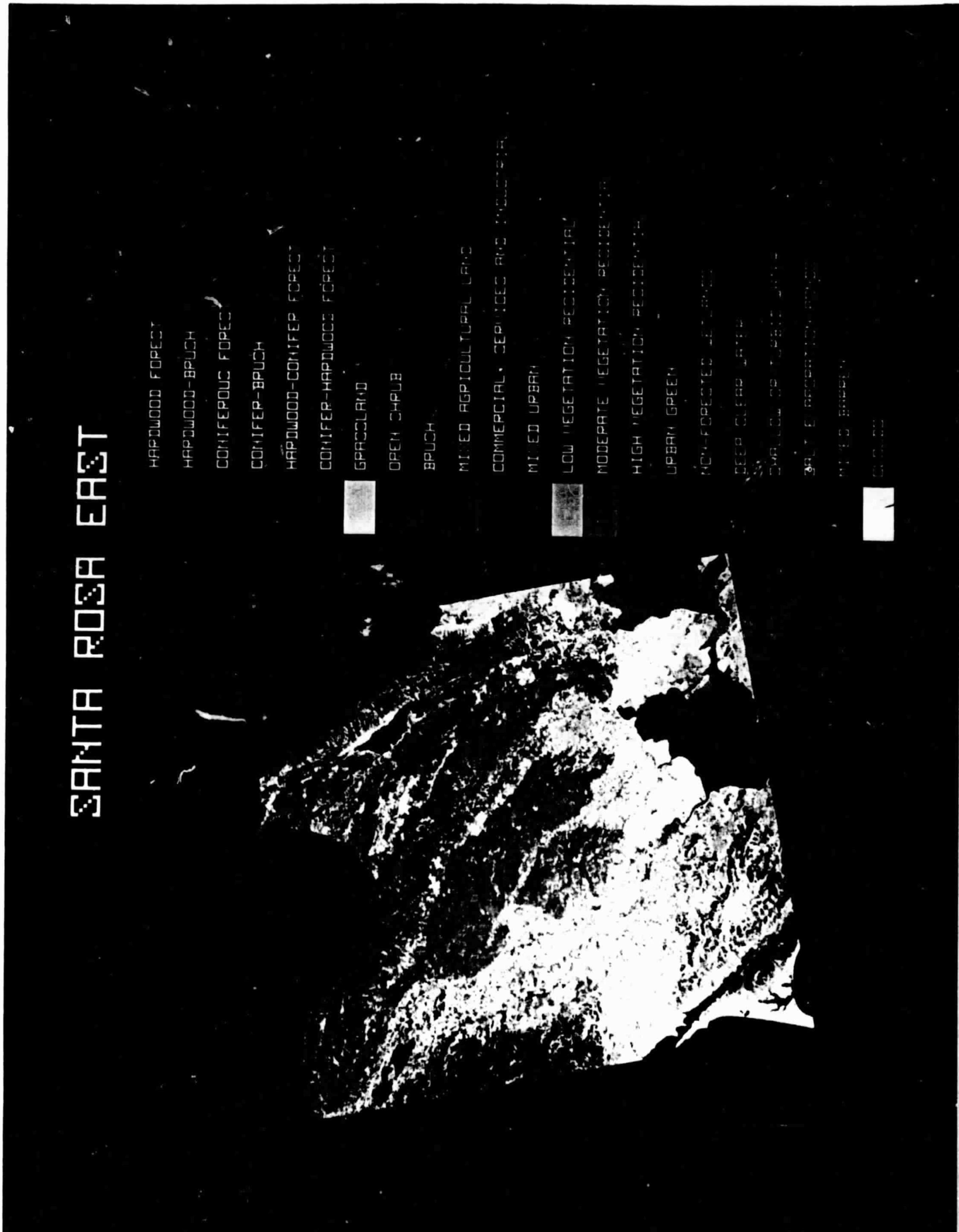

Figure 9. Santa Rosa East quad. Final ABAG information classes, after urban modeling performed at ABAG

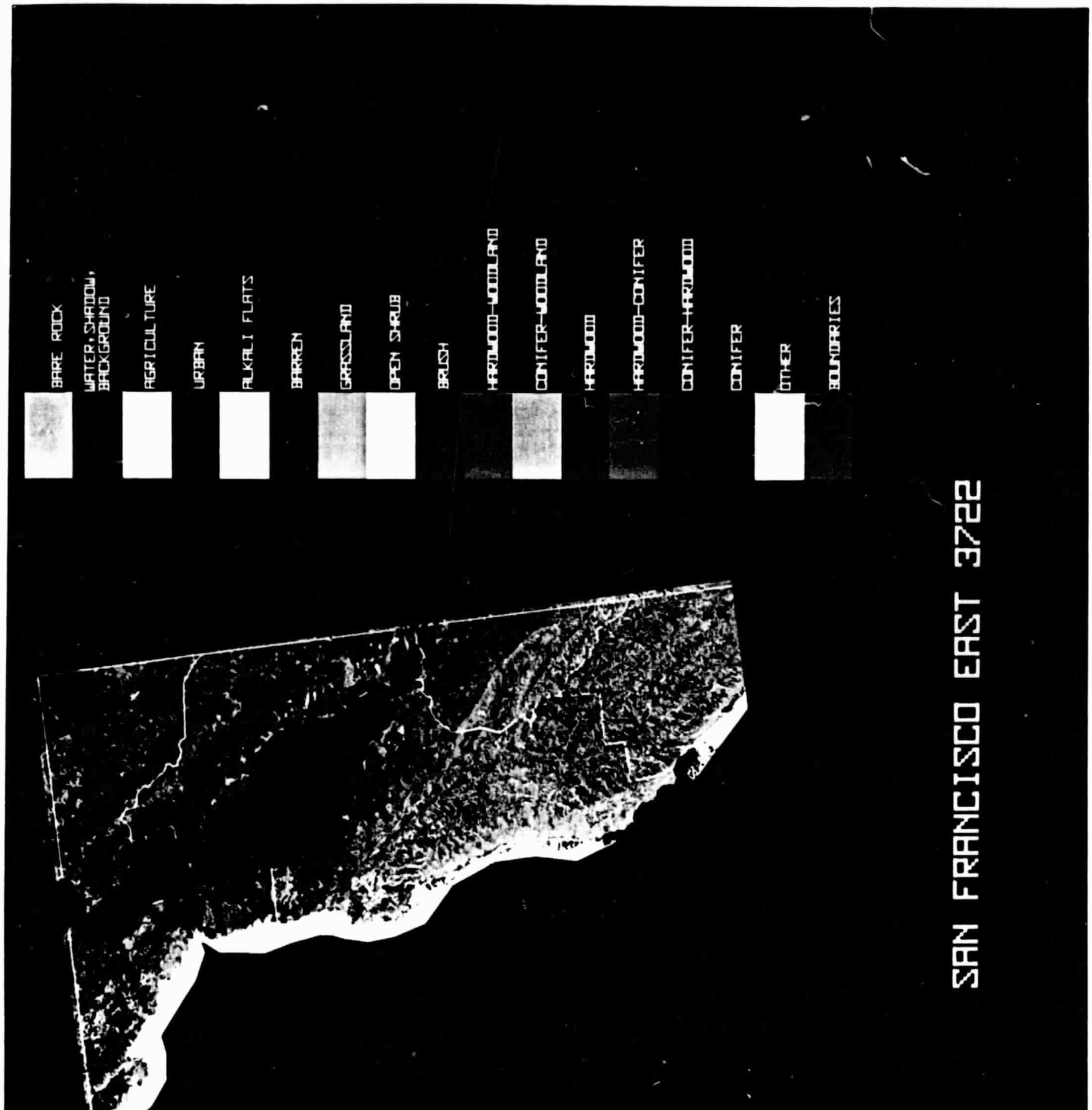

Figure 10. San Francisco East quad. Original CDF information classes.

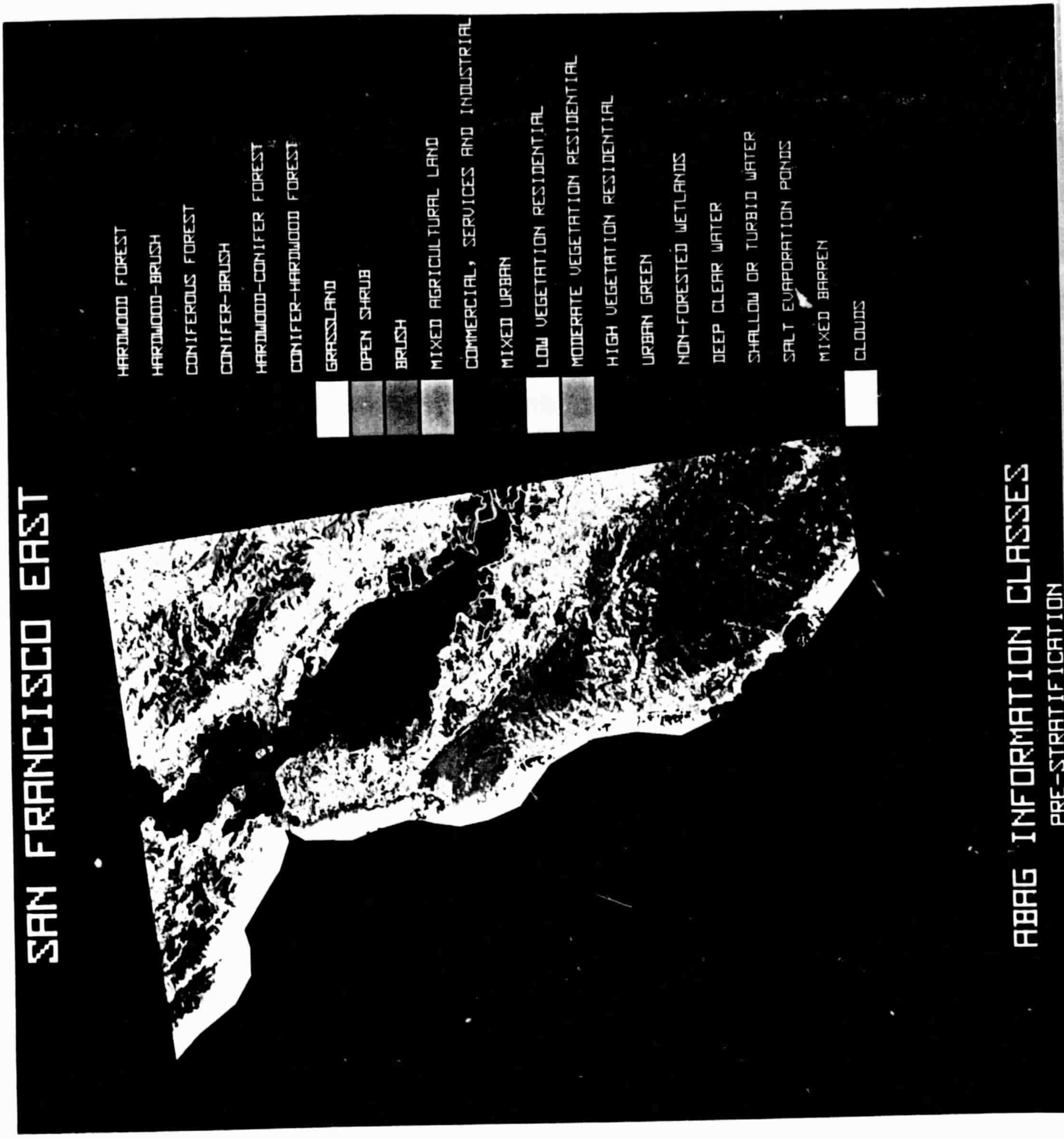

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Figure 11. San Francisco East quad. ABAG information classes, after identification and regrouping of CDF spectral clusters, prior to stratification.

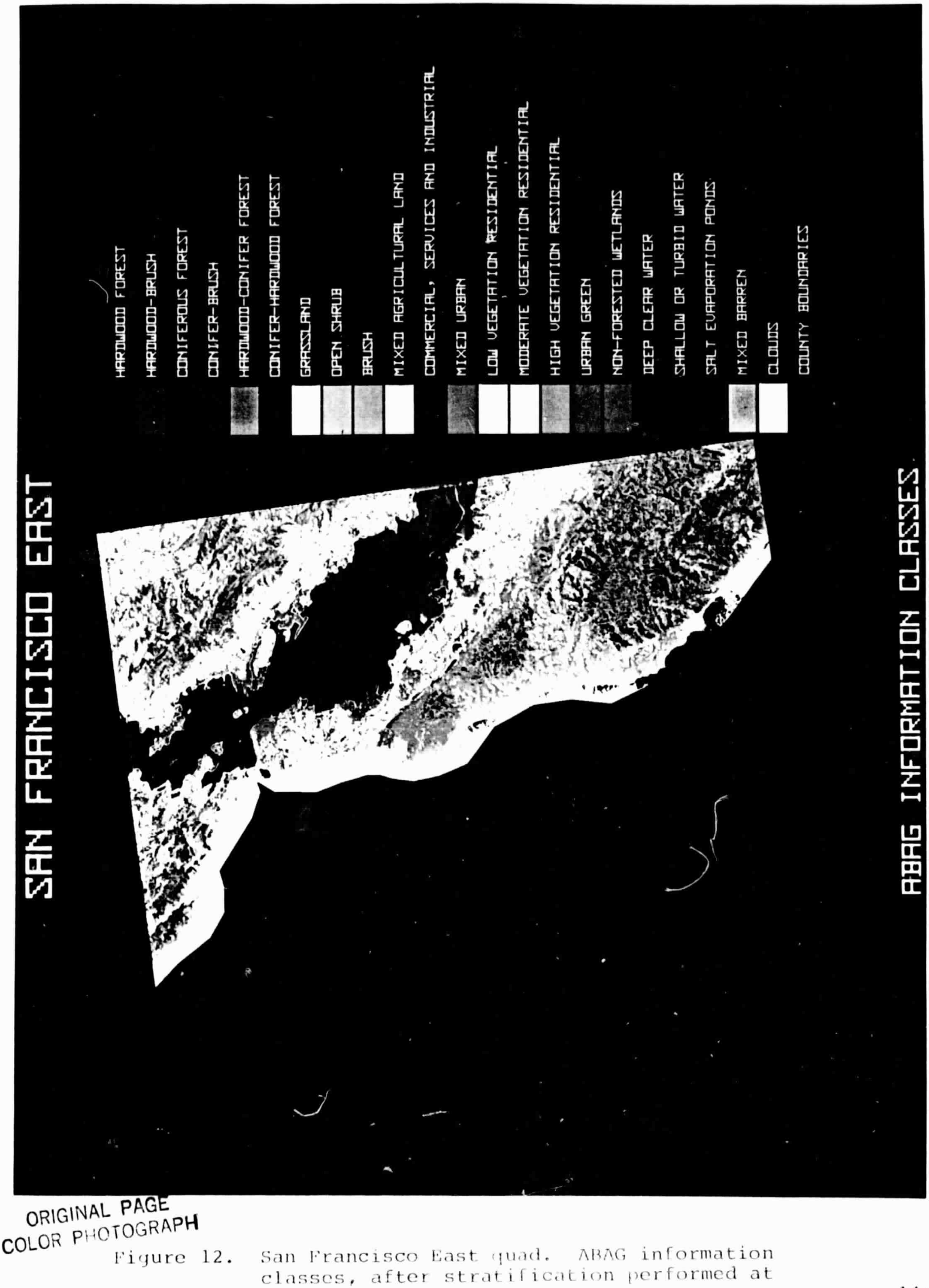

Figure 12. San Francisco East quad. ABAG information classes, after stratification performed at

Figure 13. San Francisco East quad. Final ABAG information classes, after urban modeling performed at ABAG.

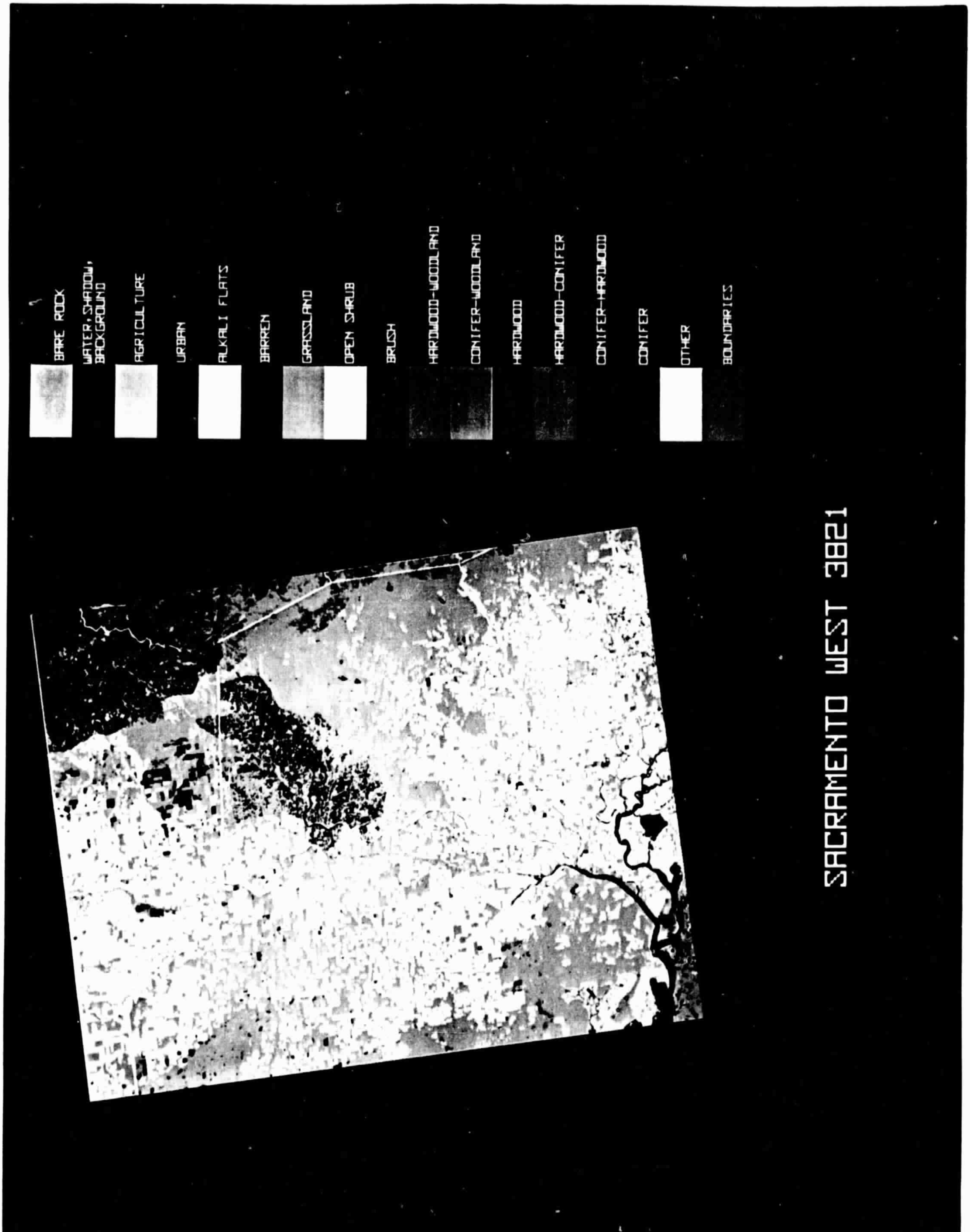

Figure 14. Sacramento West quad. Original CDF information classes.

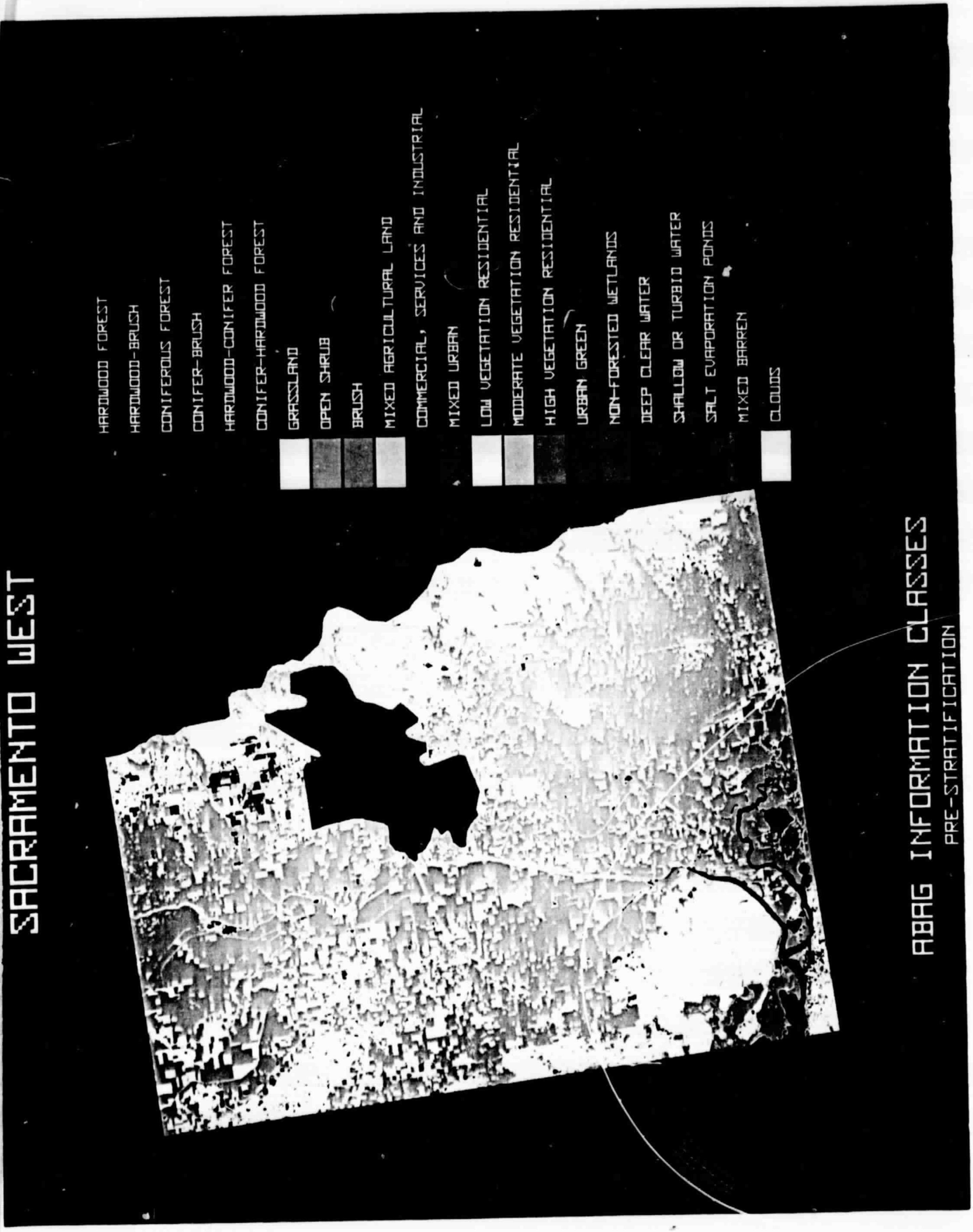

Figure 15. Sacramento West quad. ABAG information classes, after identification and regrouping of CDF spectral clusters, prior to stratification.

Figure 16. Sacramento West quad. ABAG information classes, after stratification performed at Ames.

Figure 17. Sacramento West quad. Final ABAG information classes, after urban modeling performed at ABAG.

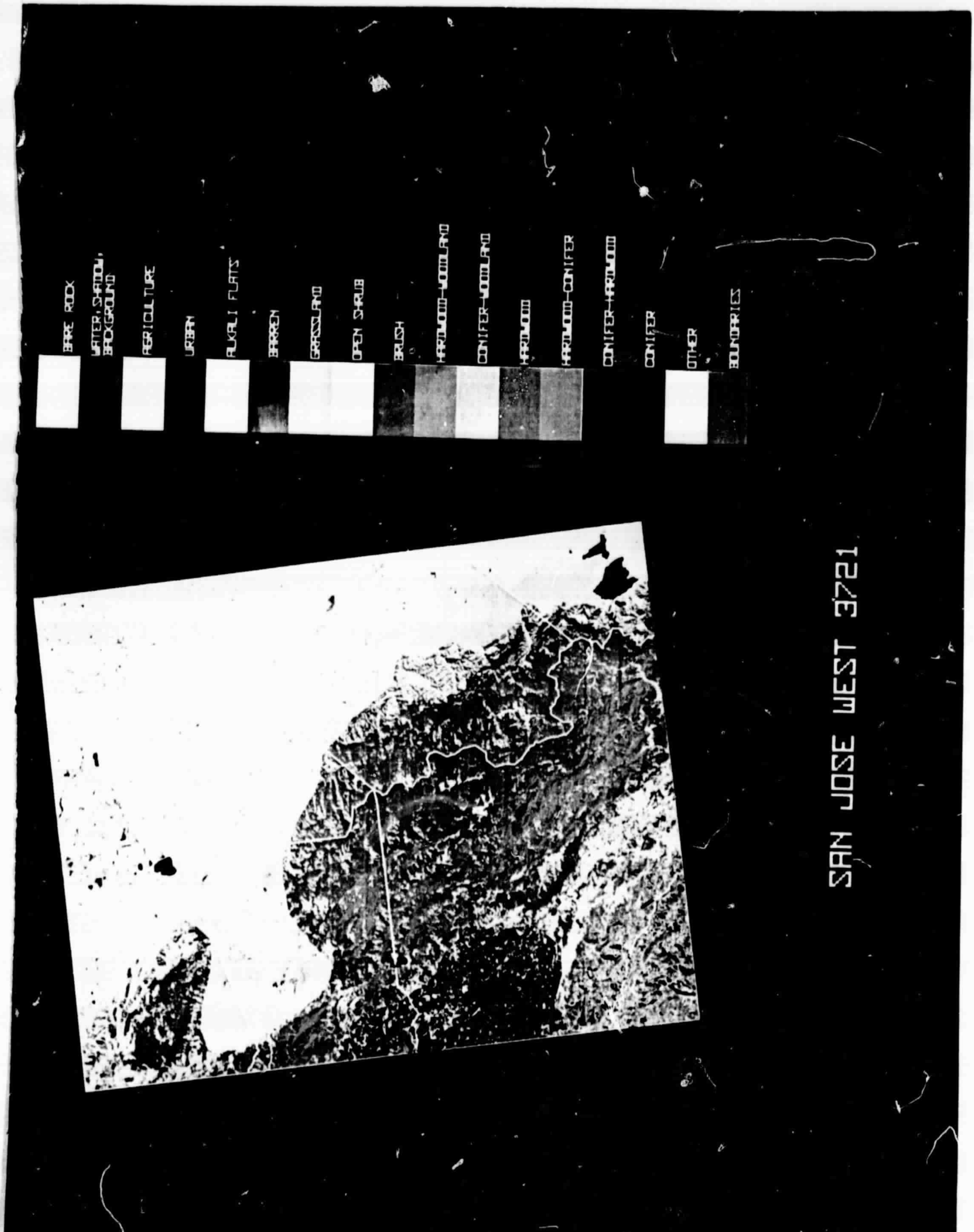

Figure 18. San Jose West quad. Original CDF information classes.

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Figure 19. San Jose West quad. ABAG information classes, after identification and regrouping of CDF spectral clusters, prior to stratification.

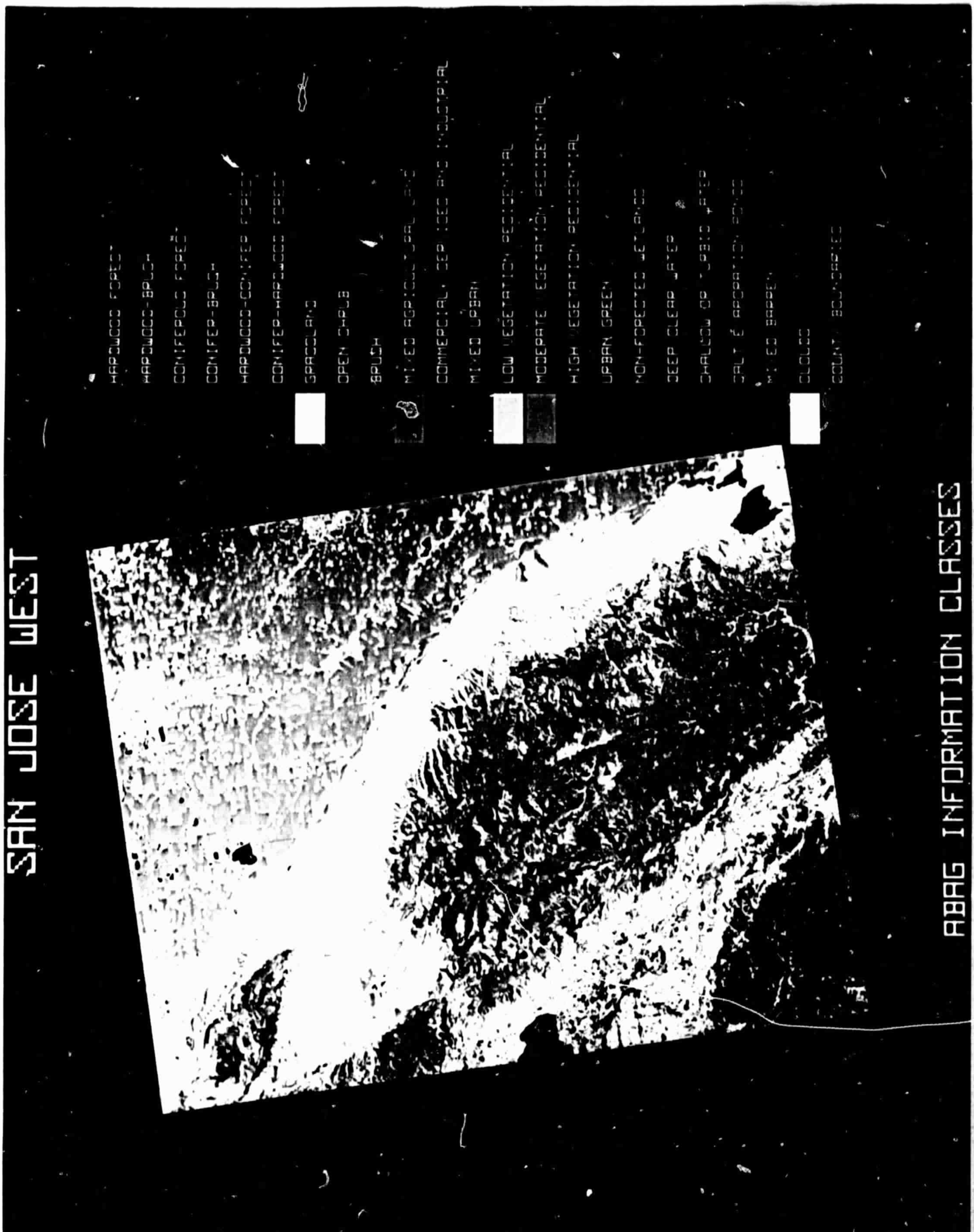

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Figure 20. San Jose West quad. ABAG information classes, after stratification performed at Ames.

Figure 21. San Jose West and Monterey West quads. Final ABAG information classes, after urban modeling performed at ABAG.

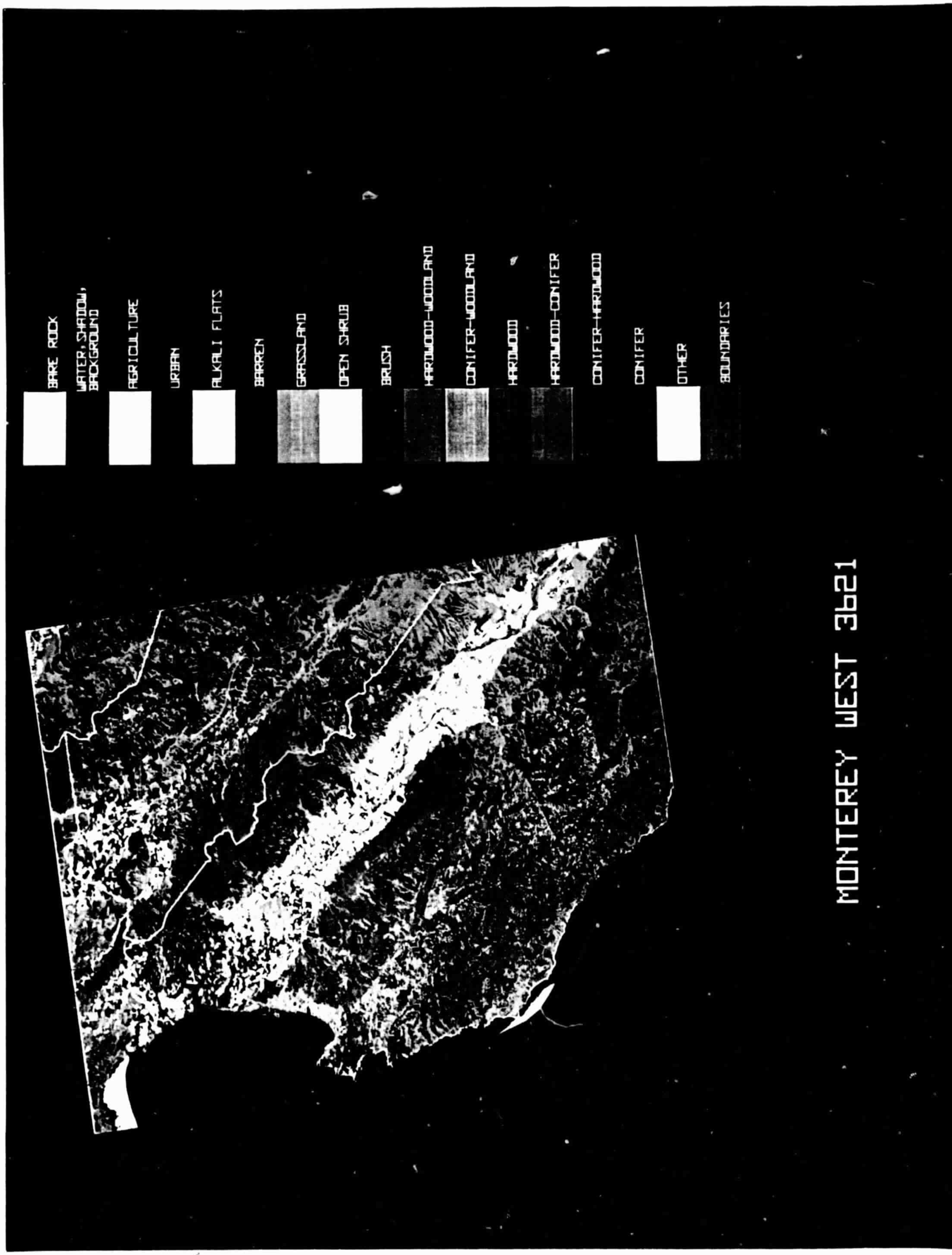

Figure 22. Monterey West quad. Original CDF information classes.

Figure 23. Monterey West quad. ABAG information classes, after identification and regrouping of CDF spectral clusters. (No stratification performed at Ames.)

APPENDIX C

Appendix C

DOCUMENTATION GENERATED FOR THE ABAG

BIOGENIC HYDROCARBON EMISSIONS INVENTORY PROJECT

The following list represents the papers and documentation that were intended to be generated, at the earlier stages of the project:

Project Plan

Working Papers

#1 Development of the vegetation inventory for the Bay Area from the California Department of Forestry (CDF) 1976 Landsat data file

#2 Selection of biogenic hydrocarbon emission factors for land cover classes found in the San Francisco Bay Area

#3 Registration of the ABAG 1976 Landsat data file

#4 Verification and evaluation of the 1976 Landsat data file of the ABAG region

#5 Compilation of a Biogenic Hydrocarbon Emissions Inventory for the evaluation of ozone control strategies in the San Francisco Bay Area

#6 Photographic product and documentation generation for the ABAG Biogenic Hydrocarbon Emissions Inventory Project

Final Report

Of the six working papers, four were written and distributed. Two were not; procedural changes were required in the method used for verification and evaluation, delaying the writing of paper #4, and while a draft of paper #6 was written, a personnel change in the project staff at NASA/Ames toward the end of the project precluded timely completion of that paper. The writing of the final project documentation (this report) closely followed the change in project personnel and, as a consequence, materials for Working Papers #4 and #6 were used in this report rather than creating separate working papers and project documentation containing some of the same material.

Nonetheless, the Working Papers were intended to provide, among other things, a type of interim project documentation and served very well as such. Examination of the dates on the Working Papers that were distributed illustrates the interim function served by those papers.

Documentation and papers emanating from this project have included:

Project Documentation

Project Plan: "The Development of a Biogenic Hydrocarbon Emissions Inventory for the San Francisco Bay Area; A Demonstration Project of the California Integrated Remote Sensing System (CIRSS), Final Work Plan"; ABAG, 1980.

Working Papers:

#1 "Development of a Vegetation Inventory for the Bay Area from the California Department of Forestry (CDF) 1976 Landsat Data File"; Roberta M. Moreland (ABAG) and Eugene A. Fosnight (TGS), August 1980.

#2 "Selection of Biogenic Hydrocarbon Emission Factors for Land Cover Classes Found in the San Francisco Bay Area"; Don Hunsaker (ABAG), May 1980, Revised January 1981. (Also cited as Air Quality Tech Memo 31 and as CIRSS Working Paper 2.)

#3 "Registration of the ABAG 1976 Landsat Data File"; Roberta M. Moreland (ABAG) and Eugene A. Fosnight (TGS), January 1981.

#5 "Compilation of a Biogenic Hydrocarbon Emissions Inventory for the Evaluation of Ozone Control Strategies in the San Francisco Bay Area"; Don Hunsaker and Roberta M. Moreland (ABAG), March 1981. (Also cited as Air Quality Tech Memo 35 and CIRSS Working Paper 5.)

Final Project Report: "ABAG Biogenic Hydrocarbon Emissions Inventory Project, Final Report"; Ed. Charlotte Carson-Henry (TGS), April 1982.

Publications

Paper for the 1981 Fall Technical Meeting of the American Society of Photogrammetry: "Methodology for Compiling a Biogenic Hydrocarbon Emissions Inventory for the Bay Area"; Eugene A. Fosnight and Roberta M. Moreland in Proceedings of the 1981 American Society of Photogrammetry Fall Technical Meeting, San Francisco, CA, pp. 273-281, September 1981.

Paper for the Seventh Annual Pecora Symposium in Sioux Falls, SD: "Remote Sensing Data Integration into a Geographic Information System for the Creation of a Biogenic Hydrocarbon Emissions Inventory of the San Francisco Bay Area"; Roberta M. Moreland and Eugene A. Fosnight, in Proceedings of the Seventh Annual Pecora Symposium, November, 1981.

Paper for Harvard Computer Graphics Week, 1981: "Vegetation and Air Pollution: Using Landsat with BASIS"; Paul M. Wilson (ABAG), July 1981.

Two excellent related papers which address issues of concern to the CIRSS Task Force are:

"Operational Alternatives for Landsat in California: Institutional Issues"; Paul M. Wilson for the California Integrated Remote Sensing System (CIRSS) Task Force, May 1981.

"Elements of Vertical Data Integration"; Paul M. Wilson for the CIRSS Task Force, December 1979.