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Indiana State Planning Services Agency

INDIANA COASTAL ZONE MANAGEMENT PROGRAM

A Report

Indiana vices Agency · Lt. Governor Robert D. Orr, Director · 143 West Market Street, Indianapolis, Indiana 46204

A REPORT ON
INDIANA LAND COVER CLASSIFICATION MANUAL: A GUIDE TO MAPPING

Prepared by the
State of Indiana
State Planning Services Agency
Lieutenant Governor Robert D. Orr, Director

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This publication is the final documentation on the development of a land cover classification system for the State of Indiana. The classification system is intended for use by planning agencies at the local, regional and State levels. In addition, the appendices of the manual contain general information on mapping techniques, scales, grid systems and aerial photography interpretation. This general data should prove useful to those performing mapping functions as well as to those utilizing various map types.

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TABLE OF CONTENTS

	Page
List of Figures	vii
List of Tables	ix
Foreword	xi
Introduction	1
STATE PLANNING SERVICES AGENCY (SPSA) LAND COVER INVENTORY	
Level I Land Cover Categories	3
Nature of Classification – Phase I	4
Format of Machine Processed LANDSAT Data	4
Characteristics of a LARSYS Alphanumeric Display	8
Interpretation of Alphanumeric Classification Display	11
Water	13
Wetlands	15
Forest Lands	16
Non Vegetated Urban/Bare Soil	17
High Density Residential/Immature Agriculture	18
Medium Density Residential/Moderately Mature Agriculture	19
Low Density Residential/Mature Agriculture	20
Urban/Rural Barren	21
Clouds	22
Shadow	22
SUMMARY OF THE PHASE I CLASSES	
Orientation	23
Statistical Summaries	24
Conclusion	25
APPENDIX A. MULTISPECTRAL REMOTE SENSING: PRINCIPLES AND TECHNIQUES	
Electromagnetic Spectrum	27

LANDSAT System 29
LANDSAT Scanners 29
Multispectral Data Machine Processing 33

APPENDIX B. MAPS

Introduction 36
The Framework for Effective Maps 36
The Elements of Maps 38
Systems of Location 41
The Cartographic Processes 55

APPENDIX C. AERIAL PHOTOGRAPHS

Introduction 58
The Properties of the Aerial Photograph 58
Using and Interpreting Aerial Photographs 65

APPENDIX D. PROCEDURES AND TECHNIQUES IN USING MAPS, AERIAL, PHOTOGRAPHS AND ALPHANUMERIC PICTURE-PRINTS

Introduction 70
Using Aerial Photographs, Maps and Picture-Prints 70

APPENDIX E. A COMPUTERIZED SYSTEM TO ENCODE, RETRIEVE AND DISPLAY LAND INVENTORY DATA

Scope 77
Collection 77
Storage 77
Retrieval 77
Flexibility 77
Operational Base 77
Multiple Identification 77
Stable File Layout 77
Conclusion 77

FIGURES

		Page
Fig. 1	Location of LANDSAT Frames Used in SPSA Phase I Inventory	5
Fig. 2	1:24000 Scale Alphanumeric Computer Map of All Phase I Inventory Classes	7
Fig. 3	1:24000 Scale Alphanumeric Computer Map Indicating the Distribution of Water Only	9
Fig. 4	1:24000 Scale Alphanumeric Computer Map Indicating the Distribution of Forest Only	10
Fig. A1	Electromagnetic Spectrum	28
Fig. A2	Interaction of Solar Energy with a Forested Area	30
Fig. A3	Flow Chart Optical Mechanical Scanner Data Collector	31
Fig. A4	Analog Tracing of Reflected Energy in a Pasture/Water Area in the Four LANDSAT Bands	32
Fig. B1	Guide for Map Construction	37
Fig. B2	Symbolization and Scaling Schemes	39
Fig. B3	Common Map Scales	41
Fig. B4	Illustrated Distortion which Appears on World and Hemisphere Projections	42
Fig. B5	Geometric Forms and Their Projection	43
Fig. B6	Meridians and Parallels	44
Fig. B7	The Township and Range Survey System Subdivision	46
Fig. B8	The Transverse Mercator Projection	48
Fig. B9	The Grid Zone-Row Designation of the UTM Grid	49
Fig. B10	A UTM Grid Zone Showing the Point of Origin, Longitudinal Extent and the Control Meridian	50
Fig. B11	False Eastings and False Northings for a Grid Zone	50

Fig. B12 Subdivision of Grid Zones into 100,000 Meter Squares. 51

Fig. B13 The Relationship of Grid Zone 16 to the State of Indiana 52

Fig. B14 Method of Grid Squares Subdivision in the UTM 53

Fig. B15 Indiana, Showing the Relationship of the UTM Grid and the TM Projection 54

Fig. C1 Portion of the Electromagnetic Spectrum Important to Aerial Photography 59

Fig. C2 Spectral Response Profile of Light Sensitive Systems 59

Fig. C3 Vertical and Oblique Aerial Photographs. 60

Fig. C4 Study Area with Flight Line Orientation and Showing Aerial Photograph Overlap. 62

Fig. C5 Characteristics of the Vertical Aerial Photograph 63

Fig. C6 An Example of an Aerial Photograph 64

Fig. C7 Image Displacement and RF Distortion on an Aerial Photograph 66

Fig. D1 One Side of the United States Geological Survey (USGS) Sheet of Map Symbols 74

Fig. D2 One Side of the United States Geological Survey (USGS) Sheet of Map Symbols 75

Fig. D3 A Symbolization Scheme To Be Used With Computer Generated Maps Produced on a Line Printer. 76

TABLES

Page

1. U.S. Geological Survey Land Cover Classification System for Use with Remote Sensor Data 6

A1 Spectral Responses of Selected Earth Surface Features in Various Electromagnetic Bands 35

FOREWORD

The Indiana Land Cover Classification Manual constitutes volume six of the Planning Information System series being published by the State Planning Services Agency.

This publication, as a guide to mapping, provides both planners and the general public with information useful in the preparation and use of maps frequently encountered in the planning process. The classification system being used with remotely sensed satellite data is thoroughly explained and presented within this manual.

We hope that the presentation of a land cover classification system is beneficial to those engaged in this type of inventory and analysis, and we trust that the general guidelines for mapping will serve all of us in mapping-related endeavors.

ROBERT D. ORR
Lieutenant Governor
Director

INDIANA LAND COVER CLASSIFICATION
MANUAL: A GUIDE TO MAPPING

INTRODUCTION

The use of our nation's land has long been a concern of government from the local level all the way to the national level. Before any meaningful analysis of this use of land can be made, it is necessary to classify it into a variety of categories. In the formative years of planning, surveys involving the uses of land were done via the "windshield" method, that is, actually observing the particular use and noting it on a tabular chart. Technology has made long and rapid strides in many fields, not least among them, the survey of the uses of land from satellites hundreds of miles above the earth's surface "tabulating" hundreds of square miles of land in a single photographic image.

This manual concerns itself with the Level I categorization of the use of land otherwise known as land coverage. Level I is then the most basic categorization of coverage namely (1) Urban and Built Up, (2) Agriculture, (3) Forest Land, (4) Water, (5) Wetlands, and (6) Barren Lands. Level I land coverage information has been efficiently and economically gathered by ERTS-A and ERTS-B (satellite) sensors and is displayed at a scale of the standard 1:24000 United States Geological Survey (U.S.G.S.) topographic map from which a substantial amount of supplemental input can also be obtained.

Current data on land coverage are vitally needed for both governmental and private sector decision making on matters related to land, such as:

(1) Existing uses of land and land resources;

(2) Projections of land use needs and land resource development including energy facilities siting needs;

(3) Housing needs, including housing assistance, and the relationship of housing to employment opportunities;

(4) Identification of public facilities, utilities, open space and recreation needs, transportation needs and other services required to support projected uses of land;

(5) The impact of the recipient's proposed policies on air and water quality, coastal zone management, waste disposal, areas of critical concern, natural resources and the need for conserving natural resources and energy;

(6) Distribution of growth including possible locations for new communities, large

scale projects and key facilities;

(7) The conservation of energy through land use strategies designed to reduce energy consumption and the development of policies designed to facilitiate the recovery of energy resources in a manner compatible with environmental protection and future reuse of lands; and

(8) The effect of major Federal activities on State, area wide and/or local planning and development.

There are several federal programs currently underway which benefit from the data obtained through this program. Certainly, the HUD 701 Comprehensive Planning Assistance Program can put it to very good use. The 701 program was designed to assist communities in the preparation of long range development plans for their land area.

Subsequent to 701, other programs more specific in nature and environmentally oriented have evolved. These were directed at water pollution and waste disposal, yet the use of land was the underlying factor in both.

Section 208 of the Federal Water Pollution Control Act of 1972 established a program for the development of areawide waste treatment management plans in highly urban-industrialized areas. Subsequent regulations combined Section 208 and Section 303 (e), basin planning, into a single program. The result of this effort is the requirement for effective coordination of state and areawide planning and implementation.

In addition to the integration of water quality programs including Sections 303 (e) and 201, facilities design and construction, on the State, areawide, and local level, Section 208 planning also requires strong coordinative ties with other major federal programs. Through a series of federal interagency agreements a process for achieving the goals of each program without duplication was developed. Through this system, water quality goals are stressed in Section 208 and land planning activities are subordinated to the extent that they are available through other programs, primarily the HUD "701" program.

The State of Indiana is also engaged in a comprehensive planning program focused on the resources of the State's coastal area -- the Lake Michigan shoreline. Under provisions of the Coastal Zone Management Act of 1972, which includes the Great Lakes states, a program is established to encourage states, through the development and implementation of management programs, to achieve wise use of the land and water uses of the coastal zone, giving full consideration to ecological, cultural, historic, and aesthetic values as well as to needs for economic development. Data obtained through the land cover mapping program described herein as providing data for the HUD 701 program is also utilized by the Coastal Zone Management program on the basis of interagency agreements between HUD and the U.S. Department of Commerce.

STATE PLANNING SERVICES AGENCY (SPSA) LAND COVER INVENTORY

Phase I, the acquisition and display of level I land cover features for Indiana, was developed through the efforts of the State Planning Services Agency (SPSA). An objective of developing level I land cover categories was to provide inventory information to help planners or other individuals assess the nature of Indiana's earth surface features. Phase I data provides only the most basic land cover information which all planners can use immediately, but these data also serve as a foundation upon which to build and add new information as it becomes available.

It must be stressed that this phase I classification is a low cost inventory designed to provide land cover information for a relatively small number of land cover classes. A more intensive analysis of two dates of LANDSAT multispectral data, if conducted, will result in development of twenty or more land cover classes. The 20 class inventory derived from intensive analysis of LANDSAT data will be easier to use than the eight class phase I analysis because delineation of urban from rural will not be required. Some of the classes will be identified more accurately in the 20 class inventory than in the phase I inventory.

The data provided in this initial classification provides valuable information and also gives insight into a new data acquisition tool. The phase I inventory should not be applied to complex planning problems which require 15 or more classes of information. Phase I is an initial attempt to develop land cover information from machine processing of multispectral data.

Level I Land Cover Categories

The land cover inventory developed for the State Planning Services Agency (SPSA) is following the classification system developed by Anderson, Hardy, and Roach in the U.S. Geological Survey Circular 671. This system of classification has been accepted widely for use in both the academic and non academic communities.

Level I, which is concerned only with very general land cover classes, has nine divisions (Table I). Six of the nine level I categories are represented in Indiana. These six categories (water, wetlands, forest, agriculture, barren land, and built-up) are the earth surface features which are examined in the SPSA phase I inventory. The distribution and amount of level I categories possible to identify were developed for each Indiana county utilizing machine processing of four bands of LANDSAT multispectral data.

Nature of the Classification – Phase I

The multispectral information used for phase I analysis was obtained from the EROS Data Center, Sioux Falls, South Dakota. Each formated LANDSAT data tape contained the four bands of multispectral data as identified previously. Even though each data tape contains spectral information for more than 11,000 square miles it nevertheless takes nine data tapes (100,000 square miles) to fully cover the state of Indiana whose area is slightly more than 36,000 square miles. Figure 1 shows how portions of LANDSAT frames were used to fully cover the state.

The LANDSAT multispectral data were analyzed using a variety of LARSYS techniques, to permit preparation of accurate and low cost land cover inventories. This analysis combined spectral information from the designated earth surface features in all four LANDSAT bands in order to maximize the accuracy of land cover classification. The exact procedures used to develop the phase I inventory are not described in this manual; however, details concerning the specific techniques used are available upon request.

Format of Machine Processed LANDSAT Data

Analysis of multispectral data leads to accurate classification of land cover which can be displayed in two basic formats. Within each format different forms of display are possible. The two basic display formats are electroncially synthesized image and the alphanumeric computer printout (Figure 2).

Image format often looks like a photograph but in reality is a display of different intensities of light in which each light or color level represents a spectral response or an individual earth surface feature. Generally these light or color levels are displayed on a cathod ray tube (CRT) and photographed through a special set of filters. The image output is similar to a high quality photograph of a television picture. The map scales of LANDSAT images available commercially are 1:250,000 to 1:3,369,000. Image displays of classified LANDSAT data or of unclassified spectral responses are very useful in providing a broad overview of earth surface feature information. These images are often very impressive in appearance; however, the information they contain (as a consequence of small scale) is insufficient to be used extensively in making planning decisions.

An image mosiac of the entire state of Indiana at a 1:250,000 scale has been prepared. The mosiac simulates a color infrared photograph. Three bands of LANDSAT multispectral data were electronically combined and photographed with special filters which creates the

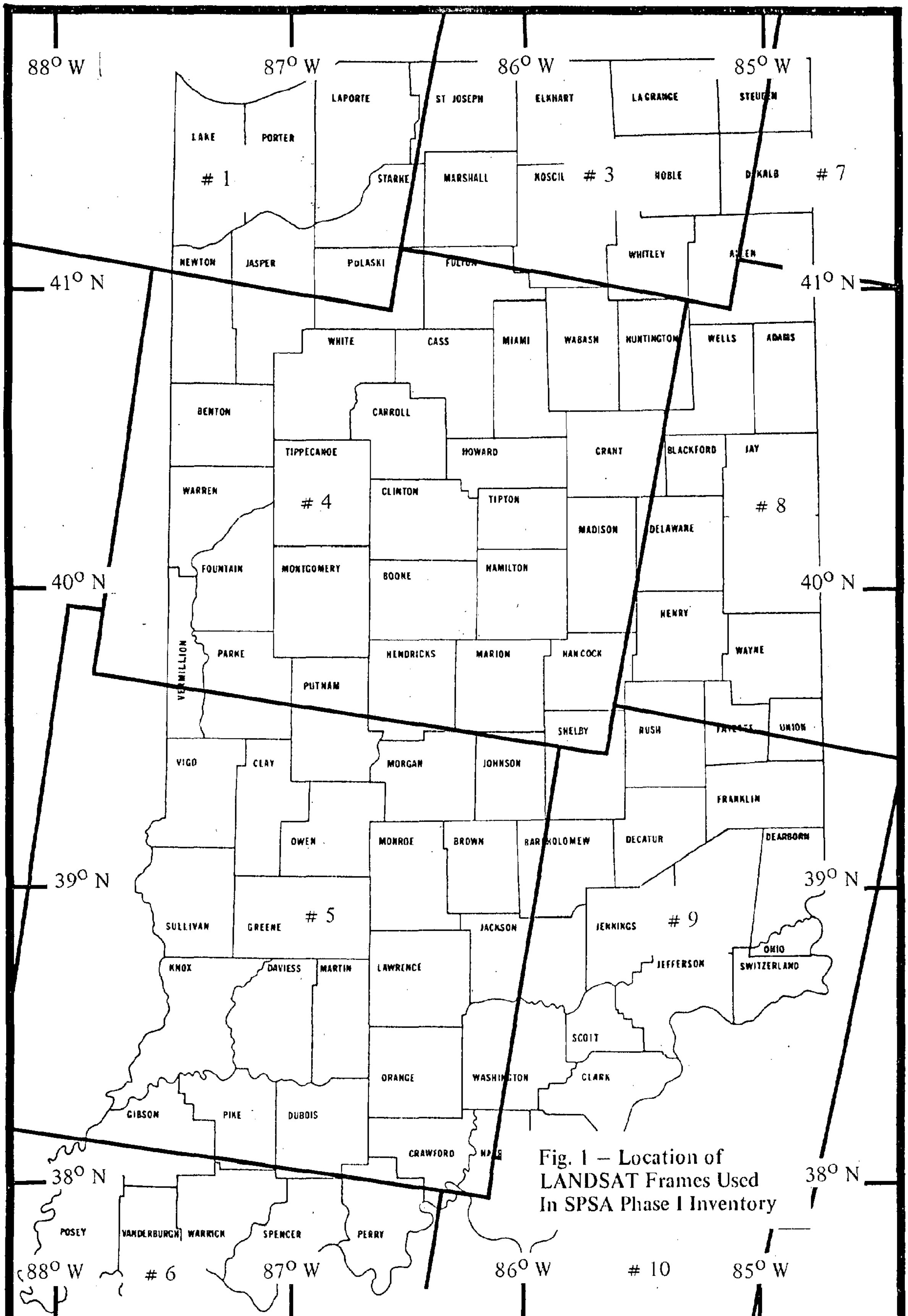

Fig. 1 – Location of LANDSAT Frames Used In SPSA Phase I Inventory

TABLE I

U.S. GEOLOGICAL SURVEY
LAND COVER CLASSIFICATION SYSTEM
FOR USE WITH REMOTE SENSOR DATA

LEVEL I	LEVEL II
1 Urban or Built-up Land	11 Residential
	12 Commercial and Services
	13 Industrial
	14 Transportation, Communications and Utilities
	15 Industrial and Commercial Complexes
	16 Mixed
	17 Other
2 Agricultural Land	21 Cropland and Pasture
	22 Orchards, Groves, Vineyards, Nurseries, and Ornamental Horticulture Areas
	23 Confined Feeding Operations
	24 Other
3 Rangeland	31 Herbaceous Range
	32 Shrub-Brushland Range
	33 Mixed
4 Forest Land	41 Deciduous
	42 Evergreen
	43 Mixed
5 Water	51 Streams and Canals
	52 Lakes
	53 Reservoirs
	54 Bays and Estuaries
6 Wetland	61 Forest
	62 Nonforested
7 Barren Land	71 Dry Salt Flats
	72 Beaches
	73 Sandy Areas Other Than Beaches
	74 Bare Exposed Rock
	75 Strip Mines, Quarries, and Gravel Pits
	76 Transitional Areas
	77 Mixed
8 Tundra	81 Shrub and Brush Tundra
	82 Herbaceous Tundra
	83 Bare Ground Tundra
	84 Wet Tundra
9 Perennial Snow or Ice	91 Perennial Snowfields
	92 Glaciers

CLASSES

SYMBOL	CLASS	SYMBOL	CLASS
&	BARREN	.	RES/AGI
S	SHADOW	-	URB/SOIL
W	WATER	I	RES/FOR
C	CLOUD	#	WETLAND
F	FOREST		OTHER
@	GREENVEG		

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     7777777777777777777777777777777777777777777777777777777
     0000000000111111111122222222223333333333444444444455555
     0123456789012345678901234567890123456789012345678901234

110  @II.@@@@@FFF.FFFFFFF@@FFFFWWWWWWWWWWWWWWF@@@@@@FFFFFFF
111  SSII@@@@...@F@@FFFFFFFFFFFFFWWWWWWWWWWWWWWFFFFFF@@FFFFFF
112  --@F@..@.@@..--@@-.FFFFFFFFWWWWWWWWWWWWWWS#FFFFFFFFFFFF
113  ---@F@@.F@.@F.--FFFFFFFFFFFFSWWWWWWWWWWWWWWWIFFFFFFFFFFFF
114  ---@F@.......C.FFFFFFFFFFFFFWWWWWWWWWWWWWWWWFFFFFFFFFFFFF
115  -I@@@@@...@.@CC..FFFFFFFFFFFIWWWWWWWWWWWWWWSFFFFFFFFFFFF
116  @@@@@@@@FFF@@@@F@FFFFFFFFFFF#SSWWWWWWWWWWWWWSSFFFFFFFFFFF
117  F@@@@@@@@@@@@@@FFFFFFFFFFFFFFFFWWWWWWWWWWWWWSF#FFFFFFFFFFF
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119  I@@@@.@.IFFFIFFFF@FFFFFFFFFFFFFFWWWWWWWWWWWWSSFFFFFFFFFFF
120  IFF@@@FF@@FFIFFFF@@@FFFFF@SSS##WWWWWWWWWWFFFFFFFFFFFFFFF
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135  -I.FF@@FFFFFFFFFFF@@@@FFF@FFFSWWWWWWWWWWW#FFFFFFFFFFFFFFF
136  --.@...@@FFFFFFFFFFFFFF@@@FF#WWWWWWWWWWWWWSFFFFFFFFFFFFFFF
137  I@I@@@I@@@@@@@FFFFFFFFFF@FFFFWWWWWWWWWWWWW#FFF@FFFFFFFFFF
138  I@@@@II@FFFFFFFFF@FFFFFFFFFFFFFSWWWWWWWWWWWW#FFFFFFFFFFFFFF
139  @@@----@FFFFFFFFFFFFFFFISWWWWIWWWWWWWWWWWWWWI@@FFFFFFFFFFF
140  @@@--I@-@@@F@FFFFFFFFFFFIIFWWWWWWWWWWWWWWWSFF@FFFFFFFFFFFF
141  @@@@@I@@@.---@@FF@-FFFFFFF#SWWWWWWWWWWWWW#FFFFFFFFFFFFFF
142  @@@I----------IIFF--@@@FFFFFFFFWWWWWWWWWWW#FFFFFFFF@@FFFF
```

Fig. 2 – 1:24,000 Scale Alphanumeric Computer Map of all Phase I Inventory Classes

false color or infrared image. The red color on the mosaic indicates the presence of green vegetation while light blue, gray, and white represent urban features and bare soil. Dark blue and black generally are associated with water features and wetlands. The 1:250,000 color infrared LANDSAT image of Indiana contains useful information about water, vegetation, soil, and cultural features but it is not a land cover classification by itself.

The alphanumeric computer map is the format used to display classification results of the land cover inventory. As shown in Figure 2, an alphanumeric computer map displays information by symbols (letters, numbers or other types of symbols). Each symbol identifies a type of earth surface or defines a range of relative spectral response values. The map is produced on a line printer which types assigned symbols (following computer instructions during machine processing) which identify the appropriate land cover class or spectral response information as determined by LARSYS (computer) analysis of LANDSAT multispectral data (LARSYS is the set of computer programs developed by the laboratory for applications of remote sensing at Purdue University, to analyze multispectral data).

Characteristics of a LARSYS Alphanumeric Display

As indicated in the general introduction section, the resolution of LANDSAT is approximately 80 meters, thus the smallest area which can be cartographically displayed is also approximately 80 meters. Actually, discrete earth surface features 60 meters by 80 meters in area can be displayed by a single symbol on a LARSYS computer map. This display is the most detailed possible using LANDSAT data. The 80 meter resolution, when displayed at the most detailed scale, results in printing at an approximately 1:24,000 map scale (2.6 inches on the map represents 1.0 mile on the earth's surface). The SPSA phase I LANDSAT data was specially formatted (geometrical correction) to assure an alphanumeric computer map with a 1:24,000 scale with correct directional properties. Geometrical correction permits virtually perfect correspondence between the classification output and 1:24,000 scale U.S.G.S. topographic maps. The ability to directly overlay classification results on topographic maps facilitates rapid and effective use of classification output by the user. Individual 60 meter by 80 meter areas on the alphanumeric maps are identified by line and column coordinates. For example the 60 by 80 meter area circled in Figure 2 has a geographic address of line and column.

The phase I inventory has been presented in a manner in which all categories are indicated on a single classification display to show classification results one or two classes at a time in a form of thematic map. Figures 3 and 4 are examples of one or more classes highlighted on a single 1:24,000 (all classes not of interest are left blank). Display in this form makes it very simple for the analyst to extract the exact information desired. The costs of displaying classification results in thematic form are not high after the full classification has been

CLASSES

SYMBOL	CLASS	SYMBOL	CLASS
	BARREN		RES/AGI
	SHADOW		URB/SOIL
W	WATER		RES/FOR
	CLOUD		WETLAND
	FOREST		OTHER
	GREENVEG		

```
     7777777777777777777777777777777777777777777777777777777
     0000000000111111111122222222223333333333444444444455555
     0123456789012345678901234567890123456789012345678901234

110                            WWWWWWWWWWWWWWW
111                             WWWWWWWWWWWWWW
112                             WWWWWWWWWWWWWW
113                              WWWWWWWWWWWWWWW
114                              WWWWWWWWWWWWWWW
115                              WWWWWWWWWWWWWW
116                               WWWWWWWWWWWWWW
117                                WWWWWWWWWWWW
118                                WWWWWWWWWWWWW
119                                WWWWWWWWWWWW
120                                 WWWWWWWWWW
121                              W WWWWWWWWWWW
122                               WWWWWWWWWWWW
123                                 WWWWWWWWWW
124                               WWWWWWWWWWWWW
125                              WW W  WW WW  W
126                                WWW  WWWWW
127                            WWWWWWWWWWWWWW
128                             WWWWWWWWWWWWW
129                             WWWWWWWWWWWWW
130                         W   WWWWWWWWWWWWW
131                           WWWWWWWWWWWWWWWW
132                              WWWWWWWWWWWW
133                             WWWWWWWWWWWWWW
134                              WWWWWWWWWWWW
135                               WWWWWWWWWW
136                              WWWWWWWWWWWW
137                              WWWWWWWWWWWW
138                               WWWWWWWWWWW
139                         WWWW WWWWWWWWWWWWW
140                            WWWWWWWWWWWWWW
141                              WWWWWWWWWWWW
142                               WWWWWWWWWWW
143                                WWWWWWWWWW
144                               WWWWWWWWWWWW
145                                WWWWWWWWWWWW
```

Fig. 3 – 1:24,000 Scale Alphanumeric Computer Map Indicating the Distribution of Water Only

CLASSES

SYMBOL	CLASS	SYMBOL	CLASS
	BARREN		RES/AGI
	SHADOW		URB/SOIL
	WATER		RES/FOR
	CLOUD		WETLAND
F	FOREST		OTHER
	GREENVEG		

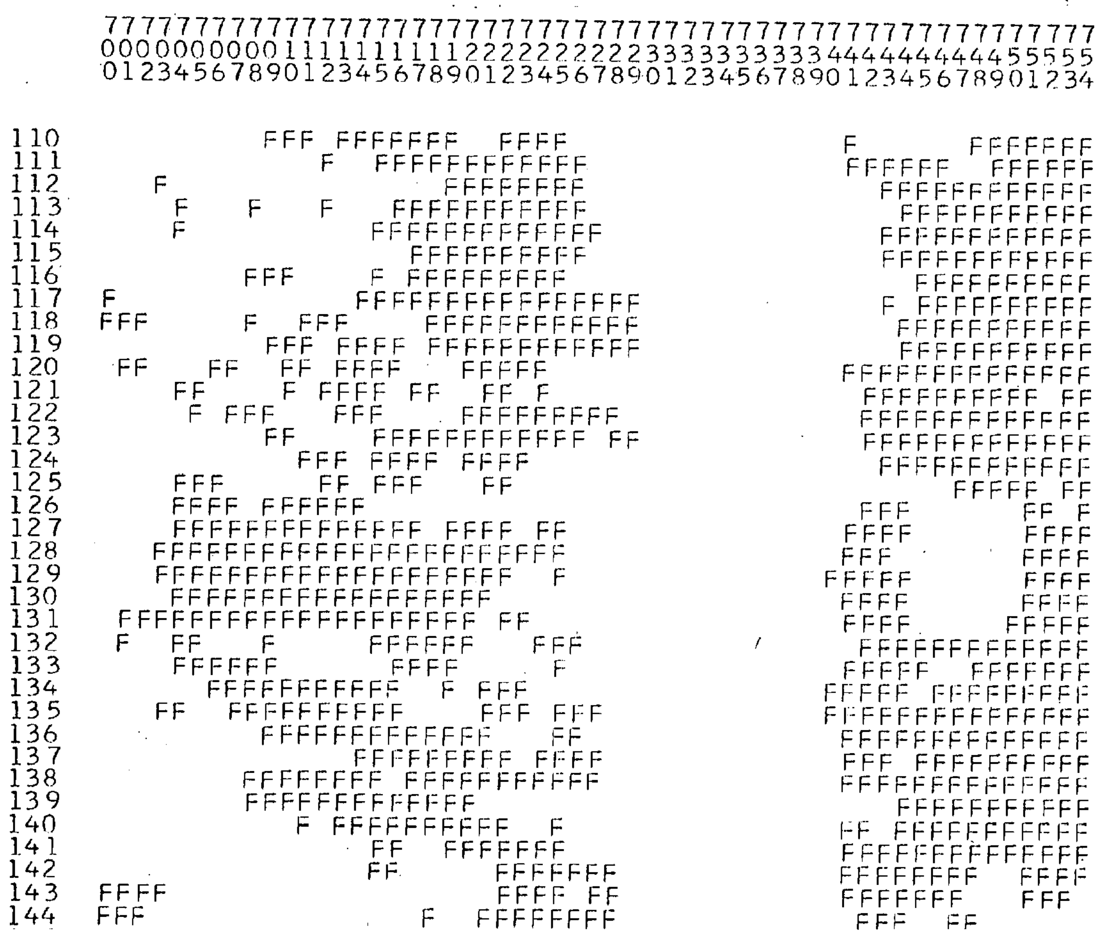


Fig. 4 – 1:24,000 Scale Alphanumeric Computer Map Indicating the Distribution of Forest Only

completed. Thematic maps are not enclosed in this package because different users might want somewhat different classes or combinations of classes highlighted.

Those wishing to obtain thematic maps of the phase I classification of a county or group of counties can do so at cost from the State Planning Services Agency. The average per county cost for each copy of a 1:24,000 scale thematic map derived from the phase I classification is reasonable.

The 1:24,000 scale should be used to extract the maximum amount of land cover information available through LARSYS analysis of multispectral data. Planners often use 1:250,000 scale maps when gross regional patterns need to be identified. The U.S.G.S. is beginning to publish 1:100,000 scale topographic maps which are anticipated to be warmly received by potential users.

Indiana planners who would like more highly generalized maps of the phase I inventory can obtain them from the State Planning Services Agency. Instead of having classification results printed for every line and every column at a 1:24,000 scale, every fourth line and every fourth column can be printed resulting in a 1:96,000 scale. Every tenth line and every tenth column can be printed to give a 1:240,000 scale. In fact, any scale in multiples of 24,000 can be developed once the basic classification has been developed. The size of an average Indiana county at a 1:24,000 scale is approximately 60 inches by 60 inches. Reducing the classification to a 1:96,000 scale results is displaying basic land cover patterns on a 15 inch by 15 inch map for an average county. A county would shrink to a six inch area at a 1:240,000 scale.

If alternate scale county maps are needed, users should contact the State Planning Services Agency. These smaller scale versions of the phase I inventory will be developed to the specifications of planners at actual cost of generation.

Interpretation of Alphanumeric Classification Display

A low cost eight category land cover inventory developed from LANDSAT multispectral data has nomenclature, display and interpretation characteristics which require explanation to be utilized effectively. The SPSA phase I inventory displays many classification results which can be taken directly from the computer maps. In some instances information from the 1:24,000 scale topographic maps must be combined with the computer map information to assure a proper interpretation of the land cover patterns displayed on the alphanumeric printouts. There are some areas on the classification map where symbols in certain spatial combinations provide additional insight into the nature of the land cover. Guidelines are provided to interpret the nature of earth surface features in areas where symbol combinations provide more data than the legend alone indicates. An 80 meter resolution imposes certain restraints on the detail and accuracy of land cover classification. The limitations on classification imposed by resolution of the system and the nature of the data processing is presented.

An absolutely accurate land cover inventory developed from data collected 550 miles about the earth's surface cannot be expected. Land cover inventories developed from interpretation of aerial photographs or on-site investigation also cannot have perfect accuracy. Photo interpretation and on-site survey methods of developing land cover inventories are not only subject to classification errors but they also are very costly and time consuming to complete. Overall, the accuracy of land cover classifications derived from intensive LARSYS analysis of LANDSAT multispectral data compares favorably with that of aerial photointerpretation or windshield survey methods, although the analytic techniques used are different. The accuracy of the SPSA Phase I land cover inventory is anticipated to approach 80 to 90 percent overall (assuming interpretative procedures discussed in the manual are followed). A feature such as water usually has a classification accuracy near 98 percent while most of the other categories of earth surface features will have lower identification accuracies which are still useful for general planning uses.

The following section contains a description of the physical characteristics of each one of the phase I land cover categories developed. The spectral characteristics used to differentiate each category from the other are presented briefly. Procedures have been developed to properly interpret the distribution and nature of each land cover feature in the phase I inventory.

It should be reemphasized that the eight category SPSA phase I land cover inventory is designed to provide a very general data base useful to planners. The concurrent use of phase I inventory can serve an important educational function because it provides insight into and introduces a powerful method of data acquisition and analysis for community planning. However, the phase I classification provides less data than machine processing of LANDSAT multispectral data is capable of producing. Phase I was developed using state-of-the-art remote sensing techniques which intentionally focused on analyzing only a very limited number of earth surface features. It is anticipated that more intensive application of the technology used to develop the phase I inventory will result in the generation of much more detailed and accurate land cover information in the near future. Planners who gain experience in using phase I data will be in an excellent position to use more sophisticated land cover data in the future. Thus the phase I information should be considered in light of its educational value as well as providing a broad current land cover data base suitable for selected planning uses.

The phase I inventory, albeit limited in number of classes to eight, nevertheless, has several classification problems which the user must recognize. LANDSAT multispectral data more intensely analyzed can result in producing a 20 category inventory with improved accuracy and greater simplicity of use. However, special interpretative procedures often should be used by a land cover analyst even in a more detailed analysis.

The first and most basic procedure which must be followed in the phase I classification is the delineation of rural from urban concentrations. A single date analysis utilizing June LANDSAT data analyzed with moderate intensity presents several classification problems which will in large part be rectified in a future LANDSAT analysis which develops 20 or more classes of earth surface information. This future phase would use more intensive analysis of Indiana LANDSAT data from a date later in the summer and possibly supplemented by early spring LANDSAT data.

The basic classification problem of phase I is caused by spectral similarities between rural and urban features. For example, many types of bare soil are spectrally similar to many urban features without vegetation. At the phase I level of classification it is not practical to try to separate these two basic features spectrally, but better spectral separation should be possible in a future inventory. If rural areas are broadly subdivided from the urban setting by using topographic maps or other data sources, then a high degree of classification accuracy can be achieved by using only phase I data. For example, in the phase I inventory the non-vegetated urban/bare soil class areas found in areas delimited as dominantly rural should be interpreted either as bare soil or land soon to be in agriculture. In contrast, land in this same category located in a dominantly urbanized or metropolitan area should be considered as non-vegetated urban.

In addition to the urban/rural combined non-vegetated urban/bare soil class, there are four other classes whose interpretation changes depending on whether or not the location is basically urban or rural. The other combined classes are: (1) low density residential/mature agriculture; (2) medium density residential/moderately mature agriculture; (3) high density residential/immature agriculture; and (4) urban/rural barren. The classes water, wetlands and forest do not require rural/urban interpretation although they may require implementation of other selected procedures to assure good classification results in some areas.

Water – The class water, identified by the symbol "W" on the alphanumeric printouts, includes all standing and moving waters which do not contain large amounts of macro-biotic forms (water with grass or trees is excluded but water with macro-plant life such as algae is included). Several different types of water based on difference in silt content, chemical content, and micro plant life can be accurately identified using LANDSAT data. A future land cover inventory containing 15 to 20 categories identified might easily differentiate three or four different spectral classes of water.

The phase I inventory of water includes all types of standing or moving waters from the purest to the most silty or eutrophied in a single class. Lakes, ponds, rivers, reservoirs, bays and estuaries are all included in the class termed water. Water is the land cover feature easiest to identify accurately because in the LANDSAT infrared bands (bands 3 and 4) water has spectral responses lower than other surface features classified in the phase I project. This unique pattern of low spectral response is easily identified during machine processing, and results in a 98 percent accuracy in classification.

Even though water is correctly identified with a 98 percent degree of accuracy, the four following conditions can cause water not to be identified correctly. In fact, some other non water earth surface feature may be identified as water.

a. A water feature smaller than 60 meters in length or width can be misclassified because features other than the water will reflect and emit energy in a pattern uncharacteristic of water in part of the LANDSAT 80 meter resolution unit. Thus, very small ponds and narrow rivers generally will not appear on the classification. Even rivers or other water bodies somewhat larger than the 80 meter resolution may not precisely define a water-non water boundary in instances where water and non water both share a portion of a single RSU (minimum size area for which multispectral data is collected). This misclassification problem disappears when the total area of a resolution unit(RSU) falls entirely within a single category of earth surface feature. The problem of misclassification caused by dissimilar earth surface features occupying a single RSU is common to all phase I classes.

b. Very silty water such as that found in many rivers or shallow ponds is spectrally similar to some types of industrial/commercial complexes that have very dark asphalt roofs or selected types of water-saturated barren lands. Thus, it is possible that few points classified as water in urban areas are part of an industrial/commercial feature. Some confusion between barren and water is also possible. Usually a planner will identify these few misclassified water points in urban areas by recognizing the fact that water as a class is not associated with most urban areas. A comparison of classification results with a 1:24,000 scale topographic map will confirm or deny the presence of water in an urban location where it is questionable. This type of misclassification is not widespread but it is a possibility in urbanized areas.

c. Spectrally, some types of wetlands appear similar to two very silty types of water. Water merges into wetlands in some instances and these transition zones are difficult to evaluate. It is possible, but not common, for some wetlands to be classified as very silty water and vice versa. It is difficult to evaluate the accuracy of water classification in very silty water-wetland transition zones because these two features occur along a continuum characterized by standing water adjacent to land strongly influenced by water but containing vegetation and/or soil.

d. Water, and to a much greater degree wetlands, is not often a stable feature which occupies exactly the same area every day of the year. For example, the distribution of standing water on the Wabash River floodplain after an extended period of heavy precipitation will be very extensive. During this period, land which is normally wetland or one of several dryland classes, is temporarily water. In a recent study at ISU it was found that in

February, 1973 the Wabash floodplain in Vigo county contained three times the amount of standing water shown on the 1:24,000 scale topographic map. A photograph taken the same day as the LANDSAT pass whose data were analyzed confirmed the presence of the greater amount of water. Undoubtedly, by late summer the distribution of water in this area corresponded much closer to what was indicated by the topographic map. The date of LANDSAT data acquisition used in this phase I inventory study was June 7-June 10, 1973 except for a small portion of southwestern Indiana which has a July 10, 1974 analysis date. The distribution of water and wetlands relates to these dates only. Some areas will change their land cover category several times a year as water fills low lying areas and slowly dries out. It is these intermittent wetland wetland areas that are difficult to classify in a single analysis. However, it is possible to determine the nature of intermittent wetlands analysis of LANDSAT if data are collected during several time periods throughout a year and for a series of years.

In as much as variations in the characteristics of selected earth surfaces vary temporally, it is possible that the distribution of phase I land cover categories will not always be identical to that indicated on a topographic map or photograph. It may well be that on-site inspection, photography, topographic maps, and phase I classification will produce somewhat different inventory data because each data display has been generated in a different manner and describes land cover distribution in a different time framework.

Wetlands – The class wetlands, designated by the symbol "#" on the printouts, is not as easily or clearly defined as are some of the other phase I categories. Wetlands include swamp and swamplike areas which may contain water with grass or trees growing in them at the time of analysis. Wet, high organic soils (with or without vegetation) which are poorly drained and not used for cultivation are considered wetlands. Very moist forested areas, primarily located in valleys, are also considered as a type of wetland. Very shallow, silty, standing water with almost as much silt as water (mud flat) without vegetation also is considered wetland.

As in the case of water, the IR bands 3 and 4 are most useful in differentiating wetlands from other earth surface features although spectral information from the visible bands 1 and 2 are more important than they were for the analysis of water. Because wetlands are a mixture of water and other materials, principally soil and green vegetation, their spectral response in the infrared bands is higher than that of water but lower than that of bare soil or vegetation in a well drained condition.

Five problems and characteristics in classification of wetlands are discussed below. They include:

a. Dense green vegetation may so thoroughly cover the very poorly drained soil or shallow standing water that the presence of water will not be detected by the LANDSAT satellite. This condition would not pose a great problem during the winter-early spring months. However, the June date of the phase I analysis may include the problem of wetlands being misclassified either as forest or agricultural land.

b. Very silty water and adjacent wetlands will be subject to some confusion in the transition zones. It is difficult to evaluate the accuracy of classification in these transition zones where water contains vegetation because of a lack of a method to precisely define where water ceases and wetland vegetation begins.

c. Some wetlands spectrally resemble selected dark colored industrial/commercial features. However, these misclassification errors generally can be detected by observing the pattern of distribution by overlaying a 1:24,000 topographic map with the phase I classification (see text in water discussion).

d. Shadows from clouds have a similar low spectral response in all bands as some dark industrial/commercial buildings and very silty water. Because of this spectral similarity, a small percentage of wetlands might be classified as shadow and vice versa. Generally this type of misclassification can be resolved because clouds are easily identified and the shadow from the clouds is uniformly cast in a westerly direction a short distance from the cloud.

e. In areas of high slope (primarily southern Indiana but also in severely stream dissected areas in other parts of the state) there may be enough shadow cast from hills to mask an earth surface in the shadow. LANDSAT passes over Indiana at approximately 9:30 a.m., thus the shadowing effect in rough terrain is a possibility. The land cover features in this type of shadow are impossible to determine spectrally; however, assigning the land cover category adjacent to the shadow generally yields good results and decreases the degree of misclassification.

The phase I inventory combines all wetlands into a single class. As in the case of water it is possible to separate wetlands into two or more subdivisions (forested and non forested wetlands can be developed) if LANDSAT multispectral data are more intensely analyzed.

Forest lands – Forest lands in Indiana as identified by the symbol "F" on the printouts, includes deciduous trees, evergreen trees, and mixed forest. Forest with grass (low density forest) is also considered forest in the phase I inventory. In contrast, areas which are dominantly pasture but contain a few trees are most similar to grass (agriculture) spectrally, thus are classified as residential-agriculture. This classification is not one of the spectrally, thus are classified as residential-agriculture.

LANDSAT spectral data obtained from forests are similar to some subclasses of land cover features which are dominated by green vegetation. The basic pattern of spectral response in which the red band (2) is very low in comparison to the near infrared band (3), is characteristic of forest as well as mature agriculture. However, in the case of forest, these responses are lower overall than most green vegetation found in the category which includes mature agriculture. Because of this spectral difference, forests can be differentiated from other earth surface features with an accuracy of approximately 90 percent.

A summary of the possible types of misclassification is provided, and reasons for the problem and procedures taken to improve classification results will be discussed briefly. The principal types of potential misclassification are: a. cloud shadow and dense, moist lowland forest; b. wetland and dense, moist lowland forest; c. mature agriculture and forest; and d. large lot suburban and forest. All of these potential misclassifications are minor.

Forest is one of the most accurately defined classes of phase I, but cloud shadow will be confused with some forest if the clouds are of a certain density. There are relatively few clouds in the phase I classification and most of those clouds do not cast a shadow which could be confused with forest. It is possible to evaluate this problem in the few areas it might exist by noting that shadows have a spatial pattern similar to clouds (also identified on the classification) which are displaced a few miles to the west of the cloud.

Very dark and moist forests that are often found in valley bottoms or on shady slopes may be classified as wetland. This classification confusion is minor and if it does occur is not a major problem because this type of forest acutally can be considered a near wetland environment. Evaluation of contour lines on topographic maps indicate where river valleys and depressions are located. This topographic evaluation can be used to help confirm or reject the presence of a wetland classed as a forest or vice versa.

A small percentage of mature cropland can be confused with dense deciduous forests because both features have similar (but generally not identical) spectral responses. Misclassifications usually can be corrected by noting that the spatial pattern of most forests is irregular while that of cropland is more rectangular.

Residential areas, particularily those built on large lots with well watered grass and trees, may spectrally appear as green vegetation with some higher reflective, non vegetated material. In a few instances, forest will be nearly identical (spectrally) in pattern to large-lot suburban, and may be identified as such.

A more intensive analysis of LANDSAT data could identify at least four classes of forest. These classes are: (1) dense stands of deciduous; (2) less dense stands of deciduous; (3) needleleaf forest (primarily associated with mine spoil and sand areas in Indiana; and (4) mixed forest.

The remaining five informational categories of the phase I classification have different interpretations depending on whether or not a classified point is located within a metropolitan region or in a predominantly rural area. It is assumed that the delineation of rural and urban areas have been made using sources other than the phase I inventory. Characteristics of these five classes and a discussion of classification problems are presented.

<u>Non Vegetated Urban/Bare Soil</u> – In urban areas this class identified by the symbol "–" or URB/soil, includes features that are totally vegetation free and constructed of materials which are moderately to highly reflective in all the LANDSAT bands. A majority of commercial buildings, many industrial buildings, transportation lines and some apartment

complexes comprise the class termed non vegetated urban. These urban features spectrally are very similar to bare soil, thus they were grouped in the phase I inventory. Large clusters of symbols associated with this class in rural areas should be considered as bare soil unless topographic information or other supplemental data indicate otherwise. Often single or small clusters of symbols in this class in rural areas are urban-like features (i.e. farmsteads, small commercial buildings).

One misclassification problem is the confusion of bare soil or non-vegetated urban features with selected barren features. A few types of dark urban/rural barren land (one of the eight basic categories in the phase I classification) are spectrally similar to some subtypes of strip mine soil, sand pits and rock areas. Some of these features will be classified as non-vegetated urban/bare soil. Using local area data from topographic maps or other sources permits an intelligent evaluation of areas where phase I classification results are subject to more than one interpretation. Analysis of the spatial patterns of the classification can help eliminate misclassification between barren lands and soil. Bare soil generally has rectangular shapes while most barren land features are irregular in shape. In addition, most barren features are located outside metropolitan areas. This information, combined with analysis of shape, usually can differentiate bare soil from barren land features.

An intensive analysis of LANDSAT data can be used to effectively differentiate non-vegetated urban/bare soil into two or three classes. The subdivisions which can be developed in a more intensive analysis are commercial/industrial/transportation, and bare soil. There is a possibility of identifying selected types of industrial features separately from the commercial/industrial class.

High Density Residential/Immature Agriculture – The class termed high density residential/immature agriculture is designated by the symbol " · " (RES/AGI) in the phase I classification. During early June, bare soil with emerging vegetation (i.e. corn, soybeans covering less than 30% of the surface) spectrally is very similar to many types of high density residential features commonly found in urbanized areas. Examples of urban features included in this class are apartment complexes which contain small amounts of green vegetation and light industrial or commercial buildings that have some landscaping. Bare soil which contains small amounts of emerging vegetation has similar proportions of inanimate material and healthy green vegetation as urban features comprised primarily of brick, stone, concrete, metal, and glass which are found in a setting with small amounts of green vegetation. In addition, transportation lines such as 4 lane roads, which have grass median strips will often appear in this class.

Identification of the appropriate features in this class is easy to make after there has been a basic delineation of urban areas from rural areas. In areas delineated as urban, from analysis of topographic maps or other data sources, this class characteristically represents apartments and selected (somewhat vegetated) industrial/commercial features. In rural areas, this class represents agricultural land which, at the date of data acquisition, was dominated by bare soil with small amounts of emerging vegetation covering a minority of the surface.

The spectral responses of features in this class tend to be high in all LANDSAT bands; however, because some green vegetation is present, the response in the visible bands is lowered somewhat. The spectral response is higher (more reflectance) in the infrared bands in response to the presence of a small amount of green vegetation.

The sources of misclassification error are minor after the basic urban/rural delineation has been made. It is possible that some bare soil will be confused with bare soil with small quantities of green vegetation. Also the rural portion of this class can be confused with more intense agricultural development which has spectral characteristics similar to a more mature agricultural area. In urban areas small amounts of commercial/industrial features without vegetation (non vegetated urban) may be classified as high density residential or bare soil with very small amounts of emerging green vegetation. These errors may be corrected with the aid of topographic maps or other source materials. However, the degree of misclassification is generally too small to modify the basic patterns of land cover represented by this category.

Medium Density Residential/Moderately Mature Agriculture – This class is designated by the symbol "I" (RES/FOR) on the alphanumeric computer maps. In urban areas, earth surface features in this class most typically are older residential or small lots of suburban residential areas. Rural areas where green vegetation covers a relatively large percentage of the soil surface (perhaps 30 to 70 percent) is spectrally similar to medium density residential. Initial differentiation of an area into its urban and rural components will permit correct identification of medium density residential features in urban areas and moderately mature agriculture in rural areas. Small concentrations of this class in predominantly rural areas in reality could be a medium density residential feature, but large areas with this designation in rural areas generally will be moderately mature agriculture.

This class contains a greater amount of green vegetation and less inanimate material (i.e. concrete, soil, metal) than is typical for the class high density residential/immature agriculture. The basic earth surface features in this class spectrally have a pattern in which the red band reflectance begins to become severely depressed because green vegetation is absorbing a high percentage of the electromagnetic energy in this portion of the spectrum. Conversely, reflectance in the infrared bands (particularly the .7-.8u band) starts to rise because electromagnetic energy in this portion of the spectrum is strongly reflected from green vegetation.

The identification accuracy of features in this class is satisfactory for planners assuming the basic urban/rural delineation has been made. A few misclassification problems can occur with phase I classes which are somewhat more dominated by green vegetation and somewhat less dominated by green vegetation than is typical for medium density residential/moderately mature agriculture features. Thus, some high density residential or immature agriculture will be identified as a feature in this class, and vice-versa. Low density (large lot) residential or nearly mature agriculture also is subject to confusion with features in this class to a minor degree. This class generally will be found adjacent to water bodies. It seems that individual RSU's are sharing water, bare soil, and vegetation in water/land interface areas which results in spectral similarity to medium density residential/moderately mature agriculture. These two types of misclassification errors are difficult to correct; however, use of additional data sources will rectify some of problems. The misclassification problems indicated are not severe enough to cause major difficulty in evaluation of land cover features.

Low Density Residential/Mature Agriculture – This class is designated by the symbol "@" (GREENVEG). In an urban context this class most commonly is comprised of large lot residential area (generally suburban) which is dominated by grass and trees. A small minority of the area is occupied by man-made features that include houses, roads, and sidewalks. Spectrally, high density residential displays similarities to soil dominantly covered by green vegetation. Low reflectance in the visible bands and high reflectance in the infrared bands are characteristics of earth surface features in this class. Mature or nearly mature agricultural land is included in the same class as large lot residential developments in the phase I inventory. Soil dominantly covered by vegetation (more than 70 percent of the surface) usually represents maturing agricultural land whose spectral response approximates that of low density residential features.

As is characteristic of several other phase I classes, a general separation of urban from rural should be made to insure correct identification of features in this class. Another source of potential misclassification is associated with confusion between features in this class with medium density residential/moderately mature agriculture. Some older residential or small lot suburban developments will be confused with suburban areas which are transitional to larger lot suburban areas.

The transition from moderately mature to mature agriculture also can be misclassified. A very precise definition of high density through low density residential and immature agriculture through mature agriculture has not been attempted in the phase I classification. The accuracy of identifying these transitional areas is difficult to determine. However, the core or central concept of each class is accurately identified in this classification.

The last three classes discussed (high density residential/immature agriculture through low density residential/mature agriculture) would be divided into several subclasses in a more intensive analysis of LANDSAT multispectral data. A more intense analysis would develop classes that include commercial/industrial, inner city, older single dwelling residential, two newer suburban classes, row crops, and small grain/pasture. It also may be possible to differentiate small grain from pasture. Thus, these three classes in the phase I classification would be expanded to seven or eight in a more intensive phase of analysis. A more intensive analysis also would permit direct identification of features without first delineating rural areas from urban.

Urban/Rural Barren – This class is indicated by the symbol "&" (BARREN). Both urban and rural types of barren land are found in Indiana. In urban areas, barren land is represented by features such as junk yards, railroad yards, and industrial areas with dark (asphalt) roofs without green vegetation. In rural areas, barren refers to strip mine spoil, sand pits, gravel pits, and sand dunes. An initial differentiation of urban from rural should be made to facilitate accurate identification of barren land features.

Barren lands are subject to several classification problems which need to be recognized by the analyst using phase I data. Most of the commercial/industrial features in urban areas will be classified as non-vegetated urban, but the least reflective of these features will be classified as barren. These less reflective (generally darker materials to the human eye) commercial/industrial features will be difficult to differentiate from other barren urban features such as junk yards, railroad yards, or large asphalt parking lots. In rural areas barren can be confused with bare soil.

Large areas of bare soil are found in Indiana in June which are subject to misclassification unless caution is taken. In the future, a more intensive analysis of LANDSAT data would eliminate this source of confusion because one of the dates for analysis would occur in mid summer when bare soil would be covered with vegetation. In the phase I June inventory, differentiation of rural barren from bare soil can be made through the analysis of the shape of features and their association with neighboring features. For example, most bare soil is characterized by rectangular shapes while most barren land features are irregular in shape. If it were determined from other sources that a specific area was in a strip mine region, it could be deduced that a feature classified as soil would logically be strip mine spoil especially if it were located on the edge of an active strip mining area or possessed an irregular shape. Some nearly barren rural features such as sand dunes with sparse vegetation or strip spoil material with sparse vegetation might be classified as immature agriculture. Once again an analysis of the shape of features under investigation should enable the differentiation of nearly barren land from immature agriculture. Many parts of Indiana were very wet on the date of data acquisition. This wetness in many bare soil areas made soil spectrally similar to barren, thus large amounts of barren in rural areas represent somewhat dark colored water saturated soil.

It a more intensive analysis, most of the barren lands classification problems would be eliminated. It is possible to create at least two basic barren lands classes which would be associated with totally non-vegetated barren (i.e. strip mine spoil) and slightly vegetated barren (older strip mine spoil starting to develop vegetation). Even in a more intensive analysis, use of additional information will be needed to accurately delineate barren land features. However, data generated from analysis of LANDSAT multispectral data will be valuable in providing information about barren lands in Indiana.

Clouds – Clouds must be included in many areas because parts of five of the nine LANDSAT frames used in the phase I analysis contained some cloud cover. Dense clouds are indicated by the symbol "C" on the classification. Very thin clouds can be confused with a variety of phase I classes because they interfere with the natural spectral response from the earth. Areas where this problem exists are discussed on supplemental information sheets distributed with county output which have special classification problems. It is very difficult to obtain an entirely cloud free condition on approximately the same date for an area as large as Indiana. Overall, approximately 2½ percent of Indiana is cloud covered or cloud influenced on the dates of LANDSAT classification. Nevertheless, almost 90 percent of the total cloud cover is concentrated in two principal areas. The area most severely cloud covered is the Washington-Scott County area with a second concentration of clouds over selected parts of southwestern Indiana. Other areas have very minor cloud cover.

Clouds generally are not confused with other phase I categories because spectral responses in all bands are higher than all other earth surface features in Indiana. Very thin clouds can be mistaken for very reflective soils or high response, non-vegetated urban features. Even though very thin cloud cover does not mask the earth's surface it does change the spectral response of features which causes accurate classification to become impossible. Counties which suffer from cloud problems will be discussed in the output provided to the individual counties. There are a few counties where dense clouds, shadows, and thin cloud problems are too extensive to permit a good evaluation of the land cover features. It may be possible to obtain and analyze LANDSAT data from a different date in these problem counties in order to provide information in areas whose surface was impossible to analyze with the phase I data. Supplemental analysis of cloudy areas, if economically possible to conduct, will be made available by October, 1976. However, a majority of the clouds which affect the small parts of Indiana in the phase I inventory are highly reflective types unlikely to be misclassified.

Shadow – The class shadow as indicated by the symbol "S" must also be included if clouds are present in any study area. Since a little more than 2 percent of the state was cloud covered in the LANDSAT data used for analysis it is likely that a similar percentage of shadow will accompany the clouds. Thus, between 4½ and 5 percent of the state's land cover characteristics cannot be ascertained via LANDSAT analysis on the dates selected because of the combined masking effect of clouds and shadows.

Shadows, unlike clouds, are subject to some confusion with the spectral response patterns of selected wetlands, very silty water, and low reflectance industrial/commercial features. In addition, some shadows are not caused by clouds. Tall buildings in urban areas cast shadows which can cause a misclassification of a few points or RSU's in urban areas. Rough terrain, particularly in southern Indiana, may cast shadows which are identified as such in the phase I analysis.

SUMMARY OF THE PHASE I CLASSES

The phase I land cover inventory displayed on 1:24,000 scale alphanumeric computer maps contains eight basic classes of data. Five of the eight basic classes have been divided into rural and urban subclasses. Supplemental information about cloud and shadow are also presented. Several suggestions concerning the nature of the classification and its utility have been made. Planners undoubtedly will encounter problems in interpretation of data not considered in this manual. Questions are encouraged in order that improvements in future editions of this manual can be made. A supplement to this manual will be provided through SPSA if a sufficient number of questions are brought to our attention. Information relative to the use of phase I data and other topics of interest to planners will be presented periodically at seminars. Specific questions concerning the phase I inventory data should be addressed to the SPSA.

Orientation

Phase I inventory data are provided by individual county on alphanumeric computer maps. These maps should be assembled so that column numbers run consecutively across the county. In some cases, more than one set of classification data must be assembled because a county occupies an area where more than one LANDSAT frame is required to cover the county. The line and column location of at least one point on a topographic map or county boundary is provided with each copy of a county's inventory.

After the phase I inventory of a county or part of a county is assembled, it is necessary to achieve geographical orientation in order to effectively extract land cover information. Generally a good initial step is to locate the larger water bodies (lakes, rivers, reservoirs) identified on the phase I inventory. Water is the class most accurately identified. The location of a majority of large basic water features can be easily located on 1:24,000 topographic maps. The general location of an area in a county can be determined by visually examining the distribution of water on both the topographic maps and the phase I inventory. At this stage, it is proper to overlay the phase I inventory and a topographic map of the same area on a light table. Known water features on the topographic map should be aligned with water identified on the phase I classification. After this alignment is made all other features classified are correctly located geographically within an accuracy of 300 feet (one RSU or Pixel).

Other features identified in the phase I classification can be used for orientation purposes but with less overall accuracy. Forest is accurately classified but the distribution of forest as indicated on topographic maps is often out-of-date or inaccurately delineated. Other features shown on topographic maps such as wide roads, parking lots, central business districts, and swamps often can be used to help achieve an accurate geographic orientation.

After the correct geographic orientation has been achieved, it is possible to extract the types of land cover information of interest to planners. No suggestions are made in this manual for specific applications of the land cover information because each user has its own unique problems which require use of this data. Technical advice on use of the phase I data as they relate to specific planning problems at the local, county, and regional level can be made available through SPSA.

Statistical Summaries

LARSYS has the capability to summarize the total number of points in each class identified in a classification. The cost of having LARSYS delineate county boundaries and summarize the amount of land in each class is prohibitive with the resources available for phase I inventory. However, it is possible to obtain an estimate of symbol distribution in a county or subcounty area by requesting statistical summaries for rectangular shaped areas which include the county area. A summary of land cover for rectangular shaped areas using LARSYS is a low cost procedure. But, because counties generally are not rectangular in shape the summary may or may not include some areas outside of the county of interest. Nevertheless, this procedure will provide the approximate percentage of each classification symbol in the inventory.

The problem of interpretation remains even if statistical summaries of land cover classes are obtained for the rectangular areas. Several of the phase I classes have double interpretations with one for rural areas, and another for urban areas. The statistical summaries will provide some valuable information about the distribution of land cover features in each county, but this information must be carefully evaluated in light of the conditions under which the summaries are developed.

CONCLUSION

The need for more detailed land cover information is apparent, but phase I will provide general land cover information useful to planners. In various sections throughout the manual, reference has been made to the possibility of more intensive analysis of LANDSAT data. The current state-of-the-art remote sensing technology using LANDSAT data can develop approximately 20 land cover classes in Indiana with an accuracy exceeding 85 percent, particularly if more detailed classification are supplemented by topographic maps and other readily available data sources.

In the 1980's, LANDSAT satellites will have less than a 30 meter resolution with several more spectral bands including thermal infrared. Similar types of machine processing as used in this phase I study can be used to analyze multispectral data from more sophisticated satellites in the future. The 8 category/subcategory classification developed for phase I and the potential future 20 categories developed from more intensive analysis of existing multispectral data will begin to provide a data base for planners. By the early 1980's it is anticipated that more sophisticated satellites and scanners will provide multispectral data which can be used to develop many more than 20 land cover categories with improved accuracy. The machine processing approach to developing spatial data is in its infancy, but already it has proven its value. Users of the phase I inventory will immediately realize that the classification does not solve all of Indiana's planning problems. However, it should be evident that phase I data has many planning applications and that more detailed information of even greater value developed through LARSYS processing can be made available to users in the near future.

Effective use of land cover inventory derived from analysis of remotely sensed data requires a working knowledge of basic principles of remote sensing, the nature and use of maps, characteristics and uses of aerial photographs, and the nature of computerized systems to encode, retrieve and display earth surface information. These and other topics with which users of land cover inventory data should be familiar are discussed at length in the Appendices of this manual.

Appendix A provides a basic background into the general principles of remote sensing and also gives insight into the nature of the Phase I land cover inventory. An appreciation of the inherent advantages and disadvantages associated with machine processing of multispectral data are provided in Appendix A.

Appendix B introduces the characteristics of maps. Land cover information often is best generalized on maps, thus knowledge of their properties for use by planners is necessary. The SPSA phase I land cover inventory relies heavily on using 1:24,000 topographic maps to provide orientation and information to supplement data displayed on alphanumeric computer maps, therefore, knowledge of the use of maps is very important.

Appendix C provides information concerning the nature of aerial photographs. Aerial photographs are very significant in developing and interpreting the phase I land cover inventory data. Photographs were used in obtaining samples of land cover information which help provide the spectral signatures used in classification. Aerial photographs, like topographic maps, should be used in conjunction with computer maps of land cover classification in order to supplement and assess the information provided in output such as that generated in the phase I inventory.

Appendix D introduces procedures and techniques which are commonly used in the interpretation of maps, photographs and selected types of alphanumeric printouts.

Appendix E advances methods of using computers to code, retrieve and display land cover information obtained from any source. Data from on-site inspection, census, photographs, maps and land cover inventories derived from analysis of remotely sensed data require computer processing to facilitate their effective use in practical planning situations.

The information provided in the Appendices will assist planners in developing and interpreting data relevant to planning processes. Additional reading on the topics discussed in the appendices may be required for a particular application; however, a basic introduction to the development, display and storage of data significant to planners is provided by the five appendices.

APPENDIX A

MULTISPECTRAL REMOTE SENSING: PRINCIPLES AND TECHNIQUES

Electromagnetic Spectrum

Sound, light, heat, microwaves and high energy particles such as cosmic rays and x-rays are all forms of electromagnetic energy. As the word implies the properties of electromagnetic energy possess both electric and magnetic components. Physicists have two dominant theories which are used to help describe the nature of electromagnetic energy. One theory assumes that electromagnetic energy is in the form of discrete and very minute particles called photons. The number of photons emitted from a substance during a unit of time determines whether the physical manifestation of the electromagnetic energy is in the form of light, heat, x-ray or in some other state. A second theory visualizes electromagnetic energy in a wave form whose individual wavelengths and speed of propagation varies as the form of energy varies. Many modern theorists see both particle and wave characteristics inherent in electromagnetic energy.

A precise mathematical and physical description of electromagnetic energy remains to be fully established. However, there are many things known about electromagnetic energy and its relationship to principles of remote sensing. Remote sensing or observation of earth phenomena from a distance or without physical contact with an object sensed utilizes a great variety of electromagnetic waves. Figure A1 is a diagram of the electromagnetic spectrum which shows the variation of the types of electromagnetic waves from the shortest and highest energy waves to the longest and lowest energy waves.

Electromagnetic waves are measured by their frequency or number of waves passing a given point during a unit of time or by length of individual waves. For example, the very shortest waves (waves with the highest frequency and energy) are cosmic rays. These very high energy electromagnetic waves are used in remotely sensing sub-atomic particles but they are not significant in analyzing earth resources of interest to planners.

X-rays are also high energy electromagnetic waves or particles which have remote sensing applications particularly in medicine and analysis of structural characteristics in metals. As in the case of the cosmic ray this part of the electromagnetic spectrum is not used for basic earth resources analysis.

As electromagnetic waves get longer, their frequency and energy decrease, however their use in the remote sensing of earth surface features increases. Wavelengths starting at approximately .3 micrometers (u) or .0000003 meters and continuing through 30.0 centimeters (with several gaps) is the part of the spectrum used most for remotely sensing earth surface features. In this wavelength range are found near ultraviolet light (.3-.4u), visible light (.4-.7u), reflective infrared light (.7-3.5u), thermal infrared heat (3.5-1000.0u), and microwave (.1 cm-30.0+ cm.).

The primary remote sensing tools which are used to observe and record earth surface features of interest to planners, environmentalists, geographers, and other scientists concerned with spatial distribution on the earth's surface use the .3u-30 cm. + portion of the electromagnetic spectrum. Cameras, optical-mechanical scanners (referred to as scanners throughout the remainder of the manual), radiometers, and radar are the four primary remote sensing instruments used to acquire earth surface features information.

Historically, remote sensing with cameras has been and continues to be the principal method of remotely acquiring land cover data. Cameras, films, lenses, and filters have been developed to produce detailed and high quality earth surface feature information. Although photography is a very useful and versatile method of showing earth surface information it does have certain disadvantages in instances where very large amounts of land use and land cover data must be developed rapidly as well as economically. Photointerpretation generally provides the greatest amount of earth surface feature information overall, but acquisition of the data often is expensive, subject to subjective decisions in interpretation, and frequently requires a relatively long analysis time. In addition, photography is limited to an important but very narrow portion of the electromagnetic spectrum. Most photography uses the .4-.7u or visible portion of the spectrum. Extended to its fullest, films can be made sensitive to the invisible near ultraviolet (.3-.4u) and very near infrared (.7-.9u). Other remote sensing instruments which are used to analyze earth surface features have a wider range of electromagnetic waves which can be used for remote sensing, thus they often can be used to develop information impossible to obtain from photography along.

A major problem in remote sensing is acquiring land cover information for thousands or tens of thousands of square miles at a modest cost in a short period of time. Because of technical or economic reasons photography and two of the other

Fig. A1 ELECTROMAGNETIC SPECTRUM

Wavelength	Band	Region
	very short wave	
.004μ	far ultraviolet*	ULTRAVIOLET
.28μ	near ultraviolet*	
.38μ	violet	VISIBLE
	blue	
.50μ	green	
	yellow	
	orange	
.65μ	red	
.72μ	reflective infrared	INFRARED
.30μ	transitional IR**	
4.5μ	thermal infrared	
14.5μ	far infrared**	
1000.0μ	short and moderate wavelength radar	RADAR MICROWAVE
19cm.	long wavelength radar	
133cm.	very long wavelength radio waves	

* usually unsuitable (theoretically) for remote sensing purposes

** theoretically feasible to use for remote sensing but no or little use currently

primary forms of earth surface feature remote sensing (radiometers and radar) cannot be used to develop large amounts of land cover data as effectively or inexpensively as optical mechanical scanners.

Inexpensive land cover information developed for large areas is best achieved by utilizing machine processing (computer) techniques on remotely sensed data acquired from earth orbiting platforms (satellites) or in some instances very high altitude aircraft (more than 50,000 feet). Currently there is no regular photographic observation of the earth from satellites. In the past, photographs of selected parts of the earth were obtained from the manned satellite SKYLAB and other manned space missions. Photography from very high flying aircraft also provides remotely sensed data but the area of the earth covered by this means is small in total.

Recently it has become feasible to process photographic positives or negatives in such a manner as to make them amenable to analysis by digital computers. Theoretically, digitized data from photographs enable a remote sensing analyst to develop land cover classification of large areas rapidly. However, the cost of preparing a photograph for intensive computer analysis can be high. In addition there is a loss of information from the photograph to its digital counterpart. The disadvantages of making photographs compatible with computers and the relative scarcity of small scale photographs makes the selection of manual photo interpretation or computer assisted photo interpretation unlikely for the development of general land cover inventories of large areas which are designed for use by planners.

There is no radar imagery available from space platforms. Aircraft radar systems are available, but in total they have been used relatively sparingly to develop earth surface feature information of practical value to planners.

Radar uses a wide variety of electromagnetic waves from .1 cm through 30+ cm yet has not proved to be very suitable for large scale land cover analysis. The forte of radar has been in analysis of weather and earth features of geomorphological interest. Other uses of radar, some of which are pertinent in developing land cover inventories, are well documented but the amount of available radar imagery which emphasize these uses is very small. In addition, computer assisted analysis of multiband radar data for land cover investigation is in the experimental, not operational, stage of development.

Radiometers (passive radar) obtain earth surface information from both satellites and aircraft utilizing the .1 cm through 30 cm wavelengths. The data generated by radiometers have poor resolution and are primarily designed to observe very large features such as cloud, ice, and ocean patterns. Temperature and moisture measurements over large earth areas also are a major use of radiometers. Although these devices serve many useful purposes they are not suitable to use to obtain land cover data required by planners.

The most feasible method to obtain general land cover inventory data for large areas at a cost local, county, regional, and state planning agencies can accept is through machine processing multispectral data obtained from earth orbiting satellites. Multispectral data generally are obtained from optical-mechanical scanners. Both aircraft and satellites carry optical-mechanical scanners which are designed to obtain spectral data in several narrow portions of the electromagnetic spectrum (multispectral data). The most economical source of multispectral data is from scanners on board the two LANDSAT satellites. Each LANDSAT satellite scans up to 8 million square miles every day. During an 18 day period it is theoretically possible to obtain spectral information from virtually the entire earth via LANDSAT.

LANDSAT System

The LANDSAT system of acquiring earth surface feature information depends on the use of optical-mechanical scanners which record electromagnetic energy coming from the earth in four distinct portions of the spectrum. The following discussion will introduce remote sensing information which is relatively unknown to most planners. Specific information concerning LANDSAT, the nature of optical-mechanical scanners, the physical principles of reflectance and emittance which are used in remotely sensing land cover, and an introduction to multispectral earth resources analysis is provided. The role computers play in the analysis of multispectral data also is discussed thoroughly.

In July, 1972 the first earth orbiting satellite whose specific mission was to examine a broad spectrum of earth resources was launched successfully. This satellite, designated ERTS-1, or Earth Resources Technology Satellite-1, was specifically designed to obtain information valuable to a large variety of scientists including planners, environmental analysts, geologists, oceanographers, climatologists, botanists, geographers, hydrologists, agronomists, and others. Ultimately the name of ERTS-1 was changed to LANDSAT-1. In January, 1975 a second satellite, identical in technical specifications to LANDSAT-1, was launched. This second satellite has been designated as LANDSAT-2. As of the date of this report (July, 1976) both LANDSAT-1 and LANDSAT-2 are scanning the earth and sending back important spectral information from its surface and atmospheric envelope.

Each LANDSAT satellite is equipped with optical mechanical scanners which obtain spectral information from two distinct segments of the visible spectrum (.5-.6u or green visible light and .6-.7u or red visible light) and two distinct segments of the electromagnetic spectrum which are invisible to the human eye (reflective infrared). One of the infrared (IR) bands used by LANDSAT also can be used by cameras with film sensitized to very near IR (.7-.8u); however, most of the second IR band used by LANDSAT (.8-1.1u) cannot be sensed photographically. Thus, LANDSAT obtains some spectral information in the part of the spectrum used by cameras, but also uses portions of the spectrum which are impossible to use by remote sensing instruments other than a scanner.

LANDSAT orbits approximately 550 statute miles (490 nautical miles) above the earth's surface. The orbit is from north to south and from pole to pole with a scanning swath of approximately 110 miles. During a single day each satellite's scanning path covers almost one-fourteenth of the total earth's surface. Not all of this area is actively scanned each day because of prohibitions on scanning foreign areas without permission and because of technical limitations on the amount of area which can be scanned (and recorded on tape for later transmission) in areas out of range of ground receiving stations. Currently there are three data receiving stations in the United States, one in Canada, one in Italy, and one in Brazil. Receiving stations are slowly being constructed elsewhere in the world (i.e. Chile, Iran and Zarie). Presently North America and parts of South America and Europe have direct access to satellite data, thus in these areas large amounts of multispectral information are available. A majority of the world outside North America is scanned by LANDSAT on an irregular basis and primarily by request of a foreign government which needs the remotely sensed data that the satellite provides.

Although the scanning swath width is more than 110 miles on both sides of the earth (a total of more than 220 miles per day) it nevertheless takes 18 days for each LANDSAT satellite to scan the same area because of overlap of scans. The multispectral data from earth areas scanned by LANDSAT are divided up into squares more than 100 miles to the side for analysis. These units of areas are called scenes or frames and contain more than 11,000 square miles each. Because there are two LANDSAT satellites in operation almost any given spot on earth can be scanned every nine days.

In actual practice (specifically for Indiana) useful multispectral data from the earth's surface is collected approximately 7 to 9 times a year from each satellite. Theoretically each satellite scans a given Indiana area 20 times a year, thus successful acquisition of data frequently occurs no more than 35 to 45 percent of the time. The primary reason for less than 50 percent success in obtaining multispectral data from the earth's surface in Indiana is because the electromagnetic waves used by cameras and optical-mechanical scanners have difficulty in penetrating clouds and fog. The orbit of the LANDSAT satellite is set so it scans Midwestern areas at approximately 9:30 a.m. every morning. This hour was selected to maximize the likelihood of cloud free conditions which are most conducive for good remote sensing.

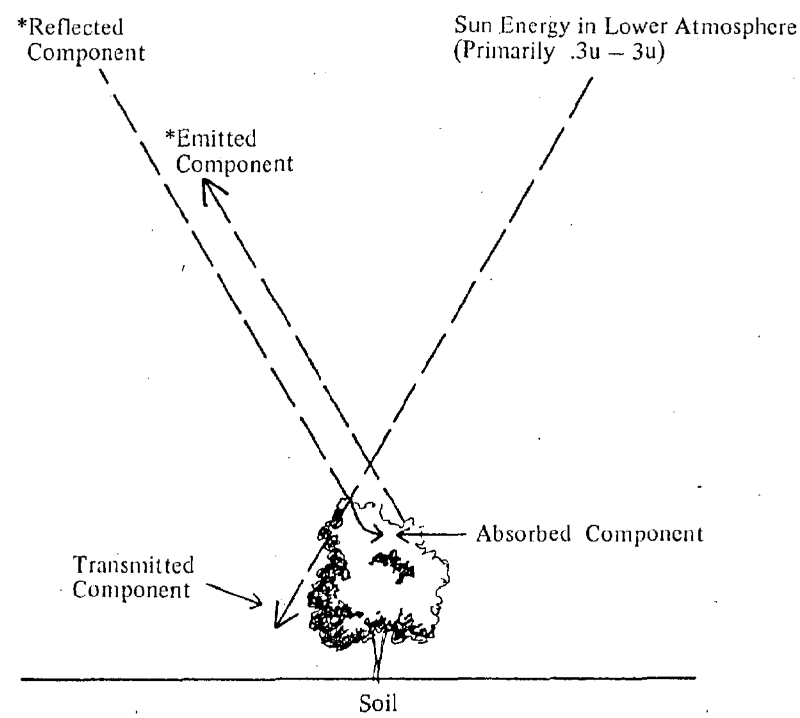
LANDSAT Scanners

An optical-mechanical scanner does not use film to generate an image, but instead measures intensity levels of electromagnetic energy which are reflected or emitted from the earth's surface. The difference in electromagnetic energy levels reflected and emitted from the earth varies in different portions of the spectrum and from one earth surface feature to another. By analyzing these spectral variations it is possible to differentiate earth surface features. This section of the manual will provide insight into the precise nature of the way electromagnetic energy is recorded and put into a form suitable for analysis by remote sensing experts who utilize computers.

Cameras, optical-mechanical scanners, and radiometers are all passive remote sensing systems. A passive system is one in which energy from an earth surface feature, in the form of reflection and emission, is directly associated with sun or solar energy. Active remote sensing systems such as radar use electromagnetic waves whose origin is not the sun but instead is generated by many. An example illustrating characteristics of a passive remote system is given in Figure A2. Solar energy reaches the object to be sensed (which in this example is a green broadleaf forest). A majority of the sun's electromagnetic waves which reach the earth's surface are in the visible portion of the spectrum. Also, significant amounts of electromagnetic energy in the near ultraviolet and reflective infrared reach the earth. The amount of electromagnetic energy reaching the earth with wavelengths less than .3u and more than 3.5u is measurable but small. As the sun's energy reaches the green leaves, four major things can happen to the electromagnetic waves in the various portions of the spectrum which interact with the tree.

Electromagnetic wave interaction with a green leaf may result in the rejection of energy with a result that the wave is immediately sent back to space where it can be detected by remote sensing instruments such as LANDSAT scanners. This rejection of electromagnetic energy is termed reflectance. An electromagnetic wave could pass through a leaf or leaf canopy in which case the energy would not be immediately available for recording by a camera or scanner located in an aircraft or space platform above the earth's surface. The movement of an electromagnetic wave through an object of interest is called transmittance.

Fig. A2 INTERACTION OF SOLAR ENERGY WITH A FORESTED AREA



* Electromagnetic waves which are detected by remote sensing instruments

Electromagnetic energy also can interact with an object whereby the electromagnetic energy becomes an intimate part of the feature. It is this energy which becomes a part of the physical-biological system which permits biochemical reactions (such as the development of chlorophyll) to occur in the case of a growing plant. This type of electromagnetic interaction with an object is termed absorptance. Electromagnetic waves which are absorbed by an earth surface feature obviously cannot be recorded directly by a remote sensing instrument located above an object to be sensed. A fourth possibility in an electromagnetic wave-earth surface feature collision is for dominantly short wave solar (electromagnetic) energy to convert to long wave (thermal infrared principally) energy after reacting with an earth feature. This conversion could occur rapidly or it could take a long period of time. For example, a rock primarily receiving short wave electromagnetic energy from the sun will reflect and absorb some of that energy. The absorbed energy might be released by the rock in a longer wavelength (heat) form long after the original short wave energy struck the rock. This long wave or thermal energy can be recorded by scanners or radiometers during the night long after the original short wave energy was absorbed by the rock. The release of this energy (waves generally longer than 3.5u) back to space is called emittance. Emitted energy can be recorded by selected remote sensing instruments located above the earth's surface. Thus, it is both reflected and emitted energy that remote sensing devices record. This recorded reflectance/emittance data provides the basic spectral information which remote sensing analysts use to identify earth surface features from a distance.

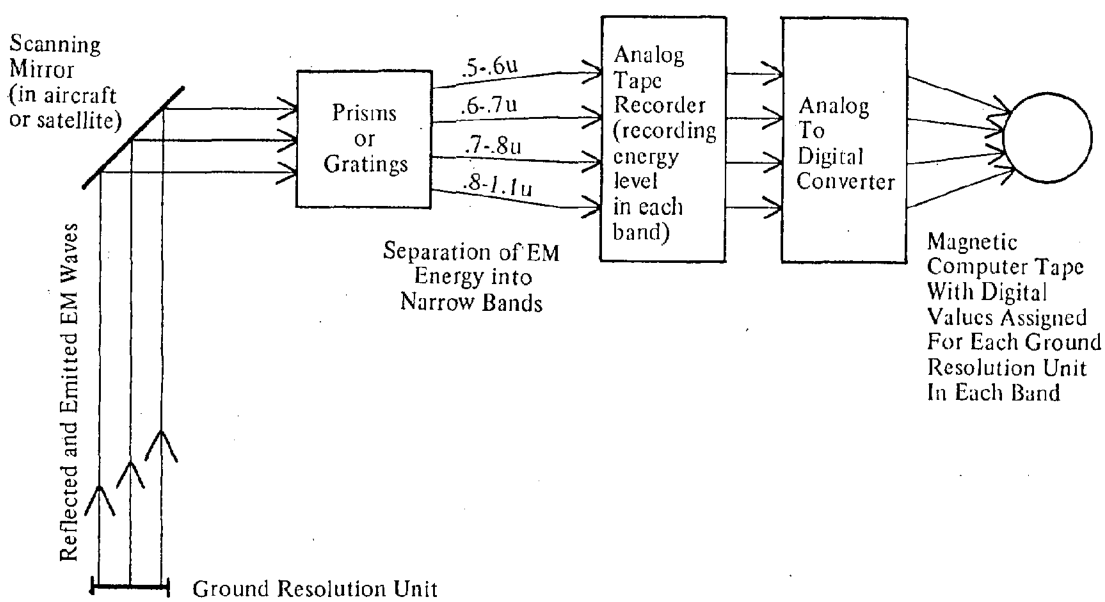
The electromagnetic energy from earth surface features which LANDSAT scanners utilize is primarily in the reflected form. Emitted energy in the part of the spectrum LANDSAT uses is very minor.

Figure A3 diagrams the procedures taken in recording electromagnetic energy as it is reflected and emitted from the earth's surface and converted into a form of measurement which is most condusive to remote sensing analysis.

Reflected and emitted energy from an earth surface object such as a grove of trees is picked up in a rapidly revolving mirror whose revolutions are syncronized with the speed of the platform carrying the remote sensing instruments. The mirror scans a path perpendicular to the direction of the platform movement. A large variety of spectral wavelengths are present in the reflected/emitted energy reaching the mirror.

The reflected/emitted energy reaching the scanning mirror is transferred into a bank of prisms and gratings which are designed to divide the continuous spectrum of electromagnetic energy reaching the mirror into small segments. The number and size of the segments can be varied by changing the characteristics of the prism and grating arrangements.

Fig. A3 FLOW CHART OPTICAL MECHANICAL SCANNER DATA COLLECTION



The exact nature of the number and spectral range of the bands of electromagnetic energy available for remote sensing depends on the specifications of the optical-mechanical scanner used to obtain this multispectral data. In the case of LANDSAT, the prisms and gratings separate the electromagnetic spectrum into four useable segments. Prisms divide the visible light into band 1 (green) with a spectral range of .5-.6u and band 2 (red) with spectral range of .6-.7u. Gratings are used to separate two bands out of the near infrared portion of the spectrum. Band 3 (very near infrared-reflective) has a spectral range of .8-1.1.

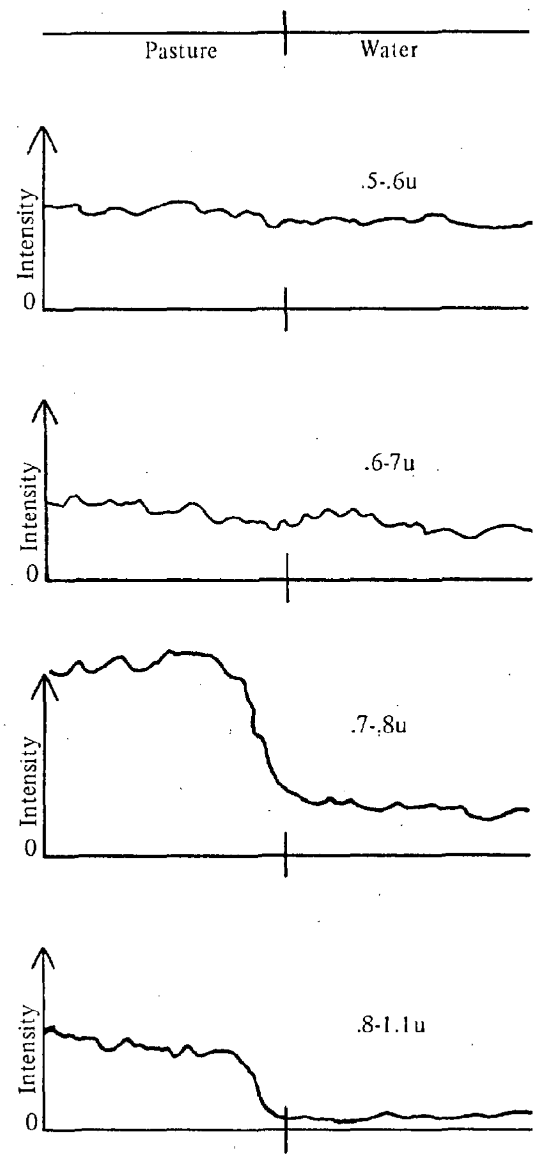
Independent measurement of electromagnetic energy in each one of the four LANDSAT bands is accomplished by tape recording energy level variations each time the scanning mirror flashes spectral information about a new segment of the earth's surface. In the case of LANDSAT scanners, electromagnetic energy is obtained from the earth in 60 meter by 80 meter parcels which are known as ground resolution units or remote sensing units (RSU). It is possible to state that the 60 meter by 80 meter RSU size approximates the ground resolution of the LANDSAT system.

The intensity of electromagnetic energy or spectral responses reflected and emitted from a given earth surface feature varies from one part of the spectrum to another. One type of earth surface feature often will have a different spectral response than another feature in the same or different band. Tape recorders are designed to measure the intensity (in analog form) of spectral responses of each band in every 60 meter by 80 meter resolution scanned by LANDSAT. Figure A4 is a tape recorder tracing of spectral intensities in each one of the four LANDSAT bands in an area scanned which contains pasture and water. Note how energy levels vary from band to band for the same earth surface feature and also how energy levels vary from pasture to forest.

Spectral data in the analog tape recorded format connot be used by digital computers for analysis which would lead to earth surface identification. The spectral information in analog form must be electronically processed to convert analog format into digital format which is acceptable to digital computers. An analog to digital converter is used to assign numbers to the analog responses. For example, if electromagnetic energy from a pasture in the .7-.8u wavelength segment made a great impression on the analog tapes than it is likely that the number assigned to pasture areas sensed would be high relative to other numbers. If the electromagnetic energy from the water in the .7-.8u infrared spectral band made a very minor electronic impression on the analog tape then, upon digitization, this earth surface feature would be assigned a relatively low value. The numbers assigned by the digitizer are considered to be a measure of relative spectral response. LANDSAT bands 1 through 3 are digitized from 0 through 128 while the range of digital values for band 4 are 0 through 64. Multispectral data obtained from aircraft scanners use a digital range from 0 through 255.

The four digital values (one for each LANDSAT band) for each 60 meter by 80 meter resolution unit (RSU) are recorded on magnetic computer

Fig. A4. Analog Tracing of Reflected Energy in a Pasture/Water Area in the Four Landsat Bands



tapes. Each resolution unit is identified by a line and column coordinate on the tape. It is these digital data tapes, containing more than 7,000,000 60 by 80 meter (1.1 acre or 1.5 acre) data points per frame (more than an 11,000 square mile area) which are used by remote sensing analysts to determine the distribution of land cover patterns through machine processing of multispectral data.

A single LANDSAT data tape provides spectral information in four bands for more than 11,000 square miles of area. Each day more than 100 different data tapes could be generated from each LANDSAT satellite (in actual practice the number is much less). The digitized spectral information is sent directly from the satellites to United States or foreign ground receiving stations. The data obtained by the United States receiving stations are collected at the Goddard Space Center near Washington, D.C. After additional minor processing, the tapes which analysts use are distributed to the public through the EROS Data Center in Sioux Falls, South Dakota. One frame of four bands of LANDSAT data costs $200. After purchase by a user agency such as the Indiana State University Remote Sensing Laboratory, the tapes again require minor adjustments called formating in order to make them compatible with the specific computer system used to analyze multispectral data. The tapes often are processed further to adjust the angularity or geometry of the area analyzed. Unless the tapes are geometrically corrected the data as displayed on computer maps or images will be at an angle 12^{0} from true north. The quality of the data is not affected by this angular distortion but the ease of using displayed LANDSAT data with conventional maps or photographs is made more difficult. The data used to develop the land cover classification for the SPSA was adjusted during analysis in order that the 1:24,000 scale computer maps displaying land cover features can be overlaid directly and with accuracy on 1:24,000 U.S.G.S. topographic maps.

In order to provide useful land cover information the spectral data on the tapes must be processed by a large and sophisticated package of computer programs which are specifically written to analyze relative spectral responses of reflected and emitted electromagnetic waves from earth surface features in several portions of the spectrum. This processing of multispectral data leads to accurately identifying a wide variety of earth surface features.

Multispectral Data Machine Processing

One of the world's best known and most thoroughly documented set of computer programs designed to analyze multispectral data in LARSYS. LARSYS was designed by the Laboratory for Applications of Remote Sensing (LARS) at Purdue University. LARSYS has gained an international reputation for its effectiveness in analyzing multispectral data.

Analyzing LANDSAT data using computer programs specifically designed to process multispectral data has several advantages over conventional methods of land cover data acquisition. Among the advantages of developing land cover information from machine assisted analysis of LANDSAT data are the following:

1. There is great objectivity in land cover classification after some initial human decisions concerning specific nature of the classification are incorporated into the LARSYS computer programs. The reason for this high degree of objectivity in classifying earth surface features is based on the fact that objective decisions are made by a computer (following initial human instruction) throughout the entire analysis. The degree of objective analysis does not vary from area to area as it might if a large region was being analyzed by several different photointerpreters. Important human decisions are made to assure a high quality land cover classification, but the computer removes the need for many subjective decisions which are made during classification procedures which are more manually oriented.

2. In the machine processing approach there is great consistency in the quality of land cover classification throughout a study area. A computer provided with appropriate multispectral data and processing instructions will classify land cover for a specific user's requirements using the identical mathematical techniques equally throughout the study area. For example, the quality of classification of forest in the northern part of a planning region will be identical to classification of the same feature in the southern part of the region. If two photointerpreters were used to classify land cover it is likely that a difference in the quality of classification would result because it is virtually impossible for two human beings to analyze with equal effectiveness an earth surface feature widely distributed over a large area.

3. Analysis of LANDSAT multispectral data permits the acquisition of land cover information for very large areas (multi-county planning regions, entire states, entire counties) at frequent intervals (several times each year which permits monitoring of change). No other remote sensing system can acquire the quantity of land cover information as does LANDSAT.

4. Unless computer programs such as LARSYS are used, it is impossible to develop a land cover inventory of a very large area through manual interpretation methods. A state as large as Indiana can have its basic land features classified and displayed at a 1:24,000 scale from a machine process-

ing analysis of LANDSAT data very rapidly. This total analysis could be completed by three remote sensing analysts in three months after receipt of the appropriate multispectral data tapes.

5. The cost of developing land cover information for a large area such as a regional planning district or an entire state is very low using computer assisted processing of LANDSAT multispectral data. For example, a twelve category land cover inventory of a 2,500 square mile area using aerial photo interpretation (including purchase of new photographs) was estimated to cost $3.59 per square mile by one of the larger Indiana planning regions. A machine assisted analysis of a similar size area extracting the same 12 basic land cover features would cost one-fourth to one-half as much as the photointerpretive method. When great detail (i.e. enumeration of individual homes) is required or the area of analysis is small (subcounty) the advantages of photographic analysis of land cover exceeds that of machine processing satellite data. For acquisition of land cover information in large areas, machine processing analysis of LANDSAT data is superior to photography overall. Aerial photography remains the remote sensing tool which can provide the maximum amount of earth surface feature information because of its excellent resolution. Photographs provide a good base upon which to map data. However, as previously indicated, obtaining and interpreting photographs can be costly and very time consuming. Also, the cost and time factor makes it difficult to obtain land cover information on a regular basis, thereby reducing the likelihood of having data available for analyzing changes in earth surface features over time.

6. Scanners have access to spectral information which other remote sensing instruments (such as cameras) do not. The scanner's broader spectral range advantage over film frequently improves the quality of land cover analysis. Many infrared spectral responses from earth surface features cannot be recorded on film but can be recorded and analyzed by scanners.

7. Scanners provide the easiest and most efficient means of collecting multispectral data. The advantages of using multispectral data in earth surface feature analysis will be explained in more detail elsewhere in this manual. However, at this time, it is sufficient to state that multispectral data offers much more useful information in total than does spectral data combined into a single wide band.

8. Machine processing techniques offer great versatility in displaying land cover classification results. Through the use of a computer it is possible to develop maps and images showing the distribution of land cover features of a study area. Parts of a classified area can be displayed by themselves. An individual category of a classification can be displayed by itself (all other categories would be left blank on such a display) in order to highlight the distribution of a particular earth surface (thematic mapping). Statistical summaries of all or a portion of a classified study area can be developed. Estimation of classification accuracy often can be obtained through computer analysis. Multiple copies of all printed output can be generated at little extra cost once the initial copy of the land cover classification has been generated. Machine processed multispectral data such as that obtained from the optical mechanical scanners on board LANDSAT overcome many of the problems associated with aerial photointerpretation of large areas for development of land cover inventories. Obviously, photointerpretation and on-site surveys are needed for acquiring many types of land cover information outside the realm of land cover inventory.

The advantages of machine processing have been discussed briefly. More lengthy discussions of the nature of the multispectral approach, as it applies to the development of land cover by the SPSA, is required to understand the nature of the land cover information which will be provided to planning agencies in Indiana.

Table A1 summarizes in tabular form the intensity of spectral responses of reflected and emitted energy from a variety of earth surface features. Column 1 of table A1 indicates responses which commonly are associated with the various earth surface features on a black and white panchromatic photograph similar to that used in photointerpretation. Columns 2, 3, 4 and 5 indicate spectral responses in the bands used by the LANDSAT scanners. This hypothetical example shows how analysis of several narrow portions of the spectrum (multispectral) differentiate earth surface features better than does a single broad band of spectral data.

Spectrally, four out of the seven features identified in Table A1 are nearly identical and consequently have a similar dark gray tone (low response) on a black and white photograph which expressed reflectance and emittance from the visible portion of the spectrum. Interpretation of the photograph can easily lead to confusion in the identification of four features; two water features and two vegetation features (all four have low spectral response in column 1 of Table A1). Thus, a black and white photograph can readily distinguish between three of the seven features but the remaining four would be difficult to identify from spectral analysis of the total visible spectrum.

Through the use of several bands of spectral data each one of the seven features can be differentiated. No single band of the four LANDSAT bands can effectively differentiate all the categories of land use and land cover identified in Table A1. Taken collectively no earth surface feature in Table A1 has the same pattern of spectral response in four bands. Differences in spectral response patterns can be identified by a computer. Computer analysis of these four band spectral response patterns can result in clear differentiation of all seven earth surface features in Table A1 even if the spectral response is different in only one of the four bands. For example, somewhat silty water and non-silty water may be spectrally too similar to differentiate from each other in the first three LANDSAT bands, but the fourth band has enough spectral difference between the two features to clearly identify each. Thus, a strength of the multispectral approach is derived from the fact that small segments of the electromagnetic spectrum analyzed collectively provide more total information valuable in identifying land cover features than does a single, wide segment of the spectrum.

TABLE A1 — SPECTRAL RESPONSES OF SELECTED EARTH SURFACE FEATURES IN VARIOUS ELECTROMAGNETIC BANDS

Feature	Spectral Response				
	.4 – .7u Panchromatic Film	.5 – .6u	.6 – .7u LANDSAT Bands	.7 – .8u	.8 – 1.1
Water, non silty	low	low	low	low	very low
Water, somewhat silty	low	low	low	low	low
Water, very silty	low-medium	low-medium	low-medium	medium	low
Forest, healthy	low	medium-low	low	very high	medium
Forest, slight disease	low	medium	low	medium	medium
Pasture	medium	medium	medium	very high	medium
Soil	high	high	high	high	medium

APPENDIX B

MAPS

Introduction

The comprehension of the spatial characteristics inherent in site requires the use of a technique that overcomes the difficulties that occur in the perception of reality. It is difficult to perceive spatial significance by direct observation because of: (1) the limited range of an individual's apparent horizon, (2) changes in scale, and (3) the complexity of detail of that which is perceived. In order to overcome these difficulties and to present the site characteristics in a meaningful manner for planning analysis it becomes necessary to express reality symbolically, i.e., maps.

In simplest terms, maps are representational symbols of reality at other than a 1:1 ratio. A map is a reflection of judgements which are manifested by symbols through a reduction of detail and simplification of the complexities found in the real world. The spatial relationships of the larger areas of the earth's surface can be presented planimetrically correct. These areas on maps encompass more than that which can be examined directly. The restricted view of the individual is thus enlarged so that maps can become analytical devices for large areas.

Secondly, maps overcome the problem of scale differences especially when sighting along the horizontal. Observations along the horizontal plane involve depth perception and it is obvious that scale and perspective are changed making a reasonable analysis of space content difficult. Maps overcome this difficulty by changing the observation from horizontal sighting to vertical sighting. The phenomena of space content being studied are thus scrutinized as from a plane above and parallel to the horizontal plane. Each infinite point of space content as represented by the map has a homologous point in the viewing plane. In a theoretical sense all points on a map are in the same spatial relationship as found on the earth's surface. The problems of scale and perspective are compromised by changing to vertical sighting.

Thirdly, by portraying reality via the map, the immense amount and complexity of detail encountered can be generalized so that only the relevant aspects remain. Basic data of the areal unit is symbolically represented in order to orient and provide a framework for the application of other pertinent information also with symbols. The cartographic processes of generalization and compilation allow a sifting of data and a retention of those data needed for intelligent analysis. A simplification of detail reduces the complexity of reality to a comprehensible scale through the identification of salient features and the symbolized spatial aspects of space content.

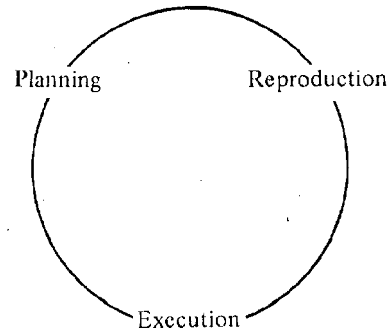
Maps, then, are symbolized reductions of the spatial characteristics of large areas to a form which makes analysis possible. But a map is other than a simple reduction of reality if it is designed and constructed using accepted cartographic techniques. As a tool, maps allow the encoding and display of the interrelationships of spatial relations. A map can be most important in the analysis of, and the planning for, the works of man.

The variety and uses are so many that to attempt to catalog maps seems almost impossible. Perhaps the most prolific use is the road map found in all formats, colors and sizes but common in the theme of providing information concerning road systems. Almost anyone would have reason to devise a map in order to show graphically locations or other types of distribution. A map may be a simple property description for personal purposes, to a much researched, highly detailed map of an urban area for planning purposes. Categories may include historical maps, weather maps, topographic maps and many examples of thematic maps. Cataloging maps according to utility may be the most positive approach as all maps are related and differ only in intended purpose or theme.

The Framework for Effective Maps

In order to achieve the purpose of a map the cartographer must use those devices which will ensure high legibility. The definition of legibility indicates "easily read" and provides an objective for a type of map communication. Further, legibility is a composite of factors some of which the cartographer cannot control. Factors over which control can be exerted would include lettering choices (style, point size, placement), symbolization schemes (point, line, area, volume), use of space, media to be used, reproduction methods, and the subject matter. On the other hand the cartographer cannot control the capacity of the map user. This capacity includes the frequency of map use by the user and the environment in which the map is being used. It is reasonable to assume that a high frequency of map use would indicate a basic understanding of spatial relationships. The converse would also apply. Thus, devices used by the cartographer for effective map communication

Fig. B1. GUIDE FOR MAP CONSTRUCTION



A. Planning	I.	Design –	Intellectual decisions regarding research and selection of subject matter and manipulation of data in conjunction with map theme.
	II.	Layout –	Decisions relative to relationship of the essentials of maps (symbols, scale, title, legends, base map adjuncts).
B. Execution	I.	"Blue line copy" –	A preliminary map used for planning purposes to finalize choices of layout.
	II.	Final copy –	A final map which incorporates all planning and is really for reproduction
C. Reproduction	I.	Methods for	non-printing reproduction (examples – xerography, diazo process).
	II.	Methods for	printing reproduction of original (involves photography and plate-making).

Listing of items should not infer order of importance but is only for convenience.

and considerations of lettering systems, symbolization systems, subject matter generalization and compilation procedures, proper use of space, and reproduction methods.

A guide for the construction of effective maps utilizing cartographic devices would include concepts of planning, execution and reproduction (see Fig. B1). It is obvious that actual map construction must commence with planning, proceed with execution and finish with reproduction, nevertheless, it must be recognized that reciprocity exists with these three concepts. In other words choices made during the planning step may be conditional on choices for reproduction methods. Further, certain methods of reproduction will condition decisions for execution.

Planning involves a number of important decisions regarding design and physical map layout. The intellectual aspect of planning (design) reflects choices concerning the subject matter of the map which must be carefully researched and data properly manipulated within the limits prescribed by the map theme. The physical layout involves the choosing of lettering styles, symbolization schemes and map essentials such as projections, legend, title and the like.

The execution step represents the drafting procedures used in preparing a "blue line" and a final copy of the intended map. A "blue line" copy is generally a free hand sketch and subsequently a scaled drawing indicating all choices decided by planning. All necessary changes, deletions or additions are made at this point. A final copy is then executed by draftsmen using a wide range of materials and techniques. It is important to recognize that the final copy represents final planning decisions. If further deletions or additions are carried out after the final copy is made ready for reproduction it is an indication that all planning had not been properly considered. Obviously this should not occur and would not when all planning proceeds correctly.

Reproduction constitutes consideration of the methods by which multiple copies of the original map are duplicated. Basically a dichotomy of printing and non-printing processes is considered. This scheme is practical as a separation based on the necessity for a printing plate and ink tends to correlate with methods based on decreasing unit costs. Printing methods which involve plate-making provide single or multiple color copies at a decreasing unit cost but initial and low number runs incur a relatively high unit cost. On the other hand, the unit of non-printing methods tends not to vary regardless of length of run. Appropriately the choice of reproduction methods depends primarily on economics although the quality of each process must also be considered.

Printing methods include letterpress, engraving and lithography which involves photography (photolithography) as preliminary to the plate-making step. All printing methods involve the transfer of the original copy to a plate (right or wrong reading) which is then used on printing presses. Each of these processes can produce excellent reproductions depending on cartographic choices of symbols, line and dot patterns and color. Normally the steps would include 1) photography (producing a film negative or positive), 2) plate-making, and 3) the press run.

The non-printing processes include 1) methods for producing direct contact positives or negatives, 2) photocopy, 3) xerography, and 4) film photography. Each of these processes can be used to produce a few duplications rapidly and at a relatively "low" unit cost and they are also most economical for maps that are being revised periodically. In addition these processes do not require a high degree of skill to operate nor are they as expensive as printing processes in equipment inventory.

Both non-printing and printing processes have characteristics which can be advantageous or not depending on the requirements of the user. Both use photography as an intermediate step to a finished product which allows original copy to be enlarged or reduced as the situation dictates. The advantage of this characteristic is that the original copy can be made at smaller sizes resulting in a considerable saving of time and materials. Some non-printing processes can only duplicate at a one-to-one ratio requiring original copy to be planned accordingly. Further non-printing processes in most cases require more exacting execution of original copy. For example, direct contact positives produced by light-sensitive diazo compounds must have original copy without opaque material or even excessive erasures. It can be generally assumed that printing processes are used for longer runs with decreasing unit cost and also (depending on paper stock) higher quality products. Conversely, non-printing processes can be effective for fewer copies although the finished copy, in some cases, is on media which cannot "take" further ink work.

The Elements of Maps

Since a map is a representation of a part of the earth's surface it is constructed by using the elements of maps. When used properly the elements facilitate the map user's accurate understanding and interpretation of a map. Elements of maps include a title, symbols, scale, projection, direction and location.

Title – A good map has a title. While its function is obvious the title should, with brevity, indicate without ambiguity the theme of the map. It is difficult to title a map, and sub-titles can be a good use whether on a single map or where a map is part of a series and the main title is the same. On some maps, topographic sheets in particular, a numbering system is used for reference to a specific map while the title identifies the particular sheet.

Symbols – The most important element is the symbolization scheme (see Fig. B2). Point, line, and area data must be symbolized for clear understanding and perception by the user. The map itself is a symbol and all cultural and physical features are depicted symbolically. Further, all superimposed abstract information must also be symbolized. Consequently, the interpretation of all map symbols must be presented in either a map legend or a legend sheet for a series. All spatial concepts, locations, distributions and relationships require an effective coding scheme for effective communication.

Point data are non-dimensional and represent points in space. These data indicate relative or absolute location and may represent place location although not the actual phenomena. Data at a point may be actual, derived and actual or derived and abstract. Symbols used to locate point-centered phenomena can vary by basic shape or visual character (circle, square), color and size.

Line data are one-dimensional and represent phenomena that are elongated. Symbols, therefore, are narrow and uniform in nature. Linear data may be concrete or abstract. Concrete linear data would include roads, railroads and canals while abstract linear data would include symbolized communication of all types, boundaries and other demarcation of abstraction. Uniform intensity of existence is generally exhibited by linear data.

Line symbols represent connectivity status of points, similarities along a course, and differences from one side to the other. Line symbols are also used to portray the third-dimension (volume data) on the two-dimensional surface of a map. These symbols may be continuous in character, broken

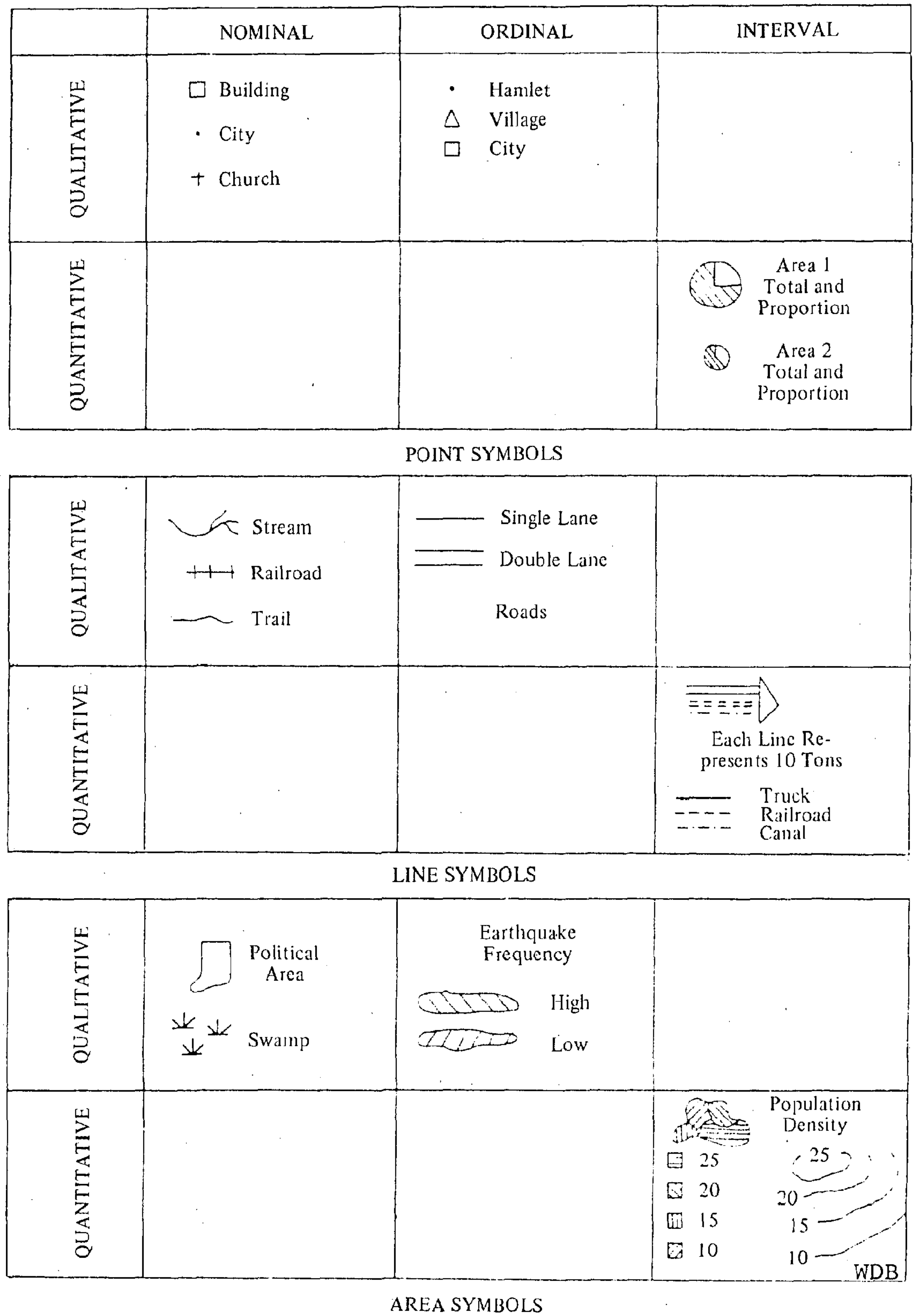


Fig. B2. Symbolization and Scale Schemes (after Robinson, Elements of Cartography, 2nd ed., 1953; Robinson and Sale, Elements of Cartography, 3rd ed. 1969).

or vary in width. Connectivity of points for depicting a transport system would be the simplest use of the line symbol. Similarity along a course would symbolize migration of all types (commodity flow, traffic movement, water volume). By varying the width of a line symbol the quantitative nature of linear data can be shown. The most complex form of line symbols (isarithm) would be used to indicate volume data.

Area data are two-dimensional and are phenomena occupying length and breadth. Examples would include bodies of water, forest areas or agricultural lands while abstract area data would include all levels of political jurisdiction and derived ratios representing all types of distributions. Various line and dot patterns (in black and white or color) are used to portray area data. Increases in density of these patterns indicate increase in the magnitude of the data being portrayed. The visual pattern thus formed would employ an increasingly darker tonal pattern indicating increasing magnitude of data.

As a map is a system for encoding information dealing cartographically with geographical points, lines, areas and volumes, it is necessary to place phenomenon in different categories. Manipulation of data involves two basic operations — that of variable location and the symbolization of differences between elements of a class. This ordering of data would involve nominal, ordinal and interval scaling (see Fig. B2).

Nominal scaling is qualitative differentiation without ranking. Phenomena are classified by identifying salient attributes and noting their location. No inference is intended regarding quanitative differences. Nominal classes are mutually exclusive. An example would be a series of dots representing different cities without an indication of rank according to social, economic or other criteria.

Ordinal scaling represents qualitative differentiation with ranking. Not only are phenomena between classes identified, but phenomena within classes are ranked qualitatively. For example, not only would urban areas (cities) be differentiated from other habitation patterns but each urban area would be ranked according to a subjective scale. This ranking might employ the terms large, medium and small. Thus, each area would be identified by a point symbol whose shape characteristic would assume three choices. Ordinal scaling does not infer magnitude of data.

Interval scaling represents quantitative differentiation along a standard unit scale with ranking. Interval scaling first differentiates among phenomena while within a class a quantitative ranking is formed. A standard unit is employed in order to rank the elements of a class and express class differences. Inherent within this scaling is the manipulation of both actual and derived data. Examples of interval scaling would be temperature in standard units of degrees (F^{O} or C^{O}), population as persons per square mile and topographic relief in linear units of meters.

Cartographic symbolism is a method by which data can be effectively encoded and retrieved. Data which are scaled and symbolized properly can create a map which is an effective means of communication. If the symbols are chosen for clarity and legibility the resultant product functions as a scientific tool for the development of planning hypotheses.

<u>Scale</u> – One of the cartographic processes common to all maps is the compilation process and its first consideration is scale. This is a system of proportionality indicating the relationship or ratio between length or area on the earth's surface and the corresponding length or area on a map. Thus all maps are reductions of the earth or portions of it. Choice of a scale or ratio for a map is primary to data collection and its subsequent portrayal. Scale sets a limit on information which can be effectively delineated. Factors such as eventual use, economics, subject matter and reproduction methods may dictate the scale, thus eventual size of the map.

A scale placed on a map is the device by which all measurements (linear or areal) are related. Its importance and functional utility is dependent upon its accuracy in expressing the ratio between the earth and its subsequent portrayal. Since scale represents a ratio, the distance on the map is usually expressed as unity. The following methods are used to express scale on a map:

1. Representative fraction: expresses as a ratio and shown as RF 1:24,000 or RF 1:250,000, etc. Distance on the map is 1 unit and represents 24,000 of the same units on the earth's surface. It must be understood that the RF of a map is non-dimensional. Commonly in the United States the RF is stated in inches due to the English system, thus the 1 is an inch. If the metric system is used 1 is a centimeter. But it should be stressed that correctly, the representative fraction is non-dimensional. (see Fig. B3)

2. Verbal statement: Statement of map distance to earth distance. For example: an RF 1:24,000 would become one unit represents 24,000 of the same units.

3. Linear bar scale: the most commonly used symbol for map scale. A line or more ornate symbol subdivided to show lengths of earth distance.

<u>Projection</u> – A map projection is a method by which locations on the earth's surface are systematically placed on a two-dimensional surface. A system of two sets of lines representing parallels of latitude and meridians of longitude is used to form

Fig. B3. COMMON MAP SCALES

MAP SCALE	ONE INCH REPRESENTS	ONE MILE SHOWN BY	ONE CENTIMETER REPRESENTS	ONE KILOMETER SHOWN BY
RF1: 24,000	0.3787 mi.	2.6400 in.	0.240 Km	4.1667 Cm
RF1: 62,500	0.9864 mi.	1.0138 in.	0.625 Km	1.6000 Cm
RF1: 63,360	1.0000 mi.	1.0000 in.	0.634 Km	1.5783 Cm
RF1: 250,000	3.9457 mi.	0.2534 in.	2.500 Km	0.4000 Cm

a framework for the data of a map. With this system, places on the earth, a three-dimensional form, can be located in proper relationship on a two-dimensional plane. This orderly transformation may come from geometric projection or from mathematical formulae.

A major problem of distortion occurs when transforming points from a spheroidal surface to a plane surface (see Fig. B4). Because of this, four major properties; conformality (true shape), equivalence (equal-area), azimuthality (correct angles), and scale (correct distances), of the spheroid cannot be simultaneously reproduced. But with mathematical analysis it is possible to produce maps which are accurate in respect to one or more of these properties depending on intent of the user.

Projections are divided into several classes depending on the surfaces used to develop the system of lines (geographic grid). The classes are cylindrical, conic, plane and mathematical. In the first three classes the grid is assumed to be projected to a geometric surface which is then developed to a two-dimensional plane (see Fig. B5).

The major function and importance of a projection is to provide a framework upon which all mapped data is located. Indication of the value of latitude and longitude should be manifested on all maps covering an earth area of one degree of arc or greater.

Direction – A map needs a clear expression of direction and orientation. A north directional arrow is mandatory on all maps which do not have a projection or a system of location indicated. It is assumed that a north arrow represents an infinite number of parallel lines superimposed on a map. Because of this a north arrow is correct on only those maps covering an earth area with dimensions less than the apparent horizon of the viewer. Further direction and orientation can be provided with an inset diagram indicating the map's area within a larger earth region. For example, a map of a county would enhance orientation with an inset of the state showing the county in question.

Location – Most often some type of coordinate system is needed on a map in order to express point or area locations accurately. Three basic systems are the geographic grid, the township and range survey system, and the transverse mercator grid. The importance of these systems is such that major characteristics of each will be discussed in a separate section.

Systems of Location

A method by which locations can be accurately expressed is necessary for all maps. A system of location provides coordinates necessary to encode and retrieve differing classes and kinds of data.

Geographic grid – The geographic grid is a construct for the earth's surface and represents the primary system of location (see Fig. B6). All points are located in degrees of arc from a known point of origin. An assumption that the earth's form is mathematically defined as an oblate spheroid must be introduced. The oblateness is due to a slight equatorial bulging with a polar flattening attributed mostly to the centrifugal force of rotation. Further, an assumption is made that an extension of the apparent axis of the earth is fixed in space. With these assumptions the north pole, south pole and the equator become points of departure to base the geographic grid.

The geographic grid consists of two sets of intersecting lines. North-South trending lines are referred to as meridians of longitude while east-west lines are parallels of latitude. All meridians are halves of great circles and all coincide with the north and south poles.

1. Meridians represent geographical N-S directions.
2. Meridians converge to common intersection at the poles.
3. An infinite number of meridians occur.
4. Meridians of longitude represent 180^{o} of

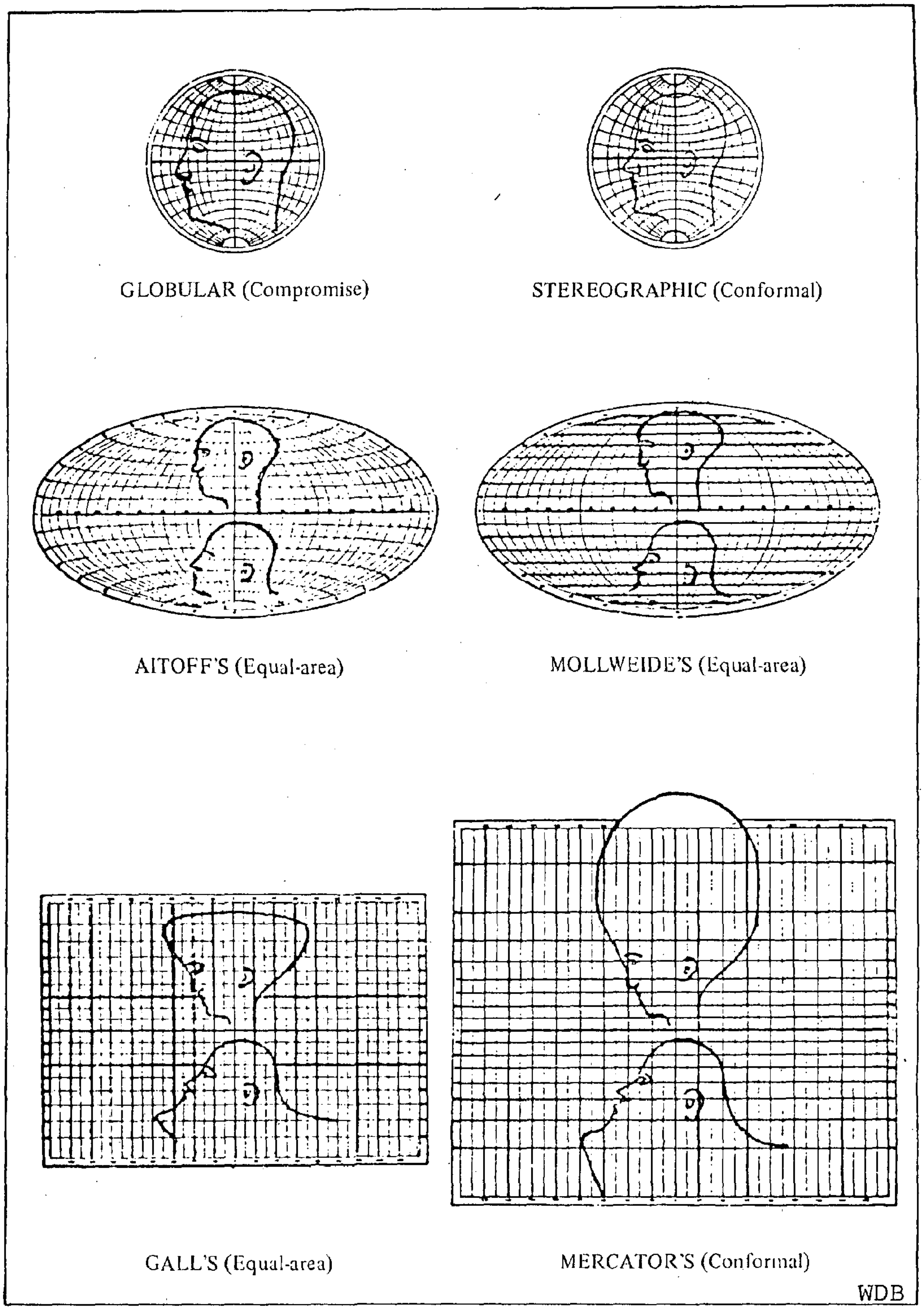


Fig. B4. Illustrated Distortion which Appears on World Hemisphere Projections (after Dietz and Adams, Elements of Map Projection, 1945).

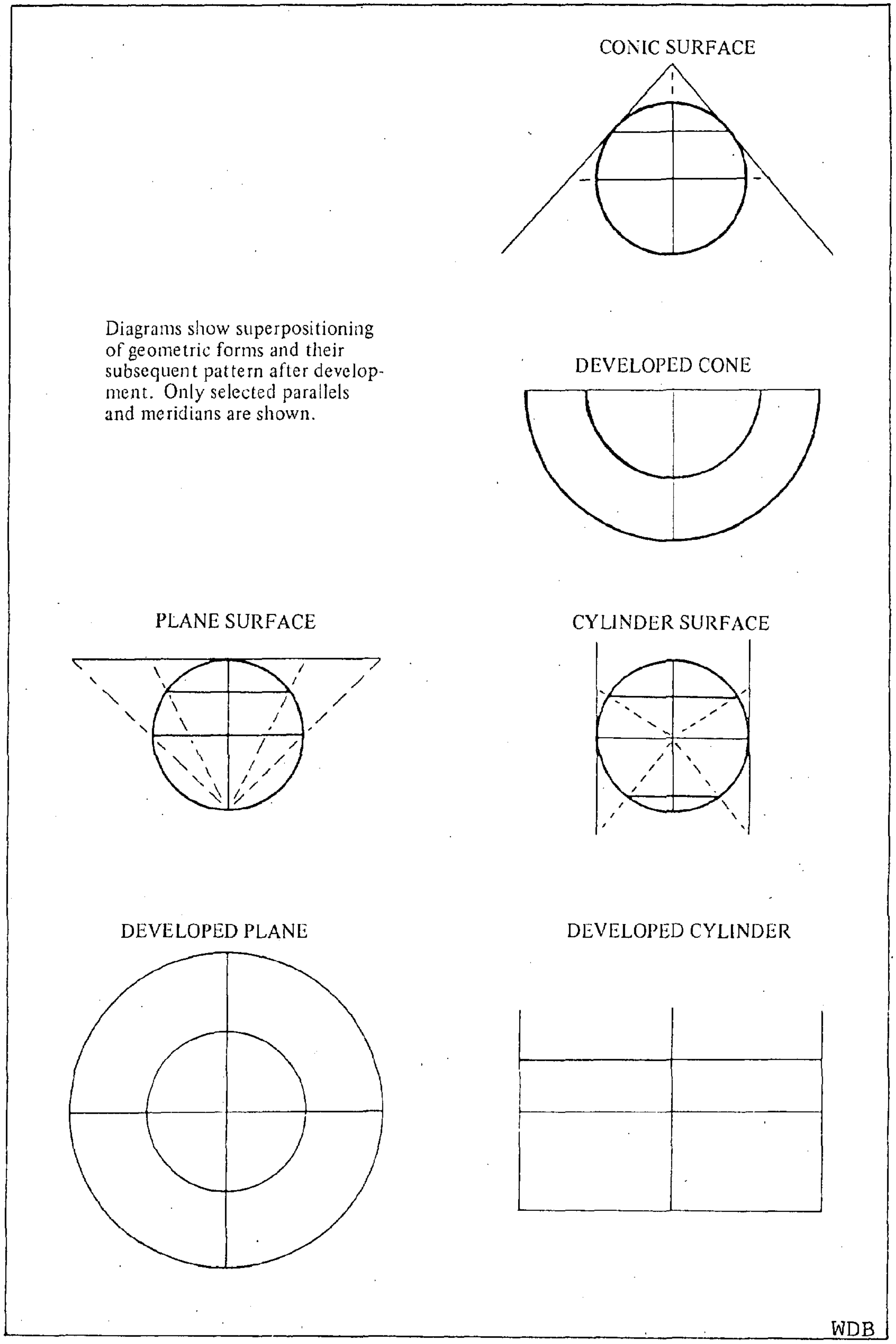


Fig. B5. Geometric Forms and their Projection (by W.D. Brooks).

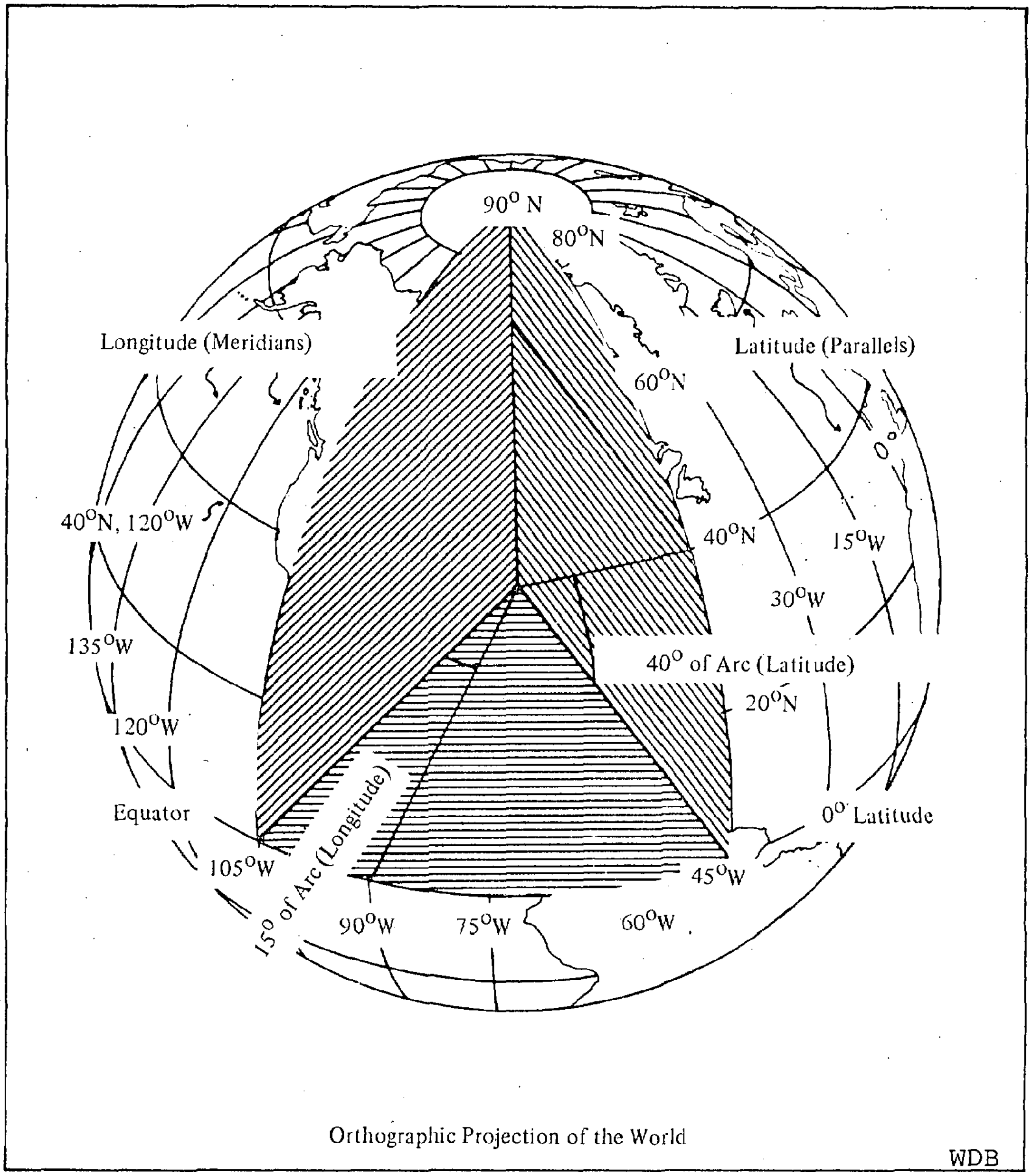


Fig. B6. Meridians and Parallels (by W.D. Brooks).

arc.

Parallels are east-west trending lines which represent an infinite number of intersections with planes parallel to the equatorial plane.

1. Parallels represent true east-west direction.
2. Parallels are always parallel to each other.
3. An infinite number of parallels occur.
4. Parallels represent 360° of arc.

Location of points using the geographic grid are given in degrees latitude and longitude. The equator is identified as 0° latitude and each succeeding parallel increments to a maximum of 90 degrees either north or south. Longitude is enumerated in degrees east or west of a prime meridian which passes through an observatory just west of London, England. The prime meridian is designated as 0° longitude and location proceeds either east or west to a maximum of 180°. It must be understood that a meridian of longitude extends from pole to pole in an arc distance of 180°. Thus the great circle of which the prime meridian is half and the meridian representing 180° is half, constitutes a full 360° of arc. The correct designation of a point using the geographic grid is written using degrees, minutes and seconds of arc for both latitude and longitude. A point is not located unless the intersection of a parallel and a meridian is designated. The location of the courthouse (as a point on a 1:24,000 USGS quadrangle) in Terre Haute is given as 39° 27' 57" N, 87° 24' 51" W.

Basic measurements of the earth for the geographic grid are as follows:

A. Earth measurements

Radius for a sphere of equal area	6370997 m	3958.7 statute mi.
Equatorial circumference	40075 Km	24902.1 mi.

B. Geographic grid

At latitude, degrees	length along 1° of longitude, statute mi.	length along 1° of latitude, mi.
0	68.704	69.172
20	68.786	65.026
40	68.993	53.063
60	69.230	34.674
80	69.386	12.051
90	69.407 (an average of 69 miles may be used)	0.000

It must be recognized at this point the relationships that exist between the geographic grid as superimposed upon the earth's surface and its manifestation as a projection on a two-dimensional plane. All points on the plane surface can be identified in latitude and longitude relative to a point of origin, but the distance, scale, shape and equivalent properties are now distorted.

Township and Range Survey System – A second major system of location is the Township and Range Survey System (see Fig. B7). Along with the geographic grid this system has had a pronounced influence on the spatial pattern of transport systems which in turn has influenced the location, shape and size of many of man's artifacts.

The point of origin of the township system is based upon a previously surveyed meridian and parallel of the geographic grid. The originating meridian is designated as a principal meridian and may be identified with a number or word (examples: 2nd P.M. (west of Indianapolis), Michigan Meridian). The originating base line is a surveyed parallel of latitude and is identified as a base line. The total system has many principal meridians and base lines.

Once a principal meridian was identified, surveyors laid off north-south strips of land east and west of the P.M. known as ranges. Each range was enumerated as R1W, R2W, etc. or R1E, R2E, etc. Since succeeding range division began to deviate from meridian of longitude an adjustment was made resulting in a total of thirty-two principal meridians.

Similarly, as a base line was identified, east-west strips of land were laid off and designated as townships. These strips were also approximately six miles in width. Due to the converging nature of the division lines for the ranges standard parallels were used as new base lines.

The interesection of a range and a township delineated a thirty-six square mile area known as a Congressional Township. Each Congressional Township is identified relative to the point of origin created by the intersection of the principal meridian and base line, e.g., T2N, R6W, 2nd P.M. The areas referenced to one principal meridian and base line vary across the country. Where two sections of the system meet there is little, if any, correspondence.

The subdivision of the Congressional Township proceeds in an orderly fashion (see Fig. B7). Square-mile sections, thirty-six in all, are enumerated beginning in the northeast corner, trending westward, thence southward one row and then eastward. This order continues to section thirty-six in the southeastern corner of the Congressional Township. Identification at this division would be Sec. 10, T2N, R6W, 2nd P.M.

Division of each section commences from its center point. From this point the section is subdivided most frequently into quarter-sections. Thus the first division of a section is designated relative to cardinal directions: SW ¼, SE ¼, NE ¼, and NW ¼, or N ½, S ½, E ½, and W ½. A further division again proceeds in a similar fashion from the central point of each divided section. Thus a 10-acre area could be correctly identified as the SE ¼, SW ¼, NW ¼, Sec. 10, T2N, R6W, 2nd P.M.

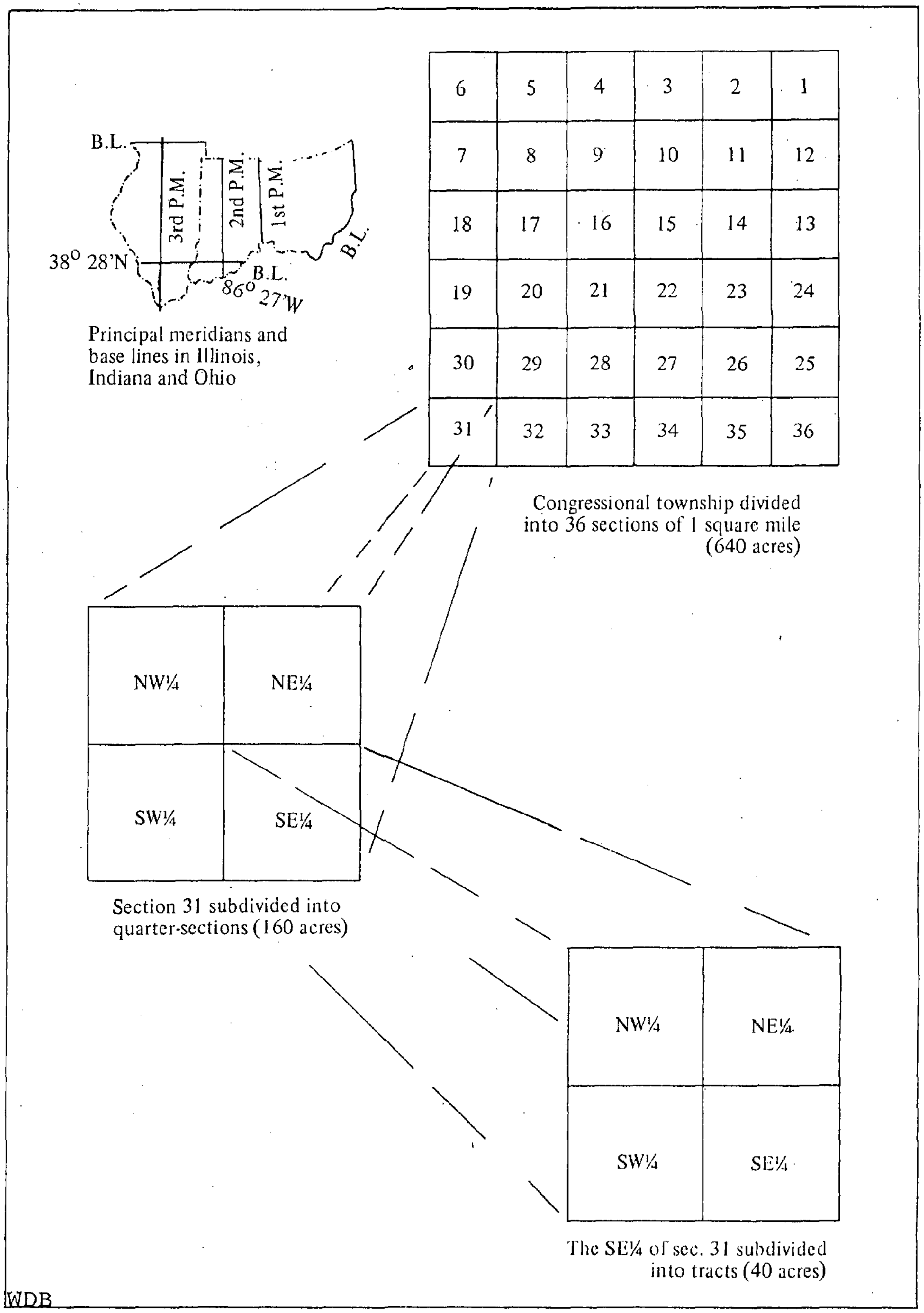


Fig. B7. The Township and Range Survey System Subdivision (by W.D. Brooks).

The Universal Transverse Mercator Grid – The first step in planning is a descriptive categorization and recording of the extent, density and dynamic relationships of phenomena. An inventory of resources for planning purposes presents a major problem due to the large amounts of data that are collected. Such data must be compatible not only to the procedures used in collection and recording but also to computer software application for manipulation, storage and retrieval. Intelligent planning requires the selection of a method by which large amounts of data can be identified, recorded and made available for immediate retrieval.

The best method for identifying and recording data is the Transverse Mercator projection (TM) used in combination with the Universal Transverse Mercator grid (UTM). The UTM is a combination of rectangular coordinates and graticule that has a number of desirable characteristics for inventorying large amounts of data.

The UTM system as presently used has been designed to represent the earth's surface between 84° S latitude. One major part of the UTM system is the Transverse Mercator Projection (TM). This projection is the transverse case of the Mercator projection (see Fig. B8). Dashed lines on Figure B8 indicate the Mercator projection while the solid lines indicate the superposition of the Transverse Mercator. It can be seen that a great circle of longitude of the Transverse Mercator occupies the parallel of 0° latitude of the Mercator thus a rotation of 90°. Hence the poles of the transverse case are located along the equator of the Mercator. Consequently, the equator of the transverse case (shown thrice) is coincident with a meridian of the Mercator.

A modification in using the Transverse Mercator increases its usefulness. Again reference to Figure B8 indicates that along the central meridian of the TM exact scale is held. Modification of this situation occurs as scale is held exact along planes parallel to the plane of the central meridian. In reality therefore, the projection is derived from the secant position. This situation allows true scale along parallel lines located equidistant from the central meridian of the projection. The surface distance referenced between lines of true scale is 360 km (360,000m).

Only a narrow extent of 3° on either side of the central meridian is actually used in conjunction with the UTM grid. Logically the total system is not used for large-scale mapping purposes. The meridians and parallels of the projection to be used are identified according to that portion of the earth to be mapped.

The Universal Transverse Mercator grid (UTM) is a system of intersecting parallel lines forming a series of rectangles (see Fig. B9). The dimensions of each rectangle can be determined according to the degree of complexity required as subdividing each square results in setting off smaller areas.

The grid is located on the earth's surface such that a vertical zone is centered on a chosen central meridian of longitude and rows are centered on the equator. Each vertical zone at the equator is 6° of longitude in width and extends from 84° N to 80° S (as presently used). Figure B9 indicates how each zone is set off and identified. Sixty zones are numbered consecutively eastward through 360° with Zone 1 at 180°.

With one exception the vertical zones are delimited into rows 8° wide. Again, Figure B9 locates the rows and the method of identification. Successive rows are lettered C to X (omitting I and O) beginning at 80° S and extending to 84° N. The resultant grid consists of rectangles bounded by parallel lines equally spaced with a peculiar location.

The identification of each rectangle at various levels is simple and straightforward. All 6° by 8° rectangles are identified by zone-row designation. Figure B9 indicates the location of one such area as 16S. Further subdivisions are based upon a method of "false eastings" and "false northings" (see Fig. B11). Using the intersection of the central meridian of each vertical zone and the equator an origin is established so that each area subsequently located always has a positive listing. The central meridian is identified as 500,000 m east while the equator of even-numbered zones is begun at 500,000 m north. Odd-numbered zones begin at 0 m north. Proceeding in the southern hemisphere is such that the equator is enumerated as 10,000,000 m north.

Figure B12 shows how each zone and row is further subdivided into 100,000 m squares. The alphabet is used to subdivide the 6° column into 100,000 m columns. Beginning at 180° longitude and proceeding eastward each 100,000 m column is identified A-Z (excluding I and O) south to north and is repeated at 2,000,000 m intervals (see Fig. B13). Each 100,000 m square is thus identified by two letters. Further subdivision to the 10,000 m, the 1,000 m and the 100 m square is accomplished by equal divisions of each square. Thus 10,000 m squares are designated by two 1 digit numbers derived from the false eastings and northings. Subsequent divisions to the 1,000 m (km) uses two 2 digit numbers and the 100 m square (hectare) uses two 3 digit numbers (see Fig. B14).

An example is as follows (see Fig. B15):

16S	locates a 6° by 8° area in Indiana and Illinois
16SDD	locates the 100,000 m square in which Terre Haute is located
16SDD66	locates the 10,000 m square in

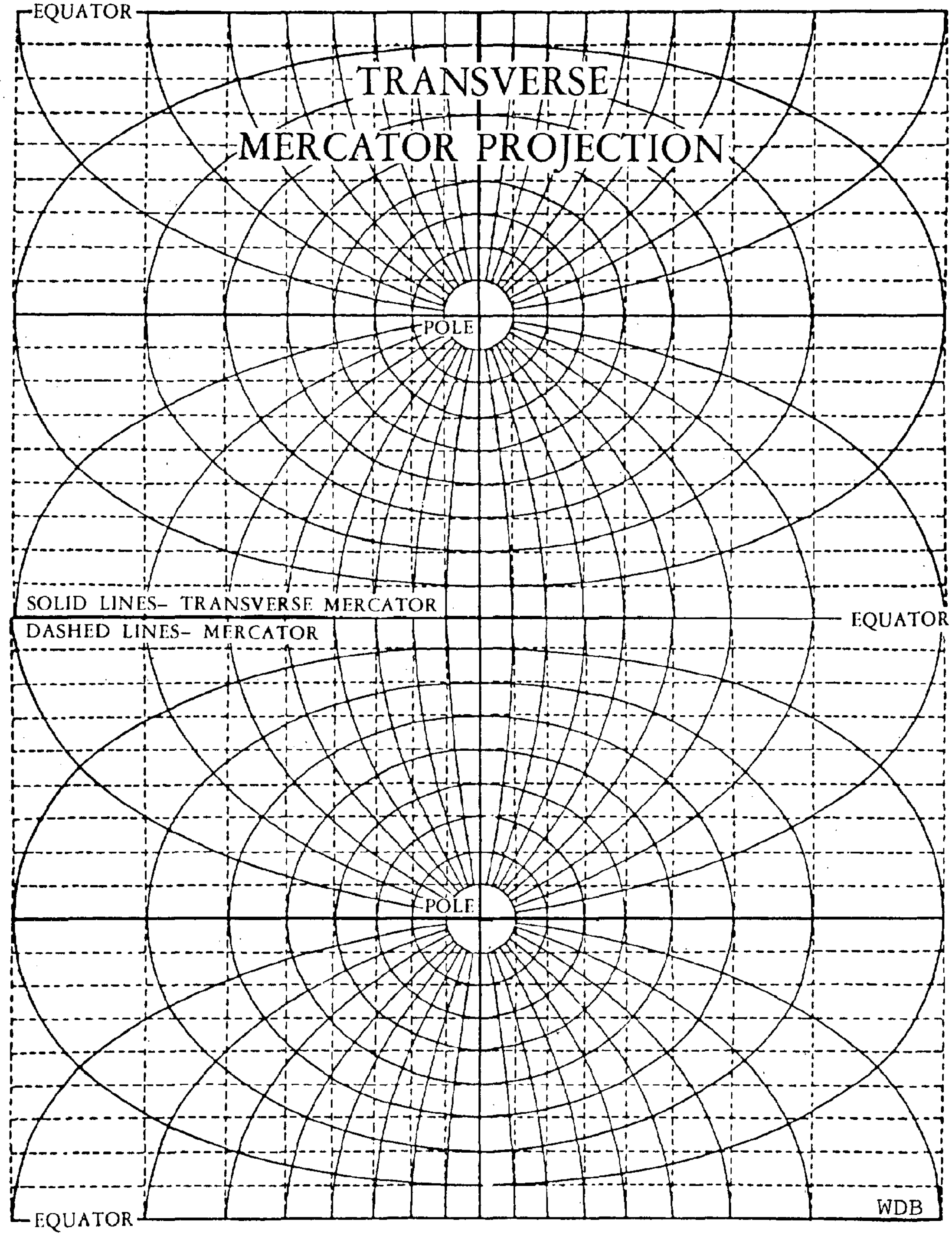


Fig. B8. The Transverse Mercator Projection (after Dietz and Adams, Elements of Map Projection, 1945).

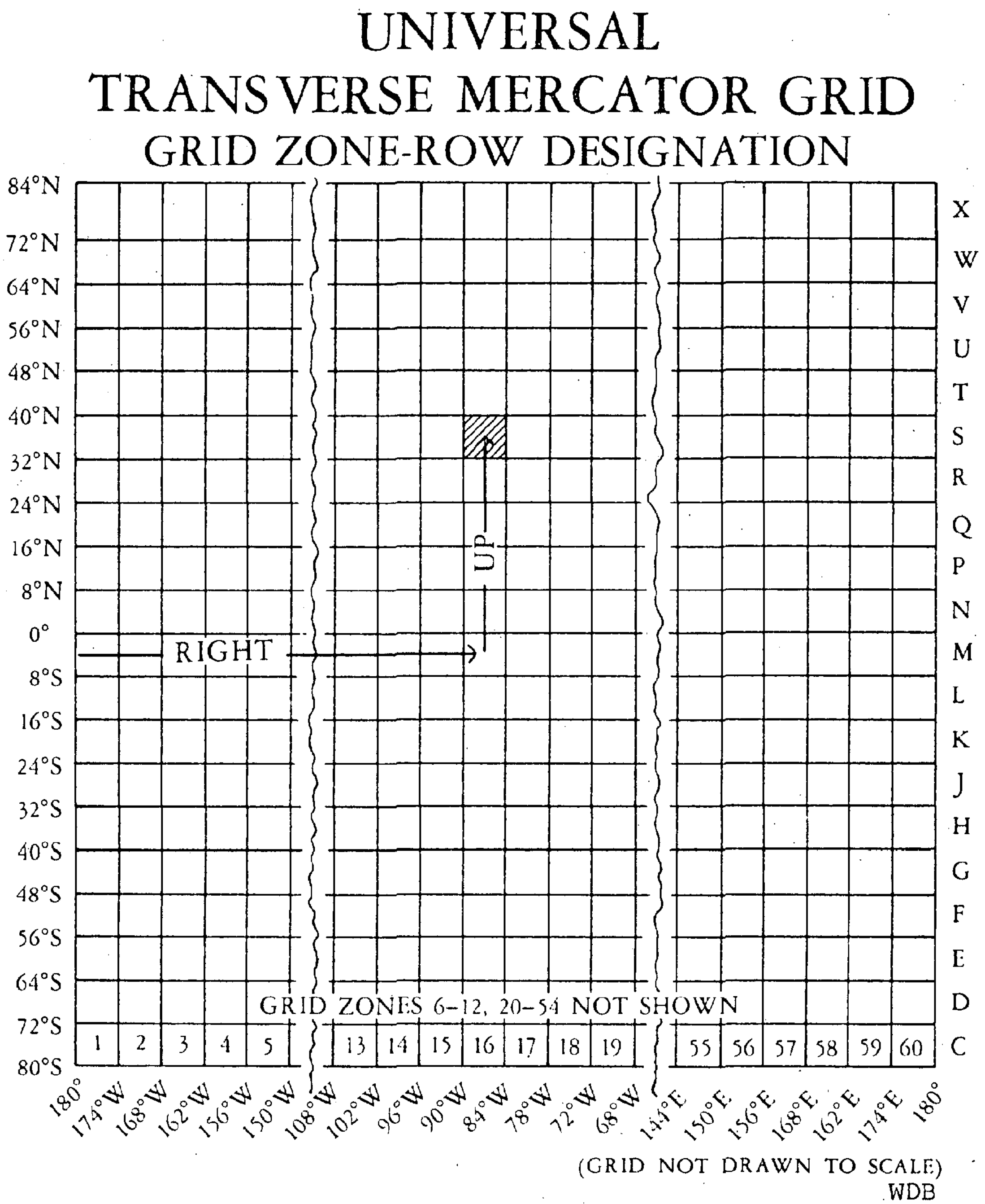
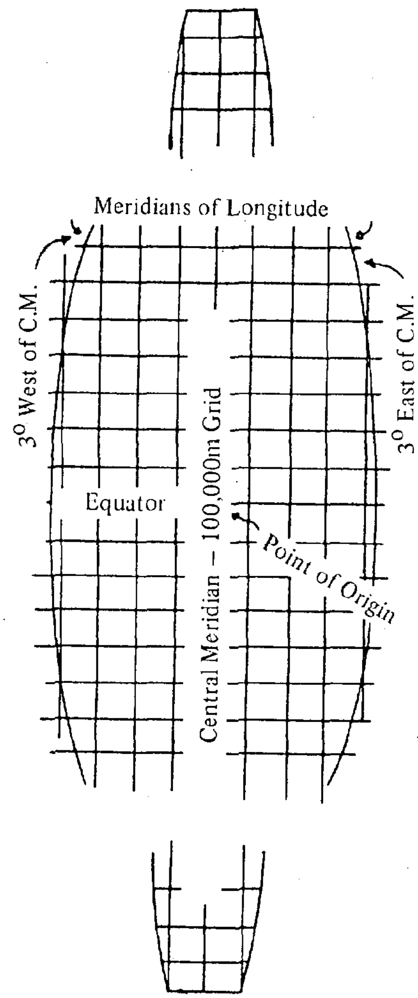


Fig. B9. The Grid Zone-Row Designation of the UTM Grid (after Brooks, "The Universal Transverse Mercator Grid," Proceedings of the Indiana Academy of Science, 1974).

Fig. B10. A UTM Grid Zone Showing the Point of Origin, Longitudinal Extent and the Control Meridian (after U.S. Department of the Army, FM 21-26, 1965).



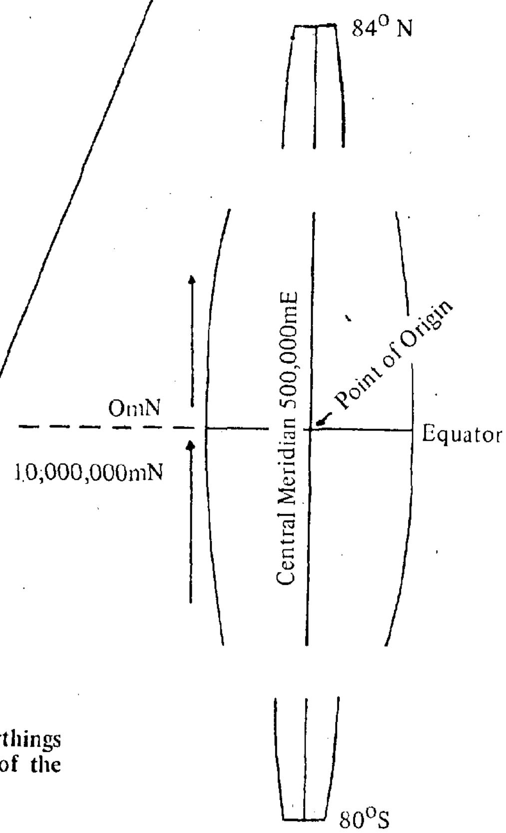


Fig. B11. False Eastings and False Northings for a Grid Zone (after U.S. Department of the Army, FM 21-26, 1965).

WDB

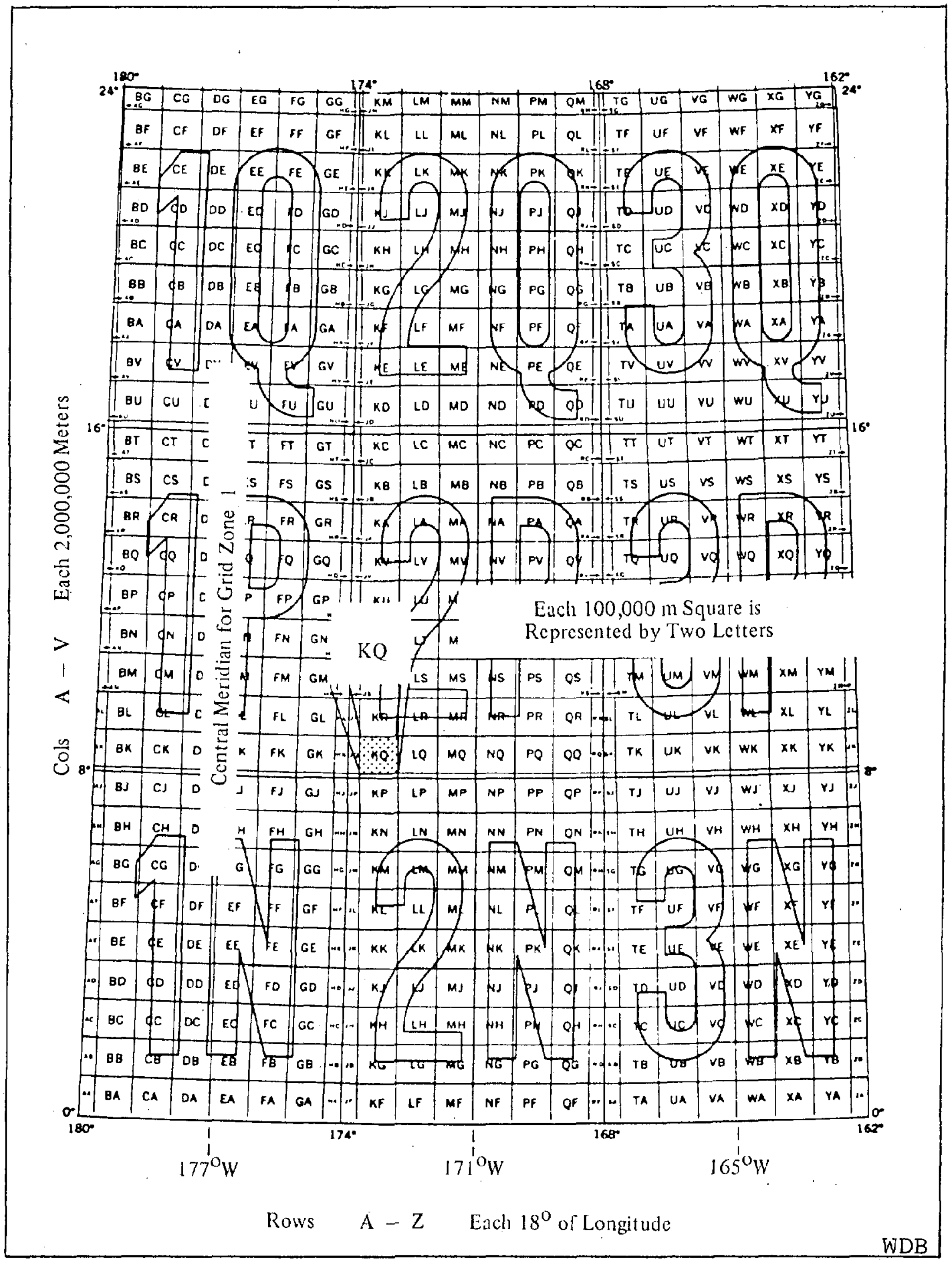


Fig. B12. Subdivision of Grid Zones into 100,000 Meter Squares (after U.S. Departments of the Army and Air Force, TM, 5-241, To 16-1-233, 1951).

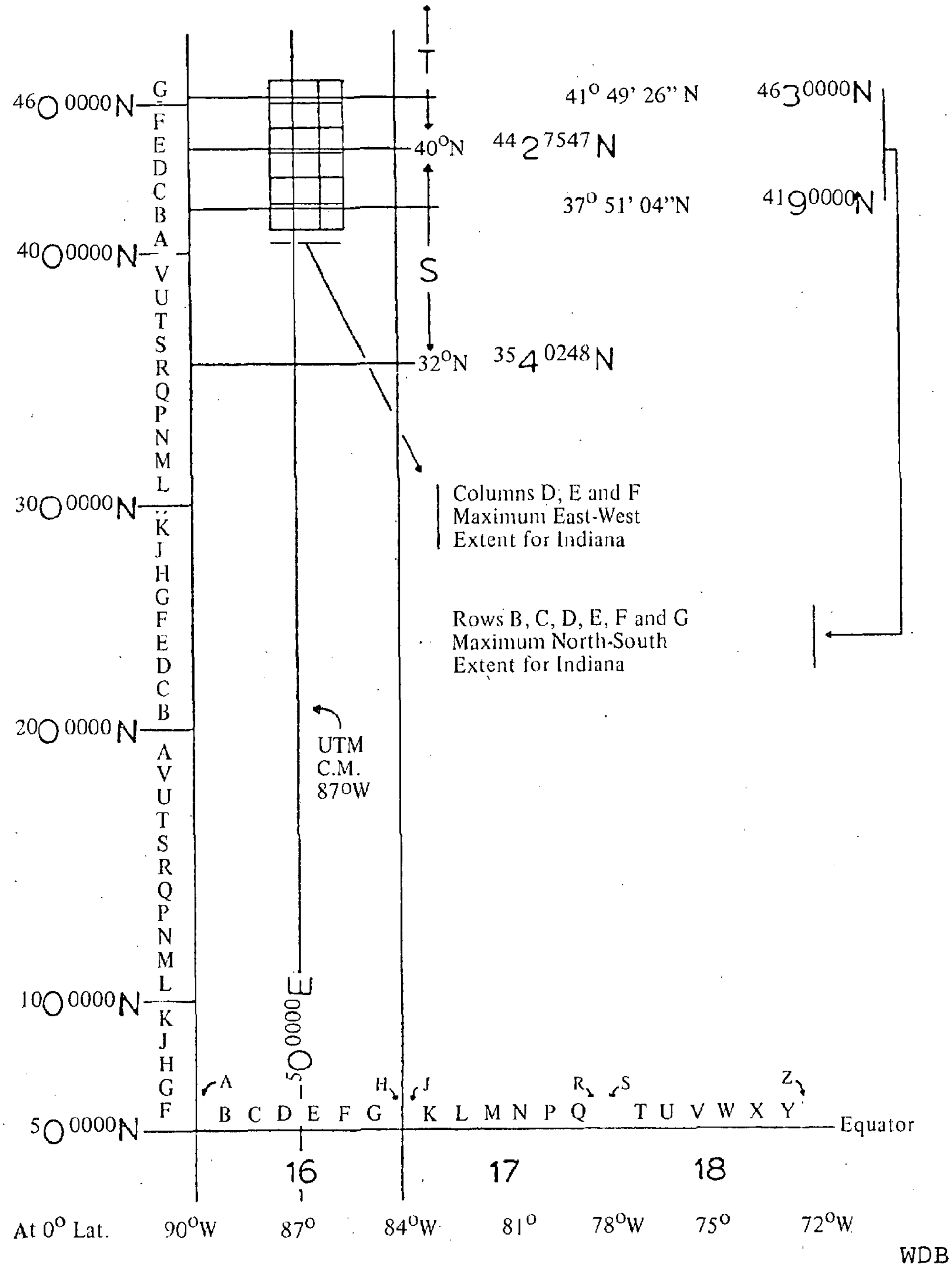
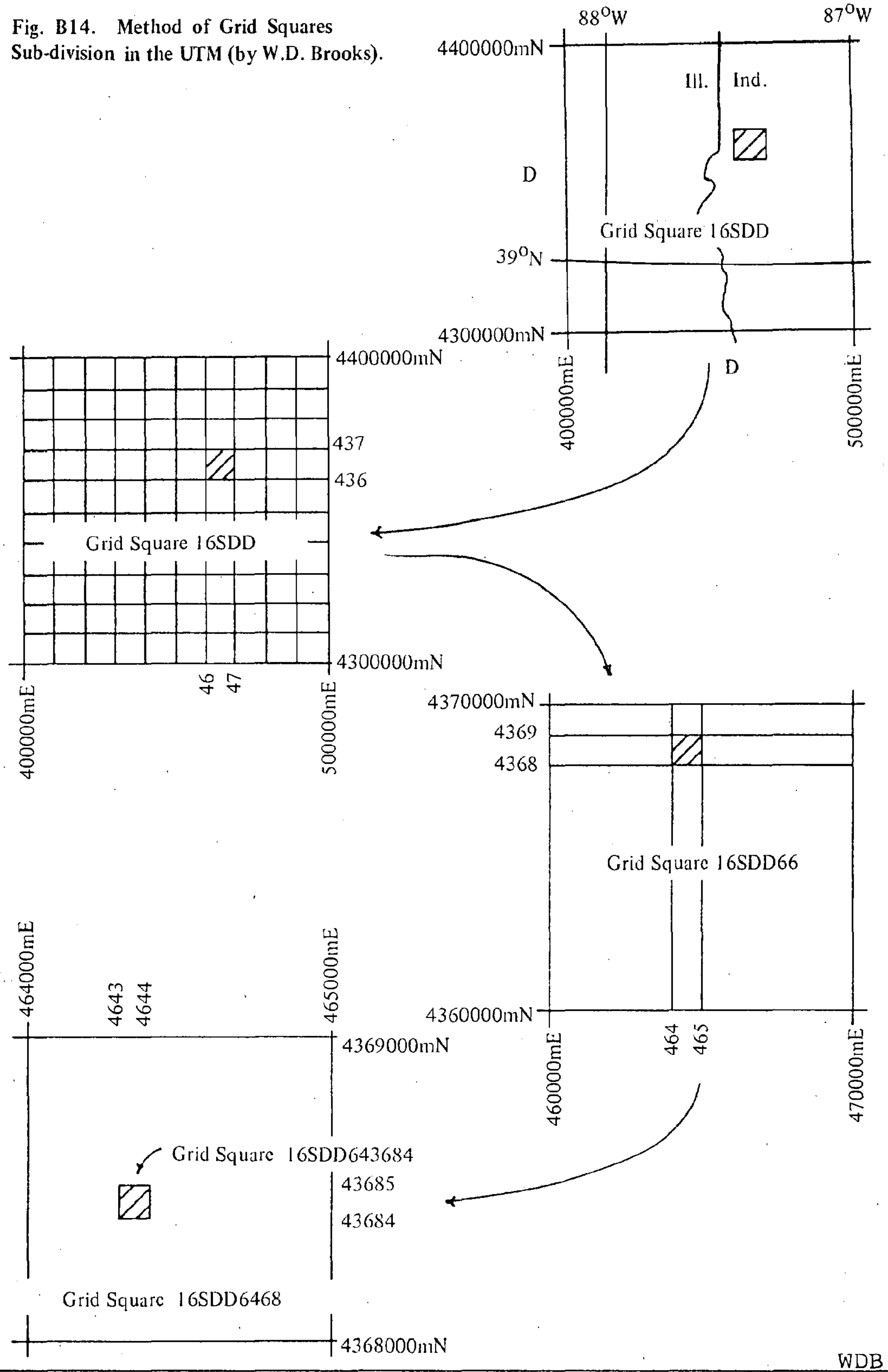


Fig. B13. The Relationship of Grid Zone 16 to the State of Indiana (after Brooks, "The Universal Transverse Mercator Grid," Proceedings of the Indiana Academy of Science, 1973).

Fig. B14. Method of Grid Squares Sub-division in the UTM (by W.D. Brooks).



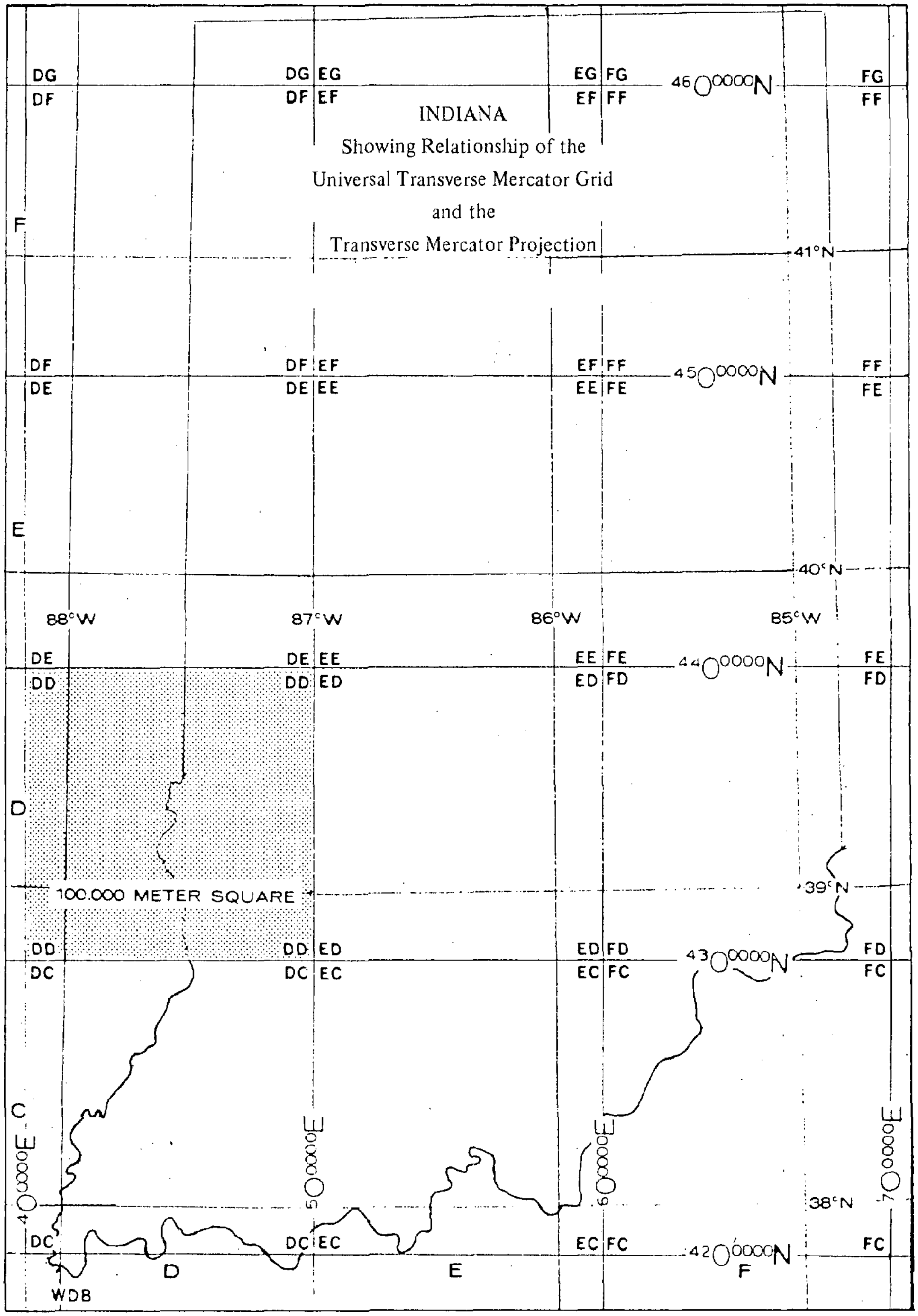


Fig. B15. Indiana, Showing the Relationship of the UTM Grid and the TM Projection (after Brooks, "The Universal Transverse Mercator Grid," Proceedings of the Indiana Academy of Science, 1973).

	which the Vigo County courthouse is located
16SDD6468	locates the 1,000 m square in which the Vigo County courthouse is more precisely located
16SDD643684	locates a 100 m square within the area occupied by the Vigo County courthouse

The case for using the UTM as a reference system encoding resource data is based upon a number of important considerations. These considerations are derived from a) the nature of the system, and b) the requirements of data encoding.

The basic reference form for the earth's surface is the ellipsoid of revolution. Since much of the mapping on the earth's surface is large-scale mapping there is an advantage to reducing the sea-level arc to a plane surface. This changes spherical coordinates to rectangular coordinates thus reducing to a minimum alteration from true scale representation. Furthermore, the transformation promotes ease in determining distance and azimuth and it also allows all present maps to be recast to a compatible identification format.

The transformation from spherical coordinates to rectangular coordinates allows for a minimum scale alteration. Large-scale mapping and surveying involves the use of rectangular coordinates and it is obvious that conformality (good shape) is a major characteristic to be maintained. The Transverse Mercator is conformal on a transverse cylinder. Conformality as a property requires that all angular relations be preserved and also scale in all directions from a point be true. More importantly with the Transverse Mercator the scale factor resulting from points on the sea level arc being projected to the plane surface would range from 0.99960000 through unity to 1.0016504. The angle from the central meridian in each grid zone is 3° 40' for the latter figure. Furthermore, the elevation of the datum would range from a minus 2,548 m at the C.M. through 0 to a plus 10,516 m at the edges of the grid zone. These figures are for a 6° width zone and it is obvious that 4° or 2° width zone would reduce scale alteration even more. These scale factors represent tolerable error for most mapping and surveying projects.

Calculation for distance and azimuth between points is reasonably simple with the UTM grid. Since the coordinate system is based on a known projection the relationship or scale distortion can be correctly established for all points.

A reference system based on the UTM would allow compatible mapping projects between discontinuous areas and can be related to a single earth-centered-reference-system. All calculations from ground inventory reduced first to sea level and then to the reference datum would insure compatible mapping between projects initiated by various agencies. Geodetic control on ground location would be the same for all mapping projects.

Requirements of data encoding and subsequent computer application produces constraints on any data encoding system which must be compromised. The UTM grid system offers a method to permit data to be recorded on a common base, provides for maximum data content and allows for up-to-date base maps on a continued basis.

The effectiveness of any inventory system is enhanced if all data can be recorded on a common base. The UTM grid system provides through intersecting parallel lines either the 1,000 m square or the 100 m square as the basic unit within which all categories of data can be referenced in the metric system. Using proper computer software many categorically different data can be assigned the same location coordinates. It is standard procedure in computer mapping for grids to overlay source maps from which x, y, z coordinates can be easily digitized. A common grid would permit interagency compatible data banks and reduce the considerable amount of duplicate effort.

The selection of a common base coupled with appropriate computer software provides for maximum data bank content. A proper resource inventory must be so organized that collected data can be used to provide maximum interpretation of land cover although maximum interpretive ability can occur only if software allows a selectivity in informational detail retrieval.

In summary the UTM is a system retaining the necessary requisites for a proper reference system. They include:

1) The system is conformal allowing true scale and preservation of all angular relationships about a point.
2) With a superpositioning of a grid small scale alterations are maintained.
3) With the superpositioning of a grid a common base for data diversity categorization is provided at either a square kilometer or hectare size.
4) The use of the UTM grid would allow compatible data banks as they would be based on the same measurement system.
5) Referencing in the metric system would simplify data encoding and would permit interface with extracontinental mapping.

The Cartographic Processes

Earlier in this text reference was made to planning, execution and reproduction as a framework for effective maps. At this point it would be instructive to look more closely at planning and execution in order to better understand the cartographic processes.

The Process of Generalization – As observed above the interpretation of spatial relationships and their subsequent analysis for planning purposes requires that earth space phenomena be reduced to a comprehensive scale. In doing so all phenomena must be modified in some manner. It is impossible to compress all earth space content to a single manageable map and have anything but chaos. Thus in encoding large amounts of data they necessarily are modified in some way. It is a selection process based on intelligent judgements which in turn are based on reasonable objectives and purposes. The end result, then, is not a one-to-one reproduction but a carefully selected set of data chosen such that the most salient characteristics of a data set will be displayed. During this process one must be rigorous in the selection process otherwise the map is not an analytical tool but a propaganda device.

The process of generalization occurs during the planning stage. This process, in order to be effective, must select and reduce in both an intellectual and physical mode. The first concern, therefore, is the modification or simplification of the data that are to be mapped. As the actual physical area of the final map is considerably smaller than that of the portion of the earth being mapped, the item symbolized will occupy a proportionately larger area. It can be shown that the amount of information which can be symbolized in a given area is reduced geometrically relative to the area designated as the map. In other words, as the physical area of the map is reduced the amount of information which can be selected is reduced. Thus, the process of data generalization must be done carefully in order to retain legibility and, perhaps more importantly, "truthful" representation.

The decision as to what will be retained or discarded when generalizing cannot be set to any rule but must proceed within the bounds set forth by the chosen map scale and the map objective. These are constraints which will control the generalization process. For example, a road map of the state of Indiana could very well show all classes of roads within the state if the actual physical size of the map is "large," i.e., six feet top to bottom. On the other hand, if the physical size of the map is to be 6 inches north to south some classes of roads could not be shown, since legibility would be grossly affected.

In line with the selection and generalization of data, its subsequent symbolization is a major aspect of the generalization process. As above, point, line and area symbols have been shown as the method used to represent earth space phenomena, and in doing so the map maker is generalizing the character of a geographical distribution.

Again the objective or purpose of the map and its scale do much to determine the degree of generalization by symbolization. To these two constraints must be added a third constraint of the limits of the symbolization system itself. As above, the point, line and area symbols must show four types of data sets by adding the problem of portraying the third dimension on two-dimensional surfaces. Again, as the amount of area from the earth that is mapped changes within a given map dimension the degree of symbolization changes. For example, a map of the city of Terre Haute, Indiana covering this page can show in some detail the differing urban character. But in the map of the United States covering this page then the city of Terre Haute becomes only a "dot." As a matter of fact depending on the urban characteristics chosen to be mapped Terre Haute may not be shown at all. Thus as the scale of a map changes from large scale (small area) to small scale (large area) the degree of symbol generalization increases. In doing so it becomes obvious that many salient characteristics of data sets become "hidden." A trade-off occurs as when generalization increases a larger portion of earth space content can be shown.

The relationship of symbol generalization to data selection in the generalization process becomes obvious. The basis for selection and modification of data plus its symbolization requires a thorough insight into the objective of the map. This constraint or control over the generalization is the most important aspect with which the cartographer has to deal. Symbolization must "capture" the essence of a distribution over and above simply locating items. The cartographer must be cognizant of the visual impression of a line, a pattern, color etc. if the value of that symbol is less than other symbols. Prominence must be assigned by symbolization as there is no other way. Graphic limits is a major constraint. The presentation must at once be simple, harmonious, balanced, patterned and show variation and contrast. A difficult job but possible if the objective is clear.

Along with the modification of data and its subsequent symbolization there must be a grouping or classification of data. There must be a sorting out and manipulating of data in order to ensure comprehensiveness. The understanding of complex magnitudes requires classification. As above, differentiation or grouping may be nominal (class only), ordinal (class and ranked qualitatively) or interval (class and ranked quantitatively).

Basically the classification of data focuses on the determination of class intervals. With nominal scaling this determination is rather easily accomplished. Certainly most geographical distributions are readily differentiated and symbols can be quickly chosen to graphically illustrate the differences. Urban-rural areas, forest-grasslands, residential-commercial and many other more complex differentiations can be resolved without much trouble. The problem without easy solution occurs in nominal categories when a "mixture" must be symbolized. In this case two or more categories must be symbolized by interdigitation, overlap of symbols or the use of a single symbol to show the mixture.

The Process of Compilation – The gathering of base and thematic map data and the actual construction of the finished map extend across the planning and execution stages and can be identified as the process of compilation. All maps whether small-scale (large area) or large-scale (small area) require certain information which is basic and provides a frame upon which the main thematic information is placed. This base information consists of the essentials of maps and physical aspects of the area mapped so that the map user is fully informed. Subsequently, the thematic information (abstract or real) is superimposed and creates meaning to the finished product.

The map data base consists of those items which will provide a framework within which the thematic data will have meaning. Thus, physical and cultural features are chosen which will most clearly portray the salient features of the mapped area. Those would include drainage features, major lakes and basic civil divisions. Other items would include the symbolization of the basic transportation net and unusual or unique public features. Finally, a map data base should show those essentials of maps as outlined above. The most important being a system of location and a scale indication. The end result is a base map which can be used either singly or in a series and will provide for meaningful spatial relations when thematic data is added. The actual amount of detail will, of course, depend upon the scale of the map.

The acquisition of the data for a map data base may come from a variety of sources. These would include field observation, graphic sources and textual materials. In each case the objective is the same, that is to provide accurate locational information for incorporation into a map base.

Field observation is the actual observation used to record first hand knowledge, to check and compromise errors and to update information files. Field observation represents the only method by which direct access to information is accomplished. All other methods present the second or more generation of data and its veracity becomes suspect. The inventory collected while in the field is the result of qualitative and quanitative measurements and observation according to preconceived and predetermined criteria and procedures.

Information gained from other sources can be checked while in the field. Questions concerning the validity of data from other sources can be substantiated or refuted and corrected. Conducted at regular intervals, field observation results in the maintenance of an updated inventory.

Graphic sources represent data inventory from already compiled maps, photographs and all kinds of remote sensing devices. Published and unpublished maps provide a wealth of information which can be used in various ways to produce a base map. As a matter of fact some published maps, such as the United States Geological Survey map series can be used as items from which to trace. Used in this manner, accurate maps can be quickly produced. Cartographic compilation and generalization procedures have resulted in planimetric and hypsometric correct location of all symbols. Locations, horizontal and vertical, are positioned correctly through precise geodetic measurements.

Aerial photographs as graphic sources become indispensable as one realizes the ability of the camera to record visible phenomena. All parts of an area are recorded by photographs thus the compilation process is promoted by contributing to precise positional locations. Interpretation of photographs involves recognition of images and recently flown photographs are useful for up-to-date accuracy and can be used for map revision.

Remote sensing devices are information gathering instruments which record reflected and emitted portions of the electromagnetic spectrum. In most cases a number of sensors are used in a supporting manner to provide input data. These devices are efficient ways by which large amounts of data can be collected.

Radiation from the sun is absorbed by various materials of the earth and when the energy is re-radiated it has a peculiar combination of frequency and wavelength. By "sensing" the spectral wavelength the various ground elements can be identified as its element has its own spectral "fingerprint."

The several remote sensing devices include television, scanning radiometers, radio and radio frequency systems. Once processed all imagery from these sensors can be presented in a map-like form and used with confidence in helping to produce a base map.

The result of the process of compilation is a composite sometimes referred to as a worksheet. The worksheet is the "blue" line copy referred to above. When completed it is a rough copy and is readied for the drafting of a final copy. Thus the process of compilation is as much a mechanical process as a mental one.

APPENDIX C

AERIAL PHOTOGRAPHS

Introduction

Since the 1920's aerial photographs have become an accepted and proven technique of assessing spatial relationships. During the 1920's and 1930's many private companies and the federal government used aerial photographs for forestry studies, urban area studies, geologic investigations and other study approaches. During World War II the aerial photograph had become a firmly entrenched method by which interpretations of large areas could be made without the investigator being present. Since that time the use of aerial photography has expanded, and besides black and white now includes color, infrared and color infrared photography.

The technology of photography has had a long development. The first photographs were recorded during the 1830's. However, because of the necessity for long exposure times and a costly, time-consuming development process, it was many years before the advantages could be realized. Essentially the black and white and color photograph is image recording through the interaction of visible light and chemicals. It is, therefore, the result of visible light being reflected from objects. The making of a photograph is considered to involve the reflectivity and emissivity factors of objects, collecting and focusing of light by a lens and the subsequent recording of an image by a chemically sensitive surface (the film).

Light, as used above, references a peculiar part of the electromagnetic spectrum. A pragmatic definition would indicate the electromagnetic spectrum to be matter in certain electrical and thermal states that can affect other matter. This is radiant energy manifesting the properties of wave motion. Therefore, once matter is excited to a higher energy level radiant energy is propagated through space and is reflected by matter or absorbed and re-radiated by other matter. Radiant energy that is propagated through space is measured by the wavelength that it manifests and these wavelengths range from extremely small to extremely large. Visible light is that part of the spectrum which we sense as white light and is the energy that is recorded as images on the sensitive emulsion of film. The wavelengths of visible light range from about 0.40 to about 0.75 microns.[1] Daylight or whitelight is a mixture of wavelengths and by passing it though a prism it can be dispersed into its spectrum. This spectrum would show increasing wavelengths and would also show a continuous color change ranging from violet on the "short-wave" end to a deep red on the "long-wave" end (see Fig. C1).[2]

The human eye as a receptor system is not sensitive to all portions of the visible light spectrum (see Fig. C2). A much greater amount of reflected energy is needed for a visible response in the violet or the red than is needed in the green portion of the spectrum. Thus, with a leaf the human perceives green as the predominant color yet the leaf reflects deep red much more strongly. Other objects are perceived in a color range according to the extent to which they reflect differing wavelengths.

On the other hand, "perception" of light by a sensitized film produces a different curve than that from the human eye. A spectral sensitivity curve for film used in aerial photography would show fairly equal response across the white light spectrum to the orange-red area where a rapid decrease occurs. Because of this the varying parts of the spectrum are "seen" differently by the human eye and film emulsion.

The spectral sensitivity of film to wavelengths greater than 0.75 microns produces infrared photography. The term infrared is usually applied to areas in the spectrum of wavelengths up to about 100 microns but infrared photography is restricted to about 1.2 microns because of the technology of sensitizing dyes.

Photographs obtained by infrared alone use different film and lens filters than those used for black and white or color. Filters are used which necessarily block all or most white light and thus restricts the recording of the spectrum to the "invisible" infrared.

The Properties of the Aerial Photograph

The aerial photograph may be oblique or vertical (see Fig. C3). An oblique photograph is the exposure of a surface when the camera is held at other than a vertical orientation. A high oblique photograph would have sufficient tilt so as to include the horizon while low oblique photographs,

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[1] One micron equals 0.001 mm.

[2] The association of color with wavelength is not entirely a correct interpretation as color results from frequency of vibration but a complete distinction at this point in the discussion is not necessary.

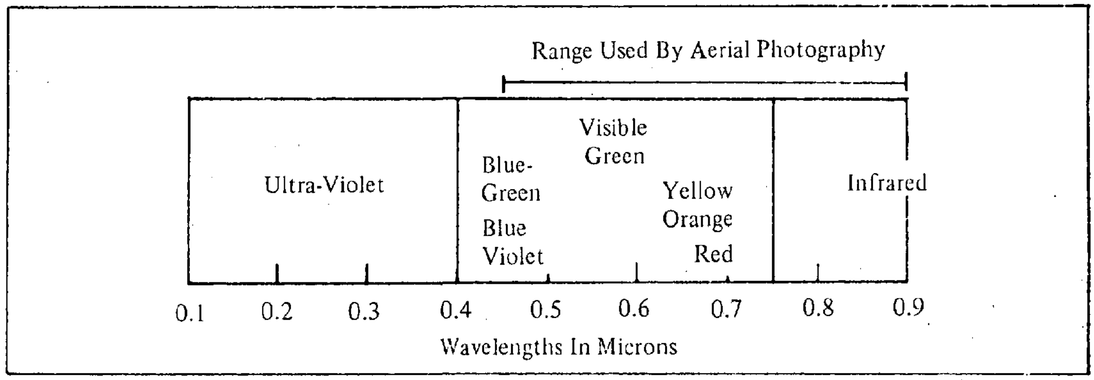


Fig. C1. Portion of the Electromagnetic Spectrum Important to Aerial Photography (by W.D. Brooks).

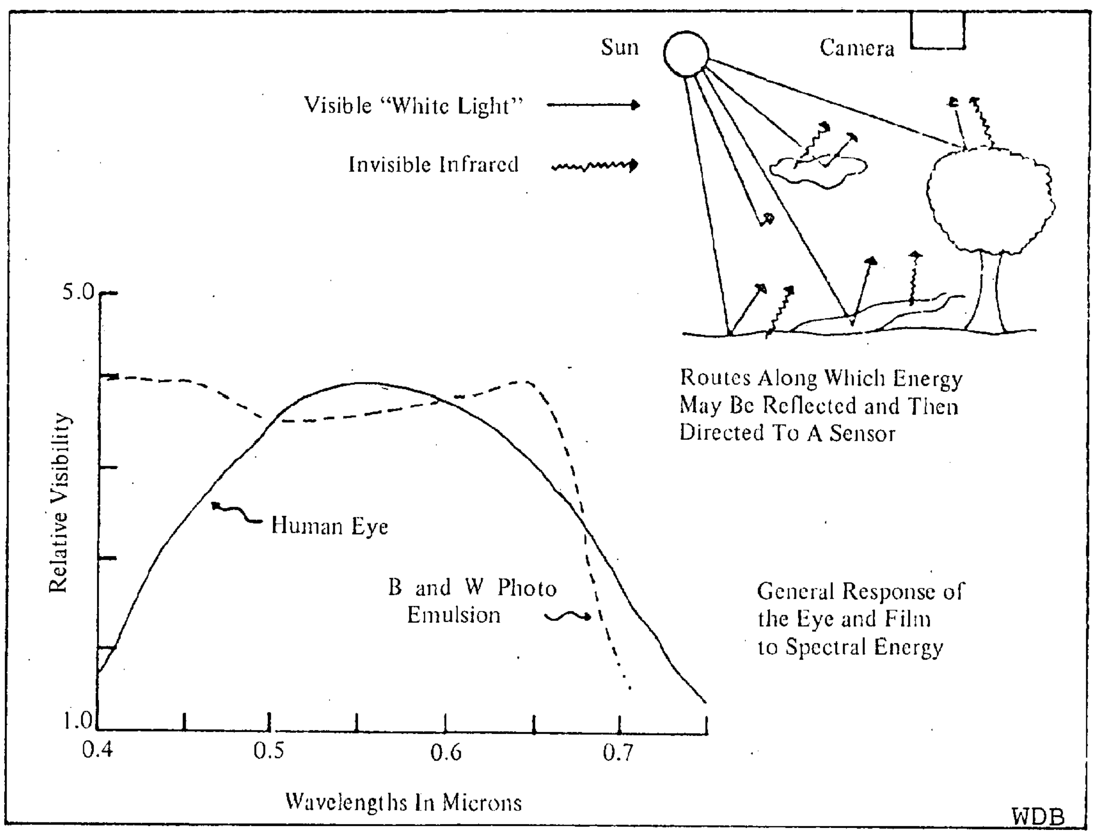


Fig. C2. Spectral Response Profile of Light Sensitive Systems (after Brook, <u>The Physical Aspects of Aerial Photography</u>, 1967).

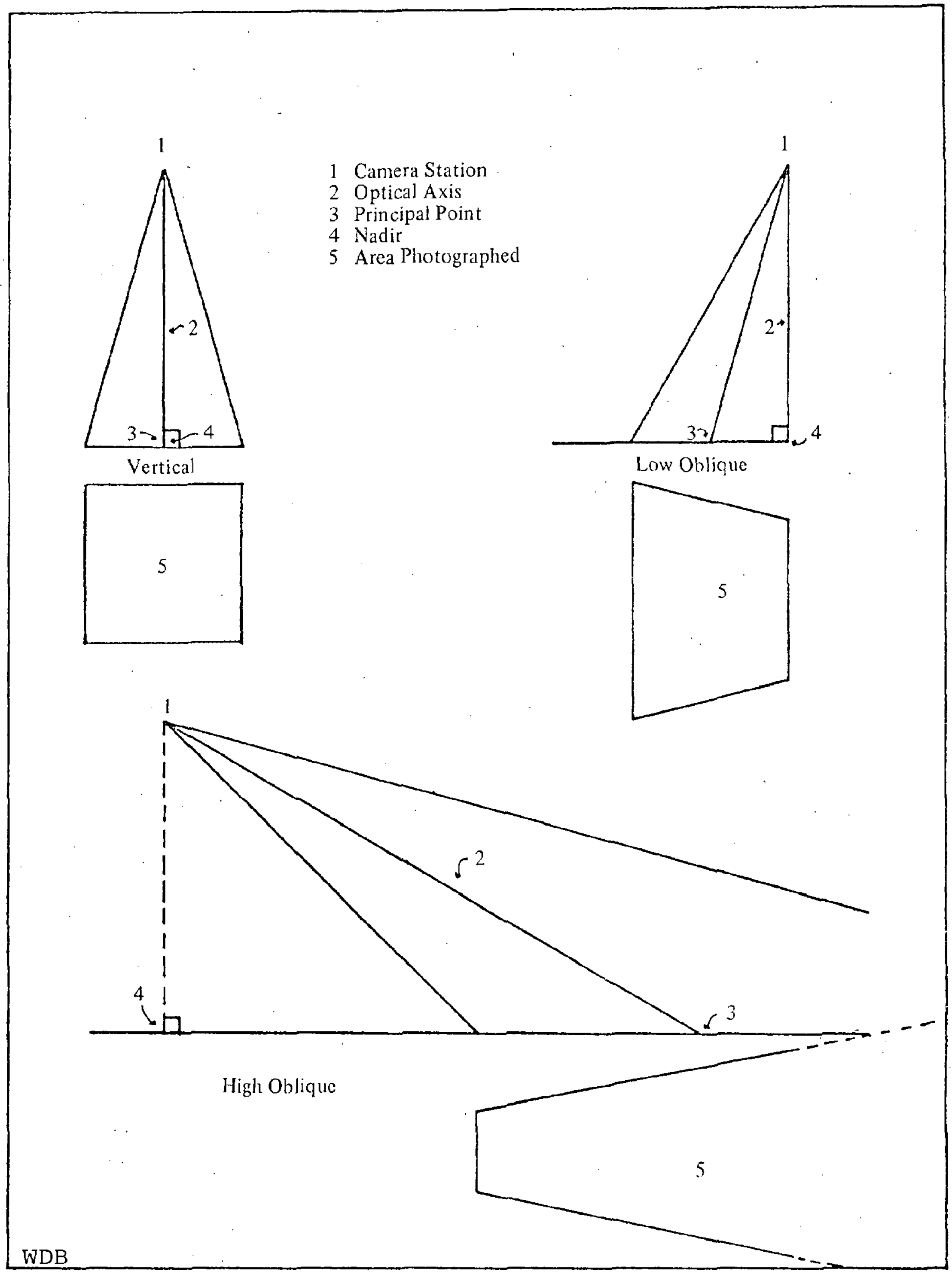


Fig. C3. Vertical and Oblique Aerial Photographs (by W.D. Brooks).

although tilted, do not include the horizon. Low and high oblique photographs are common in all types of publications but are seldom used for scientific studies due to the difficulty in assessing proper mathematical relationships between locations. The true aerial photograph is the result of a camera exposing a surface vertically. The major difference between a vertical and an oblique photograph is therefore the orientation of the optical axis of the camera where the optical axis is defined as the line along which the camera is aligned. This line is assumed to connect points representing the center of the film, the center of the lens and the center of the area being photographed. The vertical type photograph is primarily used for mapping purposes.

The procedures now used in photographing the earth's surface allow a continuous coverage (see Fig. C4). Photographs obtained from airplane camera stations are the result of repetitive flight paths which create both a sidelap and a forward overlap. The width of surface area shown is a function of the field of view of the camera and the altitude of the camera station. The vertical photographs that result from a properly executed flight plan can be used for high quality map construction and study.

Sidelap and overlap dimensions are variable because of topographic features and other considerations. In most cases sidelap ranges from 15 percent to 45 percent while forward overlap ranges from 55 percent to 65 percent. If overlap of 60 percent is planned two consecutive photographs would show all ground points. Because of this, photographs numbered 1, 3, 5, 7, etc. would show all ground points as would photographs numbered 2, 4, 6, etc. For monoscopic viewing each set is usually referred to as alternate photographs and the other set is then referred to as conjugate photographs. The advantages of overlap are that a continuous coverage is achieved and also, more importantly, overlap allows stereoscopic viewing of photographs.

Mechanical Properties – The interpretation of aerial photographs begins with a knowledge of the mechanical and geometric properties. The mechanics of the aerial photograph result from the relationship of the film (negative), lens, the positive print and the ground surface (see Fig. C5). It can be seen from Fig. C5 that if the camera is aligned in a true vertical position then the nadir and the principal point are the same. If a tilt occurs at the camera station a distortion is imparted to the photograph and the nadir and principal point will not be the same. Essentially in most good aerial photography, tilt is so slight that its effect can be safely ignored. The area of ground coverage is related directly to the height of the airplane (H) and the focal length of the camera (f). The positive that results is usually printed at a dimension of 9" by 9". On each photograph along the four sides or at the corners are located fiducial marks. These are marks that result from protuberances in the camera extending over the lens. Then when an exposure is made and printed an image appears (see Fig. C6). Although they may be of various designs their purpose is singular. When opposite fiducial marks (sometimes referred to as collimating marks) are connected with straight lines the intersection of these lines defines the principal point (PP) of the photograph. This is the geometric center of the vertical photograph and is coincident with the optical axis point.

Other information is recorded on each photograph. This may include the date of photography, the agency involved, and information regarding exposure number and roll. For example (see Fig. C6):

10-8-74	11:20 A.M.	1:20,000	SCS	ABC-12DD-112
Date	Time	Scale	Agency	

ABC – Study area identification

12DD – Film roll identification

112 – Exposure number

The beginning time and ending time plus the approximate scale is included on the first and last photograph of each flight line. Generally, for each study, film roll series identification and exposure number are numbered in an unbroken series beginning with one. This information is located on the northern side of the photograph for north-south flight lines and on the western side for east-west flight lines.

Geometric Properties – The geometry of the aerial photograph is concerned with the mathematical relationships between points on the photograph. Referring to Fig. C5 the following geometric relations are shown: the ratio of the image distance (BP) to the ground distance (B"P") is equal to the ratio of the focal length (f) to the camera height (H).

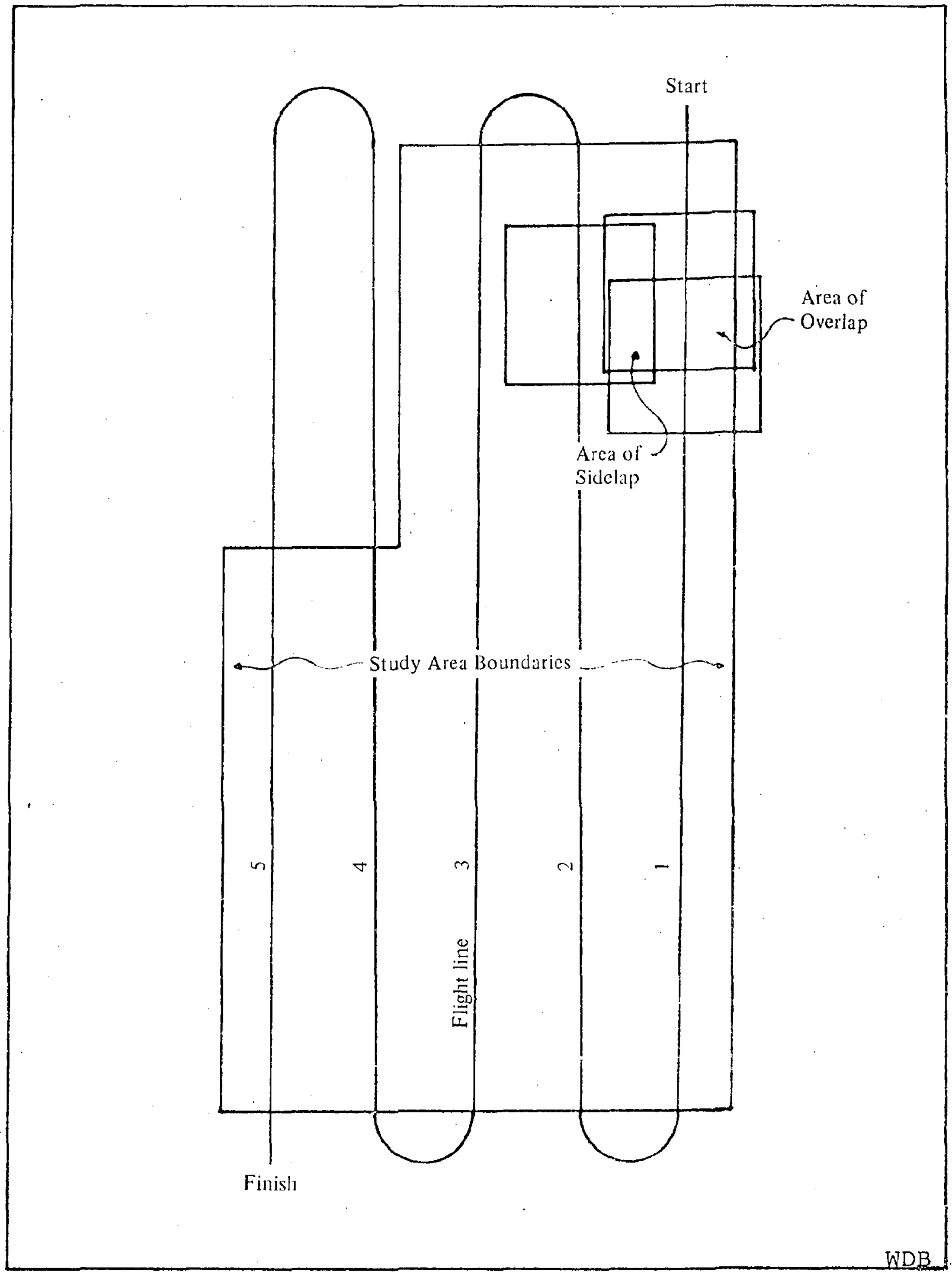


Fig. C4. **Study Area with Flight Line Orientation and Showing Aerial Photograph Overlap (after Miller, Photogeology, 1961).**

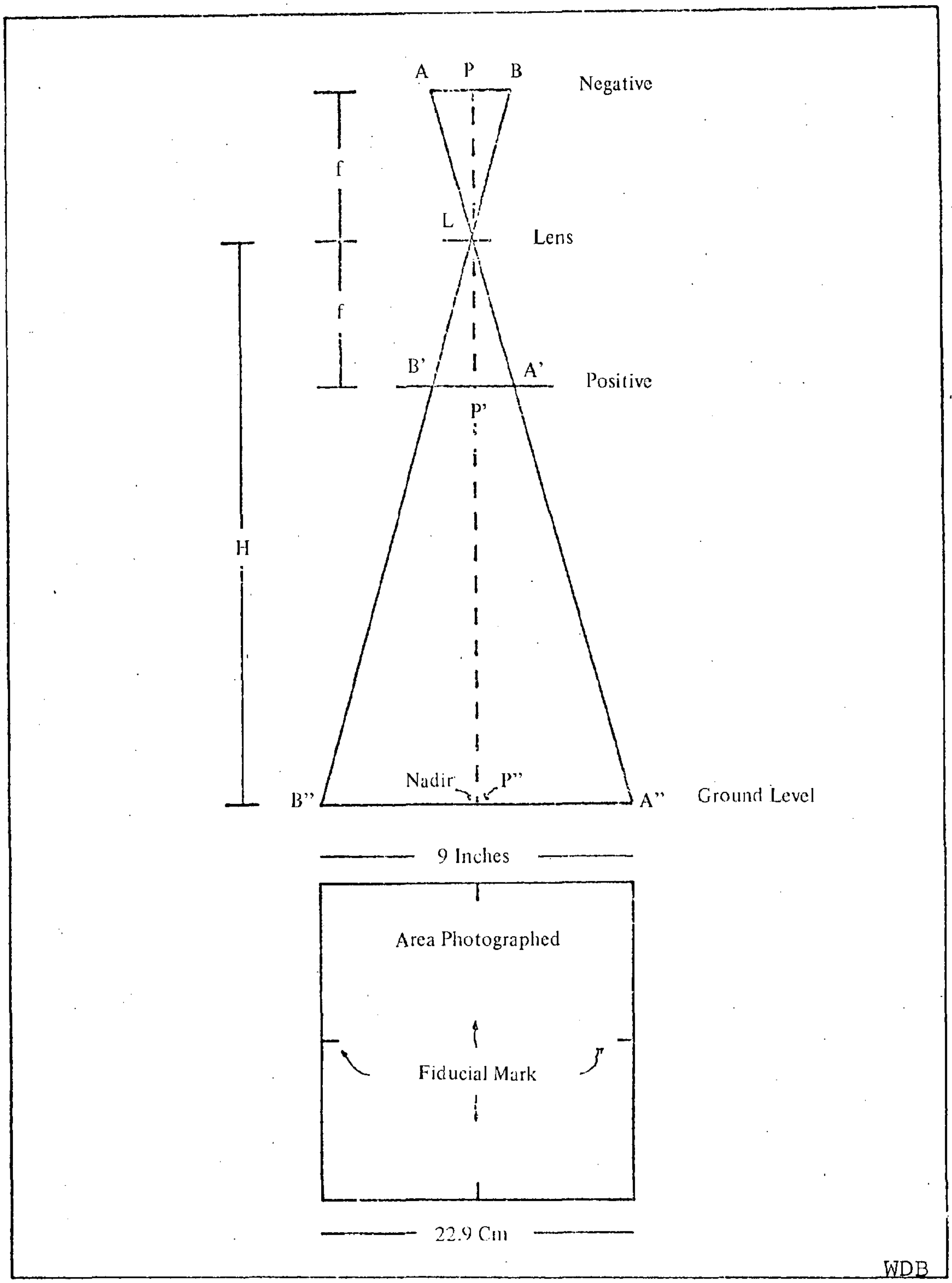
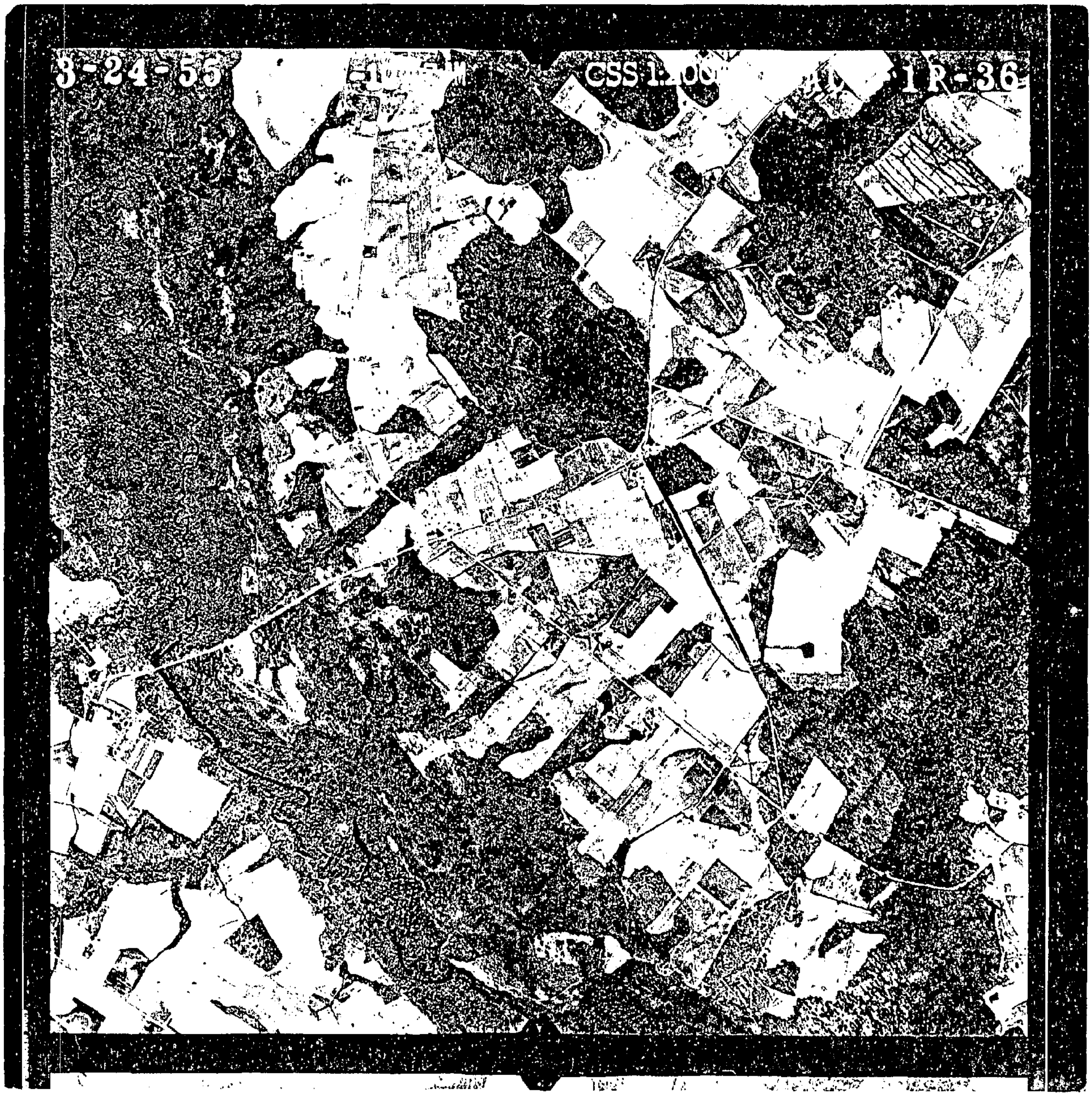


Fig. C5. Characteristics of the Vertical Aerial Photograph (by W.D. Brooks).


3-24-55
1 R-36

1. $\Delta B''P''L \sim \Delta BPL$ as $\angle PBL = \angle P''B''L$ and $\angle B''P''L = \angle LPB$ therefore $\angle PLB = \angle B''LP''$

2. $\frac{BP}{B''P''} = \frac{f}{H} =$ Photograph scale.

These statements can be applied to any series of points selected on the photographs and can be translated into a statement of photographic scale. Using the above equation with knowledge of the focal length and altitude of the camera the scale or representative fraction (RF) of the photography can be ascertained. For example, the RF of a photograph taken from an altitude of 5,000 feet above mean sea level (MSL) with a ground elevation of 1,000 feet and a focal length of 6 inches would be calculated as follows:

$$RF = \frac{0.5 \text{ ft.}}{5000 \text{ ft.} - 1000 \text{ ft.}} = \frac{0.5}{4000} = \frac{1}{8000} \text{ or } 1{:}8{,}000$$

In most cases the focal length and elevations are not readily available. In this case the RF of a photograph is calculated using an acceptable map for ground distance. Knowing this the RF can be obtained as follows:

$$RF = \frac{\text{Photographic distance between two points}}{\text{Ground or map distance between the same points}}$$

On the photograph the distance between the two selected points is recorded in inches. On the map the same distance is measured and identified in feet by using the map scale. Assume the distance between points X and Y on a photograph is 4.8 inches while on the map this distance is measured as 2,000 feet. Thus the RF is as follows:

$$RF = \frac{4.8 \text{ in.}}{2000 \text{ ft.}} = \frac{0.4}{2000} = \frac{1}{5000} \text{ or } 1{:}5{,}000$$

Setting the above information up as a proportion we have:

$$0.4{:}2{,}000 = 1{:}x$$
$$x = 5{,}000$$
$$RF \quad 1{:}5{,}000$$

Unlike a map, no two points on a photograph have the same RF. A properly rectified map has all distortions removed. Therefore, caution is necessary as RF's are calculated. Fig. C7 represents the variation. If, as in the diagram, it is shown that points B and C are equal distance from the optical axis it is also shown that point B' and C' are projected radially inward or outward from the PP on the aerial photograph. In this case the image (B') of B is displaced radially inward. The image (C') of C is displaced radially outward. Further investigation would show horizontal ground distances that are equal but at different elevations will photograph unequally. Lengths AB, BPP, CPP and CD are shown as equal ground distances but would measure differently on the photo. Finally, height illustrates another situation where images are displaced radially from the PP creating variations in the RF at different portions of a photo. A general RF for aerial photographs can be calculated using the PP as one point. However, caution is certainly advised in its use everywhere on a photograph.

In flat country, image displacement is not critical but where rolling terrain is encountered continuous changes in the RF occur. This is also true where tall objects such as trees or buildings are located.

Radial displacement of images may be computed as follows:

$$D = \frac{Nh}{H}$$

where D = amount of displacement
N = measured distance from the principal point of the photograph to the image point
L = difference between the elevation of the image point and the datum (negative if below the datum; positive if above)
H = height of the camera station above the datum

D and N may be inches.
h and H may be in feet.

Using and Interpreting Aerial Photographs

Once photographic cover of an area has been completed the photographs can be used to accomplish a number of objectives. In order to do so, a definite procedure for organizing and handling photographs must be developed.

Print laydowns and mosaics – The problem of photographic selection for a particular study area is compromised by producing either a cover diagram or a print laydown. Cover diagrams are small illustrations that reference photographic information at each end of an individual flight line. Therefore, it is possible to estimate the roll serial number and exposure number at any point within the flight line. Agencies responsible for photographic coverage have cover diagrams that are readily available, or they may be developed by the user. Print laydowns are sets of alternate photographs joined so that the entire area is shown as a single item. Each alternate photograph is placed and joined in such a way that common points of photographs are superimposed.

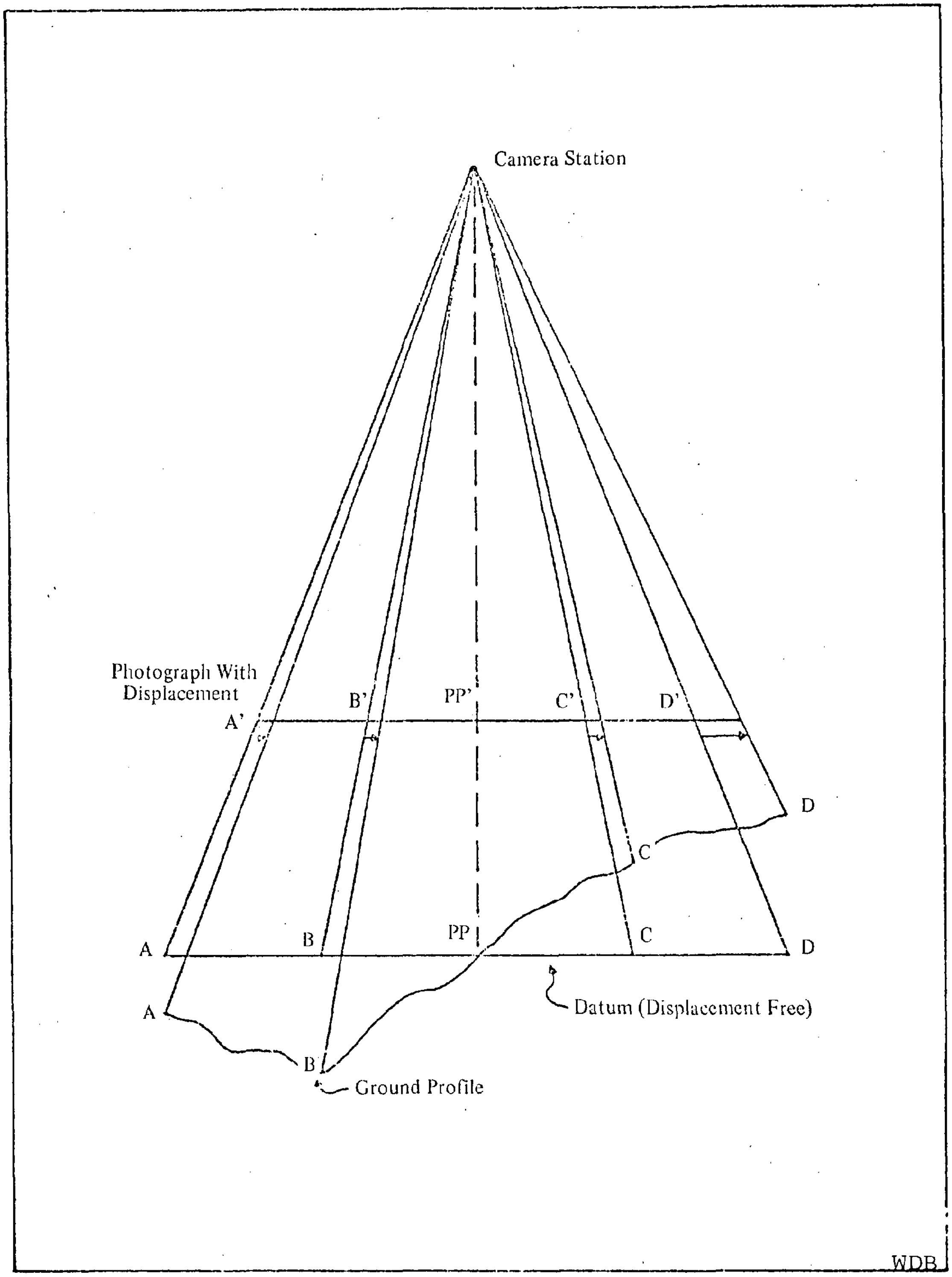


Fig. C7. Image Displacement and RF Distortion on an Aerial Photograph (by W.D. Brooks).

Similar to the print laydown is the photo index. With the photo index all photographs are located in proper sequence but in such a way that the identification information is visible. Once all photographs are laid down and matched, the grouping is photographed at a RF1:63,360. Because of this, any photograph peculiar to any part of a selected study area can be identified immediately. The cover diagram and photo index can be filed for instant reference and selection of photographs. The advantage is that individual photographs are not consumed in the process.

If the cost is not prohibitive and the particular study warrants the time, a mosaic of an area can be produced. An aerial photo mosaic is produced by assembling two or more photographs which have been trimmed of edges and systematically matched. The final product is a composite view of the area as if it were a single photograph.

Several types of mosaics are recognized but are grouped as controlled or uncontrolled. Controlled mosaics are beyond the scope of this discussion as their completion requires skilled technicians, machine rectified and dodged photographs. Uncontrolled mosaics match detail without introducing the mechanics of providing precise horizontal accuracy or control. The general central area of each photograph is used and butted with other photographs and all are cemented to a permanent, stable base.

The procedure for a simplified uncontrolled mosaic of an area is as follows:

1. Align photographs in a flight line sequence.
2. Begin with the center flight line and match endlap detail of each photograph. Adjacent flight line photographs are matched carefully in the same manner until all flight lines have been assembled and temporarily tied down.
3. Draw match lines along each flight line with a china-marking pencil and tie down securely to plywood. Location or orientation of each photograph depends on detail location. Avoid bisecting detail which later will be used in interpretation.
4. Cut photographs along match lines such that all photographs are flat-butted. Considerable effort is required to cut through several photos so a sharp knife is required.
5. Each cut photo section can now be assembled and permanently secured to a sturdy backing.

Aerial Photograph Identification and Interpretation – Using aerial photographs correctly will enhance the study of any area. Information can be complete in the sense that any object (within the limitation of resolution) can be identified which is the primary advantage of the aerial photograph. A reliable analysis of an area can be readily accomplished from a single photograph. Road networks, field patterns, urban locations, vegetation, water bodies and other aspects of the physical and cultural landscape can be recognized. If two photographs are viewed stereoscopically then a three-dimensional perspective is obtained.

When viewing a vertical aerial photograph ground features must be recognized and identified before interpretation can occur. In most cases it is the combination of the attributes of the object and the qualities of the photograph that allows identification. If this is not sufficient then field procedures are required.

Difficulty in identification may occur because the vertical view is not familiar, all objects are reduced in size and a legend is not present. Therefore, object identification on an aerial photograph requires factors of recognition to be applied. Positive object identification will result if the factors are used in combination. Each of these factors are listed below and their value stated.

1. Shape. Most individual objects have a shape which is an instant clue for identification. Cultural features generally have regular shapes while natural features appear irregular.
2. Size. Although a function of the general RF of a photograph, size of objects within the same category provide clues for their identification. Both absolute and relative size is important.
3. Pattern. The elements of a category of objects presents peculiar patterns upon the earth's surface. Orchards, residential areas and transport networks are examples of pattern. Pattern represents the spatial arrangement of the elements within a category.
4. Location or Relative Position. The occurrence of an object relative to other objects surrounding it provides information for deductive identification. Certain objects of different classes are grouped. If one object of the group is identified a clue is provided which can lead to the other objects of the group being recognized. A farmstead is an example. The residence and its relationship to various outbuildings may lead to conclusions regarding the type of agricultural economy of that farmstead.
5. Shadow. Because of the nature of photographs, shadows of taller objects are clues to identification. Shadows provide a type of "side" of normal view of objects. Smokestacks and radio towers, for example, may require perception of their shadows for identification. On the other hand, shadows may delay identification when they obscure other features.
6. Tone and Texture. These are qualities of the photograph itself but can be used to advantage in object identification. Objects of different reflectivity and emissivity of energy register in different tones or shades on a photograph. The lighter to darker shade of gray on a black and white photograph is referred to as tone. Texture, the roughness or smoothness of images, is related directly to tonal qualities. A smooth

surface (lake) reflects more evenly resulting in even tone. The converse is true. Thus, plowed ground or wind-whipped water results in tonal differences.

Unfamiliar objects can sometimes be identified through the power of suggestion. The following checklist illustrates the grouping of objects in a few categories with a number of individual elements which may increase mental acuity.

1. Water and Shoreline features – sand bars, cut-off slopes, meanders, rivers, streams, lakes, marshes, swamps, beaches, coastal embayments, inlets, harbors
2. Physiographic features – talus slopes, alluvial fans, deltas, faults, dikes, lava flows, volcanoes, gullies, hogbacks, rock outcrops
3. Forests and other Natural Vegetation – coniferous, deciduous and mixed forests, grasses, shrubs
4. Agricultural features – orchards, vineyards, fences, hedgerows, row crops, non-row crops, terraced cropland, contour plowing
5. Urban Patterns – residential, commercial and industrial buildings, outdoor theaters, swimming pools, athletic fields (football, baseball), prisons, hospitals
6. Transportation and Communication Patterns – roads, canals, railroads, airports, waterfront, harbor artifacts, electric transmission lines, pipelines

The interpretation of aerial photographs is mostly a deductive process involving subjective judgement. However, this judgement must be supplemented by information oriented toward study of the physical and cultural landscapes. General knowledge of geology, forestry, soils, water and vegetation along with the basic principles of human occupance of the land is a necessary requisite to skilled interpretation and analysis.

The task of the photo interpreter is made easier and proceeds much more effectively when done in an orderly fashion. Thus, a progression which is topically organized would be most productive. The following rules can assist the process of photo interpretation:

1. The order of interpretation should be from the general to the specific. The importance of the photo index or the mosaic is made manifest at this point. A careful study of the small-scale (large area) photography can promote a knowledge of the larger patterns on the earth's surface. With the overall characteristics in mind large-scale (small area or scales larger than RF 1:10,000) interpretation can then be started.
2. The order of interpretation should be from the known to the unknown. Experience, knowledge, source materials and field work will supplement and enhance this rule. Photo interpreters can quickly recognize and identify most objects to be found in a study area. Then, at a slower pace objects not readily recognized can be compared with similar photos on interpretation keys for positive identification. Keys for identification purposes are produced from prior object recognition.
3. Photo interpretation must be supplemented by field work. Direct observation is complimentary to photo analysis. Positive identification of features from photographs is sometimes impossible and must be field checked for veracity. Field checking or ground-truthing is absolutely invaluable when the photograph is of poor quality, a feature is obscured by shadow, resolution due to scale is too small and seasonal variations between photographs preclude recognition.
4. Identification of an object, if not positive, should have several other possibilities. If positive identification is not forthcoming deliberation should not cease. The question should be asked —— What else? Alternatives can be field checked. Along with experience and knowledge, mental discipline is necessary.

Keys are valuable aids in photo interpretation. As ways of presenting diagnostic features, keys may be either a selective or elimination type. Selective keys are illustrations and/or descriptions of the elements within categories. With photo analysis, objects are then compared to the selective key and judgements made as to their identification. Another type, the elimination key is dichotomous in nature. In other words, the interpreter selects one of two alternatives which in turn forces another dichotomous choice. The interpreter proceeds through the key until an identification is finalized.

With the above ideas in mind a guide in now presented as a general method of aerial photograph interpretation. Specific topics or problems are, of course, delineated for a study area before the application of this technique. Along with this guide procedures to record data are presented.

A. Select or produce a mosaic of the study area.
   1. Outline on the mosaic the boundaries to be used in the study area. Use a pencil that is able to mark on glass. This marking can be removed later by cleaning fluid.
   2. Examine carefully the area outside of the study area but contiguous to it. Note carefully the patterns of the major physical and cultural attributes in both areas.
   3. Record the photograph information (flight line number, exposure number) so that the proper photographs can be retrieved for monoscopic or stereoscopic viewing.

B. Initiate, continue and conclude the processes of identification, interpretation and analysis of a study area. Photographs selected and study area delineated at A3.

1. Identify and interpret all linear features within study area (drainage patterns, coastal or water-land interfaces, transportation, etc.). Use proper symbolization in order to distinguish between physical and cultural aspects.
   a. Mark all lines of a linear nature.
   b. Mark and outline all foci of linear features.
   c. Identify all related attributes of linear features-(structures, areas used, width of route, grade, junction angles, type of surface, minor or major level of functions, lines presently used or abandoned, mosaic joint or photo imperfection, etc.).
   d. Re-examine all items carefully.
2. Identify and interpret all built-up urban areas (agglomerated and agglomerated nonfarm rural).
   a. Mark and outline all areas with built-up characteristics.
   b. Within all outlined areas, mark and outline all sub-areas based on a classification scheme (vegetative urban and nonvegetative urban).
   c. Within all sub-areas mark and outline other sub-areas to the classification level previously determined (functional areas level, individual structure level).
   d. Re-examine all items carefully.
3. Identify and interpret all agricultural areas (green agriculture and bare soil agriculture).
   a. Mark and outline areas exhibiting agricultural characteristics.
   b. Subdivide all areas of B3a. Distinguish between categories of cultivated and uncultivated areas. Identify individual crops.
   c. Mark and outline farmsteads and farmstead boundaries (ownership, individual fields, building areas, etc.).
   d. Re-examine all items carefully.
4. Identify and interpret all other areas in the study area.
   a. Mark and outline all areas and sub-areas.
   b. Identify all related attributes of category level.
   c. Re-examine all items carefully.

Land-Cover Classification – As indicated in the general guide, there is the implication of a land-cover classification. If a classification is available the designation of the categories can be used as the major item to be delineated, marked and interpreted on aerial photographs.

A classification scheme is designed with a number of needs in mind. In the first instance, standardization of data collection is a requisite. This involves a system of location (see discussion concerning the UTM above) so that all data can be recorded by its locational attributes. When this is accomplished all agencies requesting particular data sets will not engage in duplication of effort. A method of organizing, encoding and retrieving large quantities of information also standardizes data collection. Further, a resolution unit which is compatible between low-altitude sensing (conventional airplane aerial photography) and high-altitude sensing (satellite flight sensing devices) is needed. Within the metric system a basic resolution unit can be either a square kilometer (1,000 meters) or a hectare (100 meters). At present, the technology of remote sensing from high-altitude flight is well within this capability as areas on the earth's surface can now be resolved to about 0.6 hectare (1.5 acres). In the near future this unit will be even smaller.

The most persistent obstacle to a good classification scheme is definition. There is and probably will continue to be diversity of opinion regarding a land-cover definition. Presently, the use of land is accepted as a working definition. However, it is possible to dintinguish between ideas regarding the activities that take place and are connected directly to the land and those items which can be best described as land cover. If major categories or level I resolution of the classification are defined as land cover then activities which take place can be deduced from the imagery produced by sensing devices. Thus, the categories at the first level for this overall report are defined from the aspect of land cover. The categories are: Forests, Water, Barren, Agriculture, Built-up Urban, and Wetland. Subsequent levels to be developed will be defined according to activity. Level I information is derived from satellite sensing, identified and defined in conjunction with low-altitude conventional photography and detailed topographic maps (United States Geologic Survey Topographic maps, RF 1:24,000 and RF 1:250,000; see above).

APPENDIX D

PROCEDURES AND TECHNIQUES IN USING MAPS, AERIAL PHOTOGRAPHS AND ALPHANUMERIC PICTURE-PRINTS

Introduction

Maps and aerial photographs are quality tools to be used for planning purposes. Conducting a resource inventory is the first step in planning procedures. Once an inventory is complete, or concurrent with it, a delineation of land cover and land activities can occur by interpretation through the attributes of a classification system. Finally, analysis of data sets will result in the formulation and implementation of use standards. The tools to be used in the first step of this procedure must be functional and as free from bias as possible. Up to this point, it has been implied that if an understanding of these tools by the planner is manifested then not only are the limitations recognized but also the advantages of these tools are recognized and thus, their usage is maximized in the planning process. If this is accomplished, the end result will be standards by which all citizens will derive the most benefit from all of our physical and cultural resources.

In this section a discussion of satellite or high-altitude sensing as a tool will be related to maps and aerial photography. Earlier it was shown that aerial photography is imagery from the energy reflected or transmitted from objects on or close to the earth's surface. Maps have been shown to be generalized and compiled data sets of reality. Satellite or high-altitude sensing is the acquisition and recording of energy reflected or transmitted from objects on or close to the surface of the earth but from a greater range of wave-lengths in the electromagnetic spectrum. In general, remote sensing devices other than the conventional camera are able to increase the quality and amount of information. Further, the processes by which this information is recorded and displayed removes much of the bias found at the recognition and interpretive stages when more conventional sensing devices are used.

In another section of this manual a more detailed discussion will focus on the characteristics of high-altitude sensing devices and the type of hard-copy output that is produced from it. The discussion to follow here will focus on procedures that will maximize the usage of maps, aerial photographs and alphanumeric picture prints as tools in the planning process.

Using Aerial Photographs, Maps and Picture-Prints

Aerial Photographs — Within any planning area a large number of photographs are required for full areal coverage. Thus, the following statements illustrate or reference procedures for organizing and using photographs.

I. Information about coverage, dates and types of photographs can be obtained from private and public agencies.
   a. Numerous private companies provide contract aerial photography.
   b. Negatives for panchromatic, color and infrared conventional aerial photographs are available from various U.S. governmental agencies at RF 1:20,000; RF 1:15,840 and RF 1:12,000.
   c. Prints obtained can have semi-matte or glossy finishes. Semi-matte surfaces are preferred as they are less reflective and much more receptive to marking. Double weight paper is also preferable for its durability and dimensional stability.
   d. Photo indexes of particular areas are available from private and public sources. Information for contract photography and sources can be found in issues of Photogrammetric Engineering. Information for technical specifications for contract photography in detail can be obtained from the Manual of Photographic Interpretation and from federal agencies.

II. Basic equipment and supplies required for photo interpretation: office and field.
   a. Measuring instruments.
      1. lens stereoscope: folding pocket type (office and field), mirror stereoscope (office).
      2. stereometer (for measuring object height).
      3. dot grids or planimeter (for area measurement).
      4. engineer's scale (for general linear measure).
      5. file cabinets for photograph storage.
   b. Plotting instruments.
      1. vertical sketchmaster (for plotting maps from single photographs).
      2. double reflecting projector (used to update maps by reflecting image of photographs to maps).
      3. radial planimetric plotter (a sophisti-

cated method of producing displacement free and planimetrically correct maps).

4. stereo-plotting instrument (produces a map of high quality and detail – an expensive instrument requiring a highly skilled operator).

c. Supplies and other equipment.

1. illuminated light table (desk or floor model).
2. drafting instrument kit (includes compasses, ruling pens, proportional dividers, etc.).
3. triangles, protractors, T-squares.
4. tracing materials (prepared tracing papers, vellums and plastics).
5. cleaning fluids and materials, erasers for plastics and other media types.
6. china-marking pencils, colored pencils, water-soluble inks (for plastic and non-plastic surfaces).
7. burnishers and needle-points.
8. clipboards (for holding stereo-pairs; for holding notes, photos in the field).
9. 5X or 10X hand held magnifying class.
10. manila folders for photograph storage.

III. Processing, indexing and filing photographs.

a. Processing photographs.

1. determine areas to be covered from USGS topographic maps (RF 1:24,000 or RF 1:250,000 series). Contract for properly scaled photography from reliable commercial firms or order from government agencies by area and reference number. Use photo index.
2. process individual photographs by trimming black borders to image.

b. Indexing photographs.

1. arrange into flight lines and temporarily secure to a base.
2. produce a print laydown or mosaic –– overlay tracing material and mark photo identification and flight lines by marking between consecutive principal points (PP).
3. photograph individual photo indexes.

c. Filing photographs.

1. gather photographs in flight line group. The first and last photo will have time and scale information.
2. Place each flight lines group in individual manila file folders and place in properly marked file cabinets. File a photo index or print laydown photograph in each flight line group.
3. if an individualized indexing sequence is used rather than a photo exposure number provide a central file catalog.

IV. Viewing and interpreting photographs.

a. Recognition factors and interpretation rules and guides have been discussed previously.

b. Viewing photographs stereoscopically allows visualization of length, breadth and depth. Requires two consecutively numbered photographs. Procedure to view stereopairs:

1. stack alternate photographs to viewer's far right side. Orient photo identification information away from viewer (this represents forward edge of individual position of camera station in the flight line).
2. select stereopair (1st and 2nd, 3rd and 4th, etc. photographs of each flight line to be examined).
3. take 1st photo of each pair and place to viewer's near center left. Take 2nd photo of each pair and place to viewer's near center right. Rotate 180^{o} so photo identification is to the viewer's left and the flight line is oriented right to left. If a pocket stereoscope is used, overlap common area on photos.
4. place stereoscope (mirror or pocket) over photos such that each lens is directly over area to be examined. With a mirror stereoscope entire photo is viewed. Line up the lift photo and the left lens. Move right lens to accommodate eye separation. Move right photograph until the common images of each photo merge and the third-dimensional view is achieved.
5. begin recognition and interpretation procedures. Use factors of recognition, interpretation rules and general guide as discussed above.
6. follow annotation procedure (see below at IVc).
7. after a stereopair has been interpreted and annotated move photograph at near center left to a stack at viewer's far left. Move photograph at near center right to near center left. Move photograph from top of stack at viewer's far right and place properly at near center right (rotate 180^{o} – see IVb3 above).
8. repeat procedure starting at IVb1 until photo interpretation sequence is finished.

c. Procedure for annotating photographs.

1. annotate directly on photograph or overlay with transparent media. Select proper marking instruments (ink pen, china-marking pencil, lead pencil, color-

ed pencils) and alternative prints.

2. mark system of location on overlay or photograph edges. Scale to resolution unit (square kilometer or hectare).
3. for best results photographs should be viewed stereoscopically as annotation proceeds. Time, precision and neatness are factors which must be taken into account. But, most importantly, maintain consistency of symbolization between interpreters. Use symbolization schemes as developed by the USGS and supplemented by individualized systems (see Fig. D1, D2).
4. actual annotation will proceed according to predetermined topic selected by planners. Specific annotation should follow general guide and classification scheme developed elsewhere in this manual.
5. it is good practice to complete as much recognition, interpretation and annotation as possible before field work. Field annotation should be accurate and neat. Annotation in the field should be restricted to up-dating and ground truthing.

Maps – Earlier in this manual maps were defined. Further, discussion focused on the design, the physical layout and elements of maps. In that section the discussion was from the map-makers point of view. At this point the discussion will focus on the map as a tool and in particular will revolve around the topographic quadrangle compiled, drafted and published by the United States Geologic Survey at the RF 1:24,000.

The "topo quad" of the USGS has had a long and interesting history. The USGS itself was established by Congress in 1879 and the agency was given the responsibility of mapping the United States in detail. The evolution of the "topo quad" since that time is such that today it represents a subtle combination of the best cartographic, printing and publishing technology.

The USGS topographic quadrangle is so named because it presents the horizontal (relative and absolute) and the verticle (relief) positions of earth features. The horizontal position of feature is in the correct relative location derived from sophisticated photogrammetric techniques. One must remember that the earth as a three-dimensional form is being symbolized on a two-dimensional surface. Unlike an aerial photograph the "topo" map does not have distortion and therefore scale relationships are correct everywhere.[3]

Further, the topographic quadrangle of RF 1:24,000 is bounded by an arc distance of 7½ degrees of longitude and 7½ degrees of latitude. Other scales bound different sized areas (see Fig. D2).

I. Marginal information of the USGS topographic quadrangle used for map interpretation. Since all maps symbolize different earth areas it is necessary to examine the marginal information carefully as the first step toward map interpretation.
   a. Quadrangle name and identification. The name of the quad is found in two places: the right side of the upper and lower margins. The quadrangle's name generally reflects a prominent physical or cultural feature of the bounded area. Also located in these marginal areas is other reference information including date of publication and/or photorevision. Sheet number and series name is also found here as is an indication of bounded arc distance (example 7½ degrees of 15 degrees).
   b. Publication and distributional agencies. Upper left and center margins. The topoquads are compiled and published by the USGS and may be distributed by a state agency (Department of Natural Resources, State of Indiana).
   c. Bar scales, representative fraction and contour interval. These items are found in the lower center margin. Scales are in miles, feet and kilometers. Contour interval (CI) is given in feet relative to a stated datum. The CI is the method by which vertical distances are calculated.
   d. Declination diagrams are located in the left center lower margin (left of the bar scales). This diagram indicates geographic north, grid north and magnetic declination. All three orientations are considered true only at the geometric center of the quad. Magnetic north declination date is given and should be used with caution because of changes that may have occurred in the intervening time period.
   e. Geodetic control information is found in the lower left margin. The agencies responsible for horizontal and vertical locational control are identified. The location systems are also indicated as are the agencies responsible for compilation and publication.
   f. A locational inset is usually found in the right center lower margin. This shows the quadrangle's general location within the state of Indiana.
   g. Adjoining sheet identification is found at

[3] In theory this is not absolutely correct but for practical applications it is an acceptable statement.

each corner and in the center of each boundary. These names and series numbers reference contiguous quadrangles.

h. Systems of location. The UTM, geographic grid, township and range survey system and state grid coordinate identification parameters are located strategically along all sides of the quadrangle.

II. Topographic quadrangle map symbols and colors. Symbols and color schemes are devices by which the map user visualizes an area of the earth's surface. Ideally all features would be represented in their true proportion, position and shape. Since this is neither practical nor desirable, all features are symbolized and the map user must become familiar with the USGS system.

a. USGS symbols are shown in figures D1 and D2 as a legend for interpretive use.
b. Point, linear and area symbols are categorized.
c. Horizontal and vertical control information is listed.
d. Information about quadrangle series, scales and sizes are shown.
e. Color symbols are explained.
f. Information about obtaining quads, state index maps and other USGS maps is listed.

Alphanumeric Picture Prints – Data that are "sensed" by satellite based devices are machine processed and output on a computer line printer. It is a "map" in the sense that earth features within area boundaries are "recognized," compiled, classified and symbolized in their true relative position. This computer printout is an alphanumeric picture print. A more detailed description and analysis of remote sensing theory, data manipulation and hard copy output from the line printer is developed elsewhere in this manual. Discussion in this section will focus on the procedures using picture prints in conjunction with topographic quadrangles and aerial photographs.

I. The output of the line printer differs from maps produced by orthodox cartographic methods (see Fig. D3).

a. The primary difference between picture prints and orthodox maps stems from the character set found on the character chain chosen for the line printer.
 1. The character set consists of the alphabet (all capitals) and digits (0-9) plus a number of other characters including, among others, the following: ? . : ; % ! # - = – *.
 2. Each character is printed within a rectangular area of 0.254 cm (0.1 inch) by 0.3175 cm (0.125 inch). In no case does any single character fill the rectangular area in which it is centered. Because of this the picture print has a "blank grid" which introduces noise on the map and produces a break in the user's eye search (see Fig. D3).

b. A secondary difference between picture prints and orthodox maps stems from restrictions on pattern development (see Fig. D3).
 1. Point, line and area symbols must be represented by step-wise progression of the line printer's character set. A continuous line or area symbolization cannot be achieved.
 2. Tonal differences are achieved by careful choice of individual characteristics. Percent area inked is an important variable and an increasing percent area inked creates a tonal change from light to dark. In order to create tonal change on picture prints, increasingly larger symbols are shown. For example, the following sequence of characters would show tonal change for six categories: . - = O # *.

II. Constructing maps and building data sets from aerial photographs and topographic quadrangles.

a. Select proper quadrangles and photographs for topical study area.
b. Overlay aerial photograph with clear plastic and UTM grid lines. Outline all areas according to classification described elsewhere in this manual. Record all UTM locations at predetermined data cell size (kilometer or hectare) for direct access disc pack storage (see procedures for encoding and retrieving computer stored data sets).
c. Take annotated aerial photographs into the field at selected sample locations for correction, validation of imagery not recognized on photos and updating. Return to office and finalize aerial photograph recognition, interpretation and annotation.
d. Transpose all photograph information to topographic quadrangle overlays. Add all necessary information found on quadrangle to overlay. Annotate completely.

III. Ground-truthing procedures for alphanumeric picture-prints. The picture-print is regarded as the primary source of information and is derived from the classification described elsewhere in this manual and therefore its veracity should be checked carefully. Ideally each

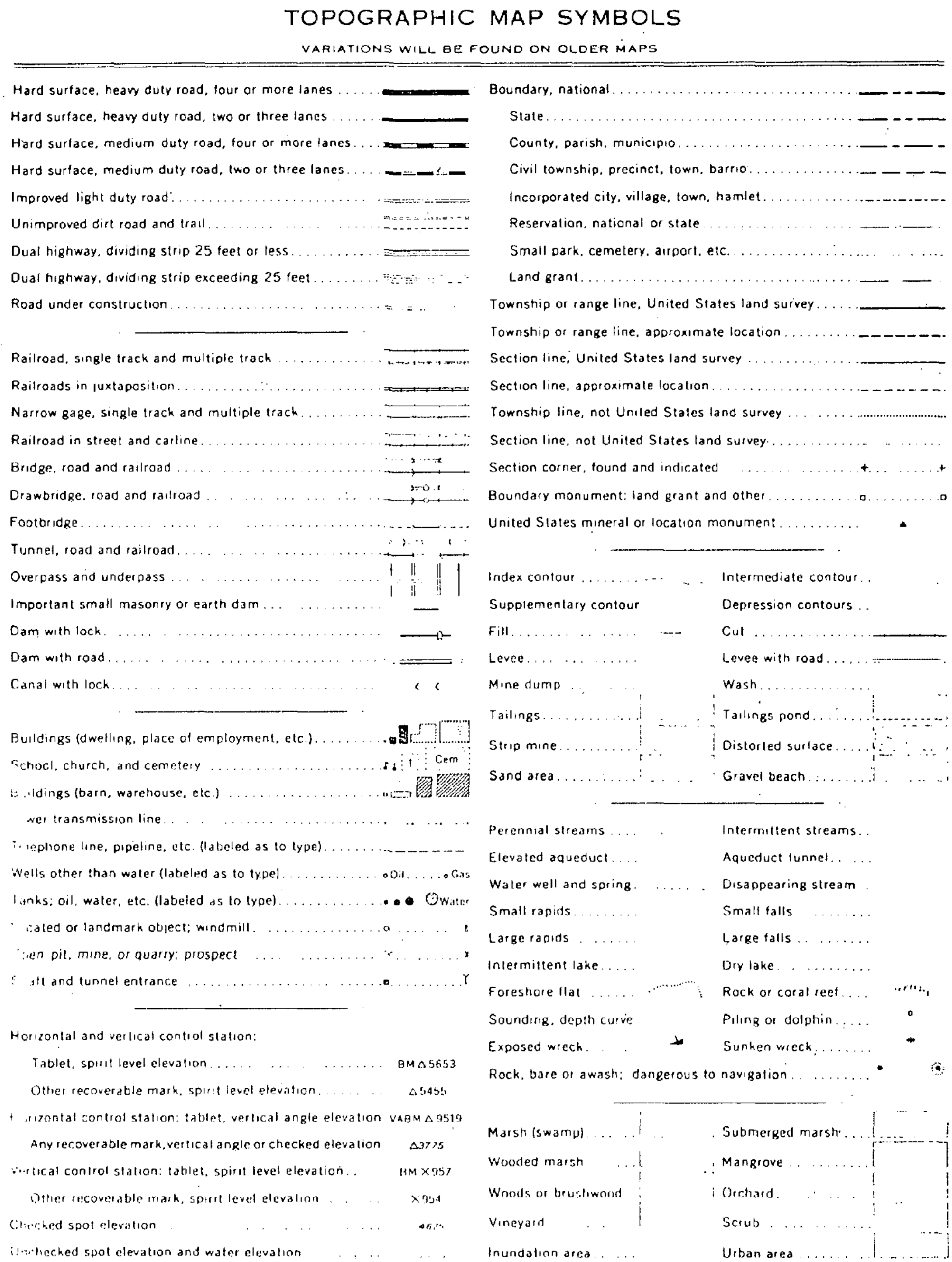


Fig. D1. One Side of the Unied States Geological Survey (USGS) Sheet of Map Symbols.

MILE SCALE 1:62 500

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

TOPOGRAPHIC
MAP SYMBOL SHEET
NOVEMBER 1966

MILE SCALE 1:24 000

FOOT SCALE 1:24 000

QUADRANGLE MAPS, AND QUADRANGLE MAP SERIES

Quadrangle maps cover four-sided areas bounded by parallels of latitude and meridians of longitude. Quadrangle size is given in minutes or degrees. The usual dimensions of quadrangles are: 7.5 by 7.5 minutes, 15 by 15 minutes, 30 by 30 minutes, and 1 degree by 1, 2, or 3 degrees.

Quadrangle map series are map groups of the same size quadrangles. In each series the maps follow a systematic quadrangle pattern, they have a uniform format, and they usually have the same scale.

MAP SCALE DEPENDS ON QUADRANGLE SIZE

The scale of a map is the ratio between a map distance and the same distance measured on the ground.
Map scale is given as a numerical ratio, and by bars marked in feet, miles, and kilometers.

STANDARD SCALES AND PRICES OF THE NATIONAL TOPOGRAPHIC MAP SERIES

SERIES	SCALE		PRICE *
7.5 minute	1:24,000	1 inch equals 2,000 feet	
15 minute	1:62,500	1 inch equals about one mile	
1:63,360 (Alaska)	1:63,360	1 inch equals one mile	
30 minute	1:125,000	1 inch equals about two miles	
1:250,000	1:250,000	1 inch equals about four miles	
1:1,000,000	1:1,000,000	1 inch equals about sixteen miles	

*Inquire at locations below.

CONTOURS SHOW LAND SHAPES AND ELEVATION

The shape of the land, portrayed by contours, is the distinctive characteristic of topographic maps.
Contours are imaginary lines following the ground surface at a constant elevation above sea level.
The contour interval is the regular elevation difference separating adjacent contour lines on maps.
Contour intervals depend on ground slope and map scale; they vary from 5 to 200 feet. Small contour intervals are used for flat terrain; larger intervals for rugged mountain areas.
Supplementary dashed or dotted contours, at less than the regular interval, are used in flat areas.
Index contours, every fourth or fifth line, are heavier than others, and have elevation figures.
Hachures, form lines, and symbol patterns are also used to show some kinds of topographic forms.
Relief shading, an overprint giving a three-dimensional effect, is used on some quadrangle maps.

COLORS DISTINGUISH CLASSES OF MAP FEATURES

Black is used for man-made or cultural features, such as roads, buildings, names, and boundaries.
Blue is used for water or hydrographic features, such as lakes, rivers, canals, and glaciers.
Brown is used for relief or hypsographic features—land shapes portrayed by contours or hachures.
Green is used for woodland cover, with typical patterns to show scrub, vineyards, or orchards.
Red emphasizes important roads, shows built-up urban areas, and public-land subdivision lines.

STATE TOPOGRAPHIC INDEXES SHOW MAPS PUBLISHED

For each State, and for Puerto Rico and the Virgin Islands, indexes show all maps distributed. Index maps give quadrangle location and name, and survey date. Listed also are: special maps and sheets with prices, map dealers and Federal distribution centers, map reference libraries, and detailed instructions for ordering topographic maps.

* HOW MAPS MAY BE OBTAINED

Mail orders for maps west of the Mississippi River should be addressed to the Geological Survey, Distribution Section, Federal Center, Denver, Colo., 80225, and for maps east of the Mississippi River to the Geological Survey, Distribution Section, Washington, D.C. 20242. Maps of Alaska may also be ordered from the Geological Survey, 520 Illinois Street, Fairbanks, Alaska 99701. Order by map name, State, and series. Maps without woodland overprint are furnished on request. A 20% discount is allowed on an order amounting to $20 or more, and 40% discount is allowed on an order amounting to $100 or more. Each order for maps should be accompanied by exact payment in cash, or by money order or check made payable to the Geological Survey. Your ZIP code is required.

Sales counters are maintained in the following Geological Survey offices where maps of the area may be purchased in person: 1200 South Eads Street, Arlington, Virginia; 1028 General Services Administration Building, Washington, D.C.; 1109 North Highland Street, Arlington, Va.; 345 Middlefield Road, Menlo Park, Calif.; 7638 Federal Building, 300 North Los Angeles Street, Los Angeles, Calif.; 504 Custom House, 555 Battery Street, San Francisco, Calif.; Federal Center, Denver, Colo.; 15426 Federal Building, Denver, Colo.; 602 Thomas Building, 1314 Wood Street, Dallas, Texas; 8102 Federal Office Building, 125 South State Street, Salt Lake City, Utah; South 157 Howard Street, Spokane, Wash.; 108 Skyline Building, 508 Second Avenue, Anchorage, Alaska; 203 Simpson Building, Juneau, Alaska; and 310 First Avenue, Fairbanks, Alaska.

State indexes and a folder describing topographic maps are furnished free on request.

Private dealers sell quadrangle maps at their own prices. Names and addresses of such dealers are listed in each State index.

FOOT SCALE 1:62 500

Fig. D2. One Side of the United States Geological Survey (USGS) Sheet of Map Symbols.

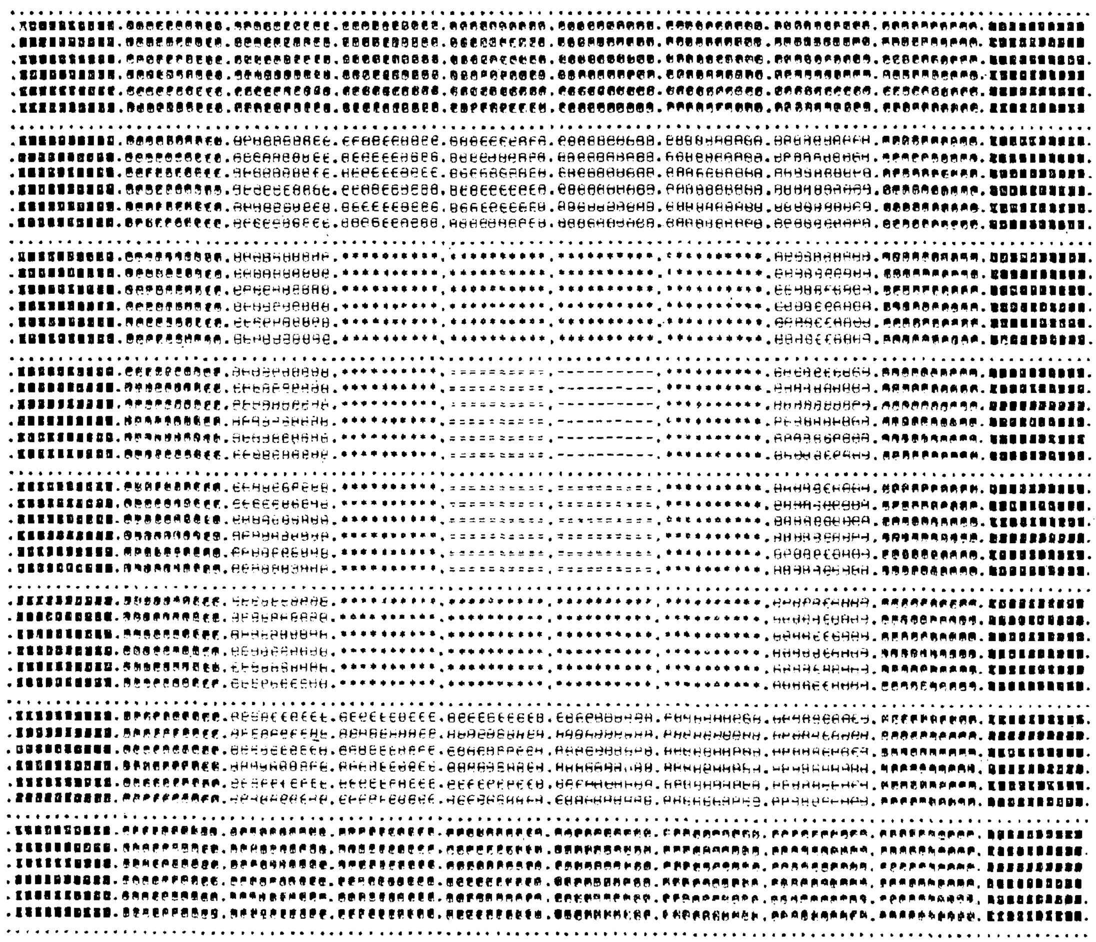


Fig. D3. A Symbolization Scheme to be used with Computer Generated Maps Produced on a Line Printer (program by W.D. Brooks, written in Fortran IV and run on an IBM 360/60).

study area should locate a number of objects whose spectral response is known before overflight occurs. Each area on the picture-print will reflect the nature of this object and its proper category symbolization can be quickly assessed.

a. Place both the alphanumeric picture-print and the corresponding topographic overlay on a light table. Align carefully.
b. Check the accordance of defined categories on both maps. Mark any boundary, area or point location where discrepancies occur.
c. Attempt to resolve boundary conflicts in the office by consulting other sources.
d. If conflicts persist, move into the field at those locations and compromise problems by interpretation of the classification definitions.

APPENDIX E

A COMPUTERIZED SYSTEM TO ENCODE, RETRIEVE AND DISPLAY LAND INVENTORY DATA

Scope

It is necessary to develop a method of acquiring, storing, and retrieving data for the optimization of the use of land space. The ways these data could be incorporated with locally collected data to build information systems include three main steps:

1. Acquiring information (collection)
2. Storing information (storage)
3. Finding the stored information again (retrieval)

Collection

The first step of a land information data system is the collection of information in language form. The language may be words or numbers, but the information may be expressed by a collection device regardless of form. Electronic data-processing uses a system of coding information by numbers, commonly on punch cards with a hole through a number that represents each bit of information.

Storage

Common devices for storing information are as follows: books, statistical tables, maps, and photographs. Punched cards, magnetic tapes, and discs have now been added to the traditional storage devices. The design of an information storage system must always include quick and convenient retrieval as the primary objective.

Retrieval

The third step is the retrieval of the stored land cover inventory information. The secret of information retrieval is proper classification for use. The efficiency of the information system is affected by its ability to provide data in a form desired with a minimum of distractive material. The effectiveness and efficiency of information retrieval should also be measured by how well the design helps the decision-makers identify relevent information.

Flexibility

Probably the most important requirement of any information system is flexibility of content. It must be easy to add or delete data items contained in the file. As the system develops over time, the needs will change. This change will result in increasing demands for information and in an increased sophistication in using the system. As these occur, needs will be seen for: (1) adding new items of information to the files which were either not anticipated or needed earlier in the development of the system; and (2) deleting items in the files which were expected to be used but over a period of time have been used little or not at all. It is imperative that file content be flexible enough to allow the system to reflect the changing needs of the clientele it serves.

Operational Ease

A second requirement is ease of use. One of the problems which any information system is designed to alleviate is inaccessibility of data. It follows that the system must facilitate the distribution of data to the requesting agencies. Further, the information should be clearly presented and available on relatively short notice to insure maximum usefulness.

Multiple Identification

The third system requirement for successful operation is a multiplicity of identifiers; i.e. land cover inventory data should be classified in as many different ways as possible to allow the system users maximum latitude in requesting information from the files.

Stable File Layout

The fourth requirement for successful system operation is a file layout keyed to elements so basic as to provide stability for the system for the foreseeable future. The changing of the basic file content should not necessitate a redefinition of the files.

Conclusion

The retrieval process is the most vital process of the entire information system, and great emphasis should be placed on designing the files and file indices. The retrieval program must be both flexible, in the types of information requests the system can process, and efficient in handling these varying types of requests.

It is very important that the whole system-storage, retrieval, and analysis components – be designed as a coherent whole. The function of any portion of the computer system will have ramifications in all the other portions and should be designed with the total system in mind. Many basic decisions and designs are needed to insure a workable and useful system.

A general alternative appears to be that a method be established which would allow for retrieval of information items from several files at a time; therefore, the records in the various files would have to be encoded identically that referred to the same entity. But, locally gathered data and the creation of a local and state file that have corresponding keys is essential for record matching.

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