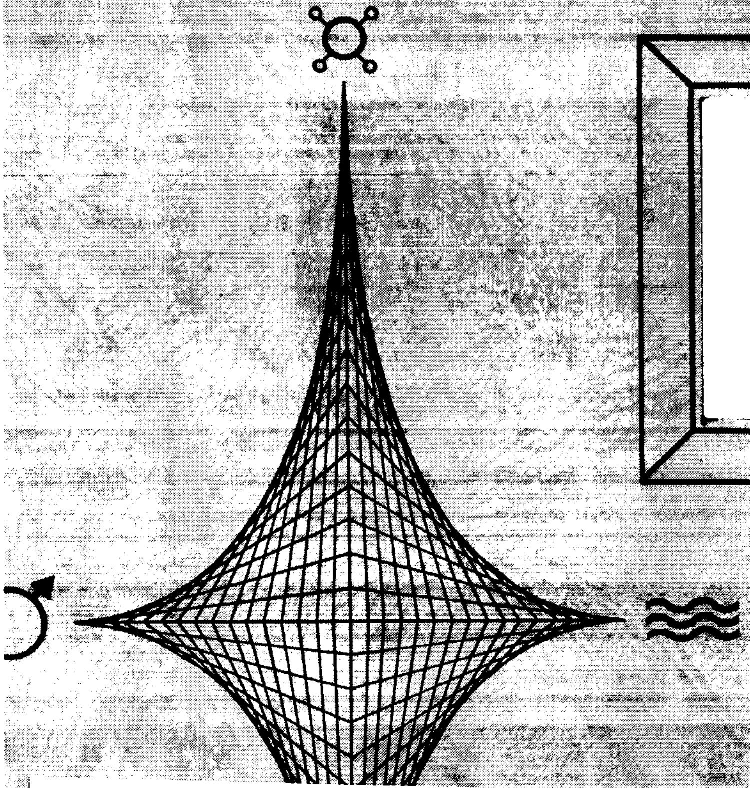


FACTORS AND PROCEDURES INFLUENCING THE RELIABILITY OF AGRICULTURAL DATA FROM EARTH ORBITING SENSOR SYSTEMS

R-09-038-001
&
R-09-038-102

GPO PRICE $ ____
CFSTI PRICE(S) $ ____
Hard copy (HC) 3.00
Microfiche (MF) ____
ff 653 July 65

FACILITY FORM 602

N68-11810	
(ACCESSION NUMBER)	(THRU)
234	1
(PAGES)	(CODE)
CR#90211	34
(NASA CR OR TMX OR AD NUMBER)	(CATEGORY)

S.T.A.R. SYSTEMS TECHNOLOGY & APPLIED RESEARCH CORP.

P. O. BOX 35851 · DALLAS, TEXAS 75235 · 214/FL 7-0475

FACTORS AND PROCEDURES INFLUENCING THE RELIABILITY OF AGRICULTURAL DATA FROM EARTH ORBITING SENSOR SYSTEMS

FINAL REPORT

Prepared For:

U. S. DEPARTMENT OF AGRICULTURE
ECONOMIC RESEARCH SERVICE
WASHINGTON, D. C.

Contract No. 12-17-04-1-295

By:

Bill Mullins

SYSTEMS TECHNOLOGY AND APPLIED RESEARCH CORPORATION
Exchange Bank Bldg., P. O. Box 35851
Dallas, Texas 75235

June 27, 1967

FOREWORD

Contract No. 12-17-04-1-295 was awarded to Systems Technology and Applied Research Corporation on 27 June 1966. The study was undertaken to identify those factors and procedures influencing the statistical reliability of agricultural data obtained with earth orbiting sensor systems.

Twelve and one half man months of effort were involved in the 12 month study contained in this Final Report. The total program was planned to achieve its goal through the performance of eight integrated tasks as follows:

1. Preliminary Agricultural Target Specification
2. Tabulation of Pertinent Satellite Systems Specifications
3. Target/System Analysis
4. Preliminary Target/System Specification
5. Areal Sampling Requirements
6. Target/System Data Format
7. Areal Statistical Sampling Requirements
8. Report Preparation

Technical emphasis was given to synthesis of the total remote sensing problem within the framework of the requirements for the development of reliable agricultural statistics for a target aggregate by the U. S. Department of Agriculture. The term statistic as used herein is deemed to be a quantifible data subset which can be used to predict a population characteristic. To obtain the data subset, spacially and temporally dispersed target aggregates associated with an agricultural complex must be located, identified, and enumerated (metric measure or count) from satellite obtained imagery.

The author is indebted to Dr. Chen Tuan Li of Bishop College, Dallas, Texas for his review and critique of statistical areal sampling and to Mr. R. D. Crall, registered engineer, for his review of system concepts.

SYSTEMS TECHNOLOGY AND APPLIED
RESEARCH CORPORATION

Bill Mullins

Bill Mullins
President

SUMMARY

The primary factor influencing the reliability in the transformation of areal targets into the intelligence of an areal sum from earth orbiting sensor systems is:

- The practical inability to search and identify, measure and sum target acreage (crops) spacially dispersed over millions of acres and temporally dispersed in time.

It has been shown that areal aggregates can be sampled in a practical manner by the dot technique (a 2-dimensional random spacial distribution of dots over the area of interest) if the crop can be readily identified from a photographic mosaic by color rather than by complicated subjective photo-interpretive techniques. If the crop is identifiable by color or spectral response from a photograph then a system is possible for complete enumeration and therefore, sampling is unnecessary to predict an areal sum.

The entire United States as an area of interest can be photographed from a polar orbiting satellite with a ground resolution of 10-20 feet at 200 nautical miles in 22 days with 1 degree longitude swath widths at any specified hour ± 2 hours.

To reduce the obscuring of targets by cloud cover during a 22 day flight, photographic coverage should be two swaths wide ($\approx$ 120 n mi) to provide complete coverage at two different times. A maximum of 176 days may be required to reduce the effect of cloud cover to a marginal quantity for the smallest and greatest number of areal targets.

For the latter case and an initial launch time of 00:00 hours Central Standard Time, the polar orbiting system will move into the dawn/dusk interface in about 91.3 days. Another 182.6 days will be required before the dawn/dusk position is repeated.

For general land usage purposes where targets are classified as to be readily identified (farmland, rangeland, forests, etc.) a photographic mosaic can be reduced by the dot sampling technique in a relatively practical manner.

The results of this study based upon system resolution and the variety of targets of interest warrant the opinion that the greatest good to the greatest number will come initially from high resolution (10-20 ft) large scale photographic imagery. Photographic systems can be readily designed and the data package containing the film can be recovered over the Continental United States.

RECOMMENDATIONS

As a consequence of this study, a recommendation must be to continue research efforts toward solving the problem of automatic crop identification, e.g., maximum non-redundant target enhancement.

A primary recommendation is the initiation of a major research by the USDA for the purpose of appraising the problems in analyzing areal terrain data with the direct application to national and world satellite surveys.

The entire United States can be photographed in a short time with a ground resolution of 10 to 20 feet. The quantity of useful, useless, and redundant information of such a large terrain complex is very nearly infinite. The major problem is in the functional classification of useful interacting areal environmental units with the knowledge that areal intelligence is dependent upon the scale of observation.

Areal terrain data must be transformed into direct functional economic, social and physical intelligence. The problems to be attacked as a function of scale are:

1. Terrain Classification
2. Terrain Quantification
3. Functional Interaction of Classified and Quantitied Areal Units.

The basis for this recommendation is:

1. If wheat acreage made up of individual areal members in the United States is considered to be economically significant then the aggregate must be dealt with to transform wheat acreage into the intelligence represented by the total wheat acreage.

2. Much effort is being given to what intelligence can be obtained from remote sensing, the results evolving from the small to the large, from the local to the regional effects.

It is time, because of the present survey area capability at ultra-high altitudes, to develop functional intelligence requirements from the large to the small, e.g., classify and deal directly with the aggregate as a mass before moving downwards to treat individual members.

Therefore, as an initial research requirement, primary areal environmental classification as developed within the earth science disciplines of:

1. Geography
2. Biology
3. Zoology
4. Geology
5. Geophysics
6. Oceanography
7. Meteorology

need be defined and examined to determine if systems can sense the aggregate quality specified by the areal classification of interest to these disciplines at orbital altitudes.

If the population aggregate can be sensed, areal boundaries can be specified, first order population homogeneities within the boundary located and sample areas for population enumeration or discrete ground truth measurements can be defined.

It must be emphasized that the initial problem is one of terrain classification and as such is subject to the logic requirements of a classificatory science. Physically and from a systems viewpoint, the problem is given two classifications of aggregates with regional overlap, can the two be separated? Or stated another way, a mixture of tiny yellow and green pebbles viewed at distance would appear yellow green because of the integrating characteristics of the eye. Can the yellow and green be separated as an integrated sum over the region to establish the per cent area of the region in yellow or green, or is it necessary to examine and discriminate each pebble?

There is a major question as to whether or not an aggregate sum represented by crop acreage can be dealt with on an individual member (field) basis. Approximately 92.8% of the total planted wheat acreage in the United States (53.02×10^6 acres) was distributed among 17 states with a combined area of 953.84×10^6 acres. There could be over a half million individual members distributed over 1 billion acres for location and identification.

It seems reasonable that a basic reason for obtaining imagery at higher altitudes is the increasing over-view. If a microscopic analysis of the over-view is insisted upon, the sheer number of individual members making up the aggregate may be an impossible barrier, especially when compounded by the number of different aggregates of interest.

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont.)

CHAPTER TITLE PAGE

3 (Cont.)

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES (Cont.)

LIST OF APPENDICES

CHAPTER I

INTRODUCTION

1.1 PURPOSE AND SCOPE

The Natural Resources Economic Division, Economics Research Service (ERS) of the United States Department of Agriculture is undertaking a study of the Potential Economic Benefits and Systems of Data from Agricultural Resource Surveys by Remote Sensing Methods.

Their specific research objectives are:

1. Identification of potential agricultural applications of remote sensing from space platforms.
2. Assessment of the potential benefits of satellite data collection for each application.
3. Development of systems of data for the applications including sampling schemes.

The purpose of the accompanying research discussed in this report is to study those factors influencing the acquisition of statistically reliable satellite obtained data (imagery) for worldwide agricultural development and prediction.

Since this is a complex remote sensing problem involving many user, system, vehicle, operational and logistic requirements, a framework need be established to weave this research into the mechanics of acquiring and using the data within the practical requirements of a specific user.

To this end, the U. S. Department of Agriculture has been chosen as the user with the practical problem of developing agricultural statistics from one primary data base, e.g., local, regional and national distributions of crop acreage within the United States.

The report is divided into chapters treating:

- The nature of the needs and services of the USDA as a potential user of high altitude imagery in the preparation of agricultural statistics.
- Targets of interest in agriculture and forestry with a potential for high altitude discrimination including emphasis on spacial and temporal dispersion of select targets.

- The nature of and requirements for areal sampling.
- General satellite remote sensing systems capabilities and requirements.
- Orbital requirements.
- Summary of Conclusions and Recommendations.

1.2 CONSIDERATIONS IN EXTRACTING AGRICULTURE INTELLIGENCE FROM IMAGERY

Intelligence obtained from imagery for the preparation of agricultural statistics requires:

- target identification
- enumeration (metric measure or count)

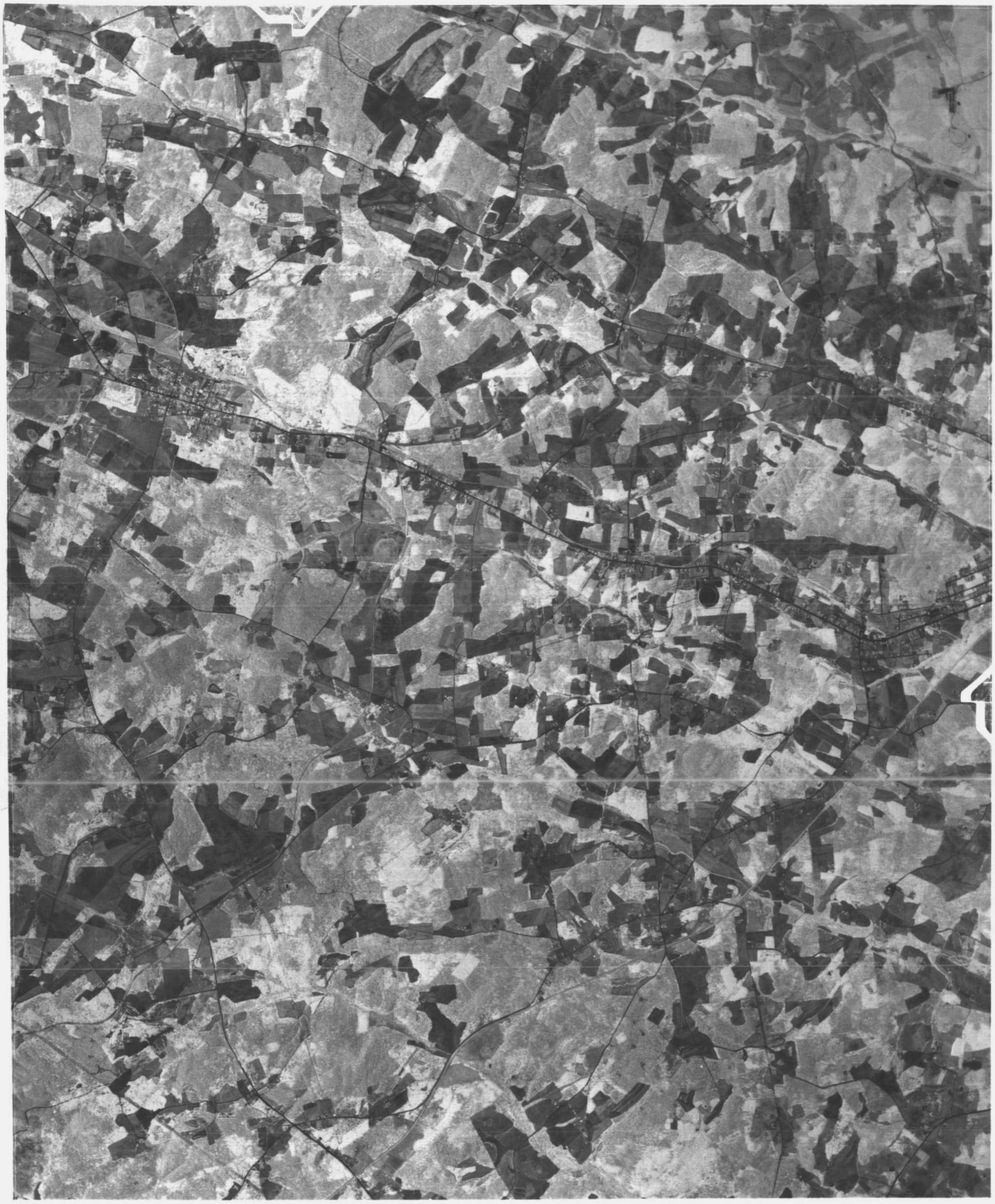
Any factor influencing identification influences enumeration and enumeration is the numerical foundation for statistical analysis.

The 3 primary barriers to general use of satellite imagery relative to target area are:

1. Target identification
2. Spacial and temporal dispersion of target members
3. Cloud cover

Figure 1 is an aerial photograph of an agricultural complex in North Carolina with a photographic scale of 1:58,000. This scale can be obtained with a 155 inch focal length system at an altitude of 142 statute miles[16]. The photograph is representative of the information content and target display which must be transformed into statistical intelligence by classification and enumeration of areal targets over large land masses.

It is reasonable to assume that practical discrimination and identification of crops from high altitude imagery on a gross scale must be done with multispectral sensing techniques[1]. If this cannot be done, crop identification becomes a problem in photointerpretation and identification made by secondary inference, e.g., information based upon secondary pattern association and subtle tonal differences which provide a basis for judgement. This cannot be dealt with in an a priori quantitative manner, except by a highly subjective psychological experiment for the development of a statistic to describe the reliability of interpretative judgement for the targets of interest[2].



1 Mile

Figure 1. Aerial Photograph of Representative Agricultural Complex.

The reliability of a statistic developed from an enumeration will depend primarily upon the ability to classify correctly. The primary assumption throughout this research effort will be that the reliability of classification of agricultural targets from satellite obtained imagery is 100%[3]. A logical consequence of reliable identification for a wide range of areal targets is automatic transformation of the data into intelligence. Factors influencing the enumeration or metric measurements of pattern from imagery other than spectral analysis of target signatures are assessable from system and flight specifications, environmental considerations, spacial and temporal dispersion of the targets.

The importance of spacial and temporal target dispersion is indicated by the problem of estimating the total crop acreage or other land usages in a region. In the United States, 92.8% or 53.02×10^6 acres of the planted wheat acreage is distributed among 17 states with a combined area of 953.84×10^6 acres. Depending upon the definition of a field and the average field size, there may be over one-half million "fields" distributed over the region. Some percentage must be located, identified, and perhaps measured for the development of a national crop statistic.

Factors influencing the area measurements of fields: image tilt, ground resolution, photographic scale, planimetric accuracy, film stretch, enlargement precision, etc., are not necessarily compensating and could introduce a sizeable error or bias in a final prediction based upon several hundred thousand discrete area measurements. Ideally, planimetric measurements for a large number of small highly dispersed targets should be avoided if possible. The techniques and problems of spacial dispersion as discussed in Chapter 3 may eliminate or reduce the effect of the above factors for a wide variety of areal land usage targets.

A primary reason for imaging at higher altitudes is larger coverage per frame or the over-view. There are, of course, other reasons justified by the fact that the imaging systems used for the macroscopic are capable of the microscopic (subject to vehicle constraint), e.g., areal terrain targets ranging from a few square feet to thousands of square miles can be imaged at orbital altitudes.

To establish practical bounds to areal coverage ranging from small to large, system optical parameters, targets, spacial and temporal dispersion and vehicle constraints must be integrated with the user and his purpose.

The principal users of aerial photography and the nature of their needs are important in determining practical methods of utilizing the advantages of space imagery.

1.3 PRINCIPLE USERS OF AERIAL PHOTOGRAPHY IN THE U. S. DEPARTMENT OF AGRICULTURE

The principle users of aerial photography in the U. S. Department of Agriculture are[4]:

ASCS Agricultural Stabilization & Conservation Service

Crop control designed to reduce surplus production of major crops, e.g., corn, wheat, oats, cotton. Maps 200 million acres annually with aerial photography; corn area data by farm and field.

SCS Soil Conservation Service

Conservation and inventory of land resources, soil mapping and classification, watershed protection, flood control, erosion, etc. Maps 50 million acres annually.

SRS Statistical Reporting Service

Annual crop and livestock surveys, 176 crops, land capability and use, crop yield.

FS Forest Service

Management of national forests and public domain, range management for livestock.

ERS Economic Research Service

Land use as related to economic research, areal interest limited primarily to a few townships or counties.

Other users are the Bureau of Land Management (BLM) and the Department of Interior.

Aerial photography is primarily used as an aid in land resources surveys with the objective to classify, map and measure vegetation, soils and land use to varying detail. The largest user is the ASCS for their crop control program. ASCS annually determines the acreage of certain primary crops totaling two million acres. The majority of the imagery is procured by ASCS and made available to other users. The characteristics of the aerial photographs are[5]:

- maximum vertical departure: 4°
- panchromatic, 9"x9" film, stereoscopic
- scale: 1:20,000
- resolution: 20 lines/mm, ground resolution approximately 3.3 ft.

Photographs obtained by ASCS include 80% of the Continental United States, exclusive of Alaska. The general practice of the ASCS, SCS and SRS is to classify and map the subject of interest on the ground using the aerial photos as the mapping base. The enumerative crop surveys of the SRS are conducted on a sample basis. Aerial photographs can point out sample discrepancies, and provide for readjustment of a sampling distribution.

During the 1959 census of agriculture, an ES (farm) was identified by an evaluation survey. The enumerator (interviewer) of the particular farm was required to determine the acreage of the farm and sketch in all fields on a transparent overlay of an aerial photograph. The crop acreages as reported by the farmer were then checked using the aerial photograph.

The photographic scale of a mosaic is a function of the intended use. A rough classification consists of:

a. Small scale - 1:20,000 and smaller - geology, forestry, reclamation, flood control, etc.

b. Medium scale - 1:10,000 to 1:20,000 - city planning, highway planning, pipelines, etc.

c. Large scale - 1:10,000 - detailed work, urban planning, tax maps, bridge sites, land evaluation surveys, etc.

Mosaics have served as a particularly useful tool in mapping of grassland, brushland and timberland interfaces. In general, map scales of 1:60,000 have been used for recording the data. The 1:20,000 photographic scale is suitable for USGS map compilation of the 7-1/2 minute quadrangle series. Small scale reconnaissance mapping at scale of $1{:}10^6$ and 1:250,000 may be compiled from 1:40,000 to 1:80,000 scale photography. A summary of the USDA application of aerial photography is given in Tables 1 and 2.

1.4 STATISTICAL SERVICES OF THE U. S. DEPARTMENT OF AGRICULTURE

The Census Bureau makes a complete census of agriculture every 5 years (for years ending "4" and "9"). The collected information includes acreage in farms, acreage in crops and other land uses, production and

TABLE 1

Agricultural Applications of Aerial Photography[4]

User	Application	Field Survey Frequency	Areal Scope (mil. acres)	Method of Data Acquisition	Nature of Acquired Data
Agricultural Stabilization & Conservation Service	crop acreage control	annually	200	field mapping	crop area data by farm and field
Soil Conservation Service	soil classification and mapping	continuing	50	field mapping	detailed soils map
	farm conservation planning	continuing	-	field mapping	land capability - use map and area data for individual farms
	watershed protection	irregular	-	field mapping	land use data by flood frequency zones
	conservation needs inventory	one survey	-	field mapping	land capability - use area data by sample segment
Statistical Reporting Service	crop production estimation	annually	limited	field mapping	crop and other area data by sample segment
Forest Service	range resources inventory	continuing	-	interpretation - field mapping	carrying capacity (physical resources) map

TABLE 1 (Cont.)

User	Application	Field Survey Frequency	Areal Scope (mil. acres)	Method of Data Acquisition	Nature of Acquired Data
Economic Research Service	various economic studies	irregular	limited	interpretation	current and historical land use data (often comparative area data)
	land use mapping	one survey	1,902	interpretation	generalized map of major land uses
Bureau of Land Management	range-resources inventory	continuing	-	interpretation-field mapping	physical resources map

TABLE 2. TABULAR REVIEW OF APPLICATIONS IN AGRICULTURE FOR REMOTE SENSING SYSTEMS[2]

	Application	Coverage	Units	Resolution (expressed in feet)	Repetition Times***	Processing Time
1.	Agricultural Census	100% of agri. areas	Minor civil divisions*	Area Measurement 20'-40' Crop Ident.** 20'-40'	1-2/yr 2-4/yr	2-4 months
2.	Agricultural Programs	100% of agri. areas	Farms	Area Measurement 4'-8' Crop Ident. 20'-40'	1-2/yr	2 months
3.	Agricultural Statistics	Sampling fractions of f = $\frac{1}{200}$ to $\frac{1}{100}$	1/4 Sections to Sections	Area Measurement 20'-40' Crop Ident. 20'-40'	Monthly	3-4 weeks
4.	Resource Surveys	Variable: counties or watersheds up to several states	Sections to Townships	Crude Area Measurement 40'-60' Resource Ident. 50'-100'	Occasional	4-6 months
5.	Soil Classification and Mapping	Both sampling and 100%	1/4 Sections to Sections	Mapping 8'-20' Soil Boundaries 20'-40'	5-10/yr	6-12 months
6.	Conservation Programs	Variable: counties or watersheds up to several states	1/4 Sections to Sections	Mapping 10'-20' Area Measurement 8'-20'	Occasional (before and after)	3-6 months
7.	Agricultural Geography	Both sampling and 100%	Minor civil divisions to counties	For sampling 8'-20' For 100%, 50'-100'	Initial plus occasional (1/5 years)	6-12 months
8.	Changes in Land Use	100% of agri. areas	Minor civil divisions	Area Measurement 4'-8' Use Ident. 10'-20'	Annual or Biennial	4-6 months

TABLE 2 (Cont.)

Application	Coverage	Units	Resolution (expressed in feet)	Repetition Times***	Processing Time
9. Economic Studies	Selected small areas: 100% Large areas by sampling $f = \frac{1}{1000}$ to $\frac{1}{10}$	Farms to minor civil divisions	Mapping 4'-8' Crop or land use Ident. 20'-40'	Occasional	3-6 months
10. Damage Detection & Assessment	Selected areas 100% Some sampling	Sections to townships	Area Measurement 4'-8' Identification 10'-20'	2-5/yr	3-4 weeks
11. Snow Surveys	Snow areas: 100% or by sampling	Townships, counties and watersheds	50'-100'	2-3/yr	1-2 weeks
12. Water Supply Prediction	Both 100% and sampling	Townships, counties, watersheds and lakes	50'-100'	2-4/yr	1-2 weeks

---

*Towns, townships and parishes.

**Ident. = Identification. The resolution shown in this table for crop identifications are based on the problems of identifying crops where strip cropping, terracing and contour farming are present and fields appear as long narrow strips. Text discussion of resolution for each of the applications is based on square or rectangular fields.

***Some of the applications will utilize more frequent sensing if made available because of the needs of other applications. Examples are applications 6 and 7 using the outputs from applications 2 and 3.

sales of agriculture products, etc.

Current statistics on agriculture production are collected primarily by the Statistical Reporting Service (SRS) of the Department of Agriculture[6]. Estimates are made on the basis of sample data reported in mailed questionnaires to farmers, processors, and others, and then adjusted to benchmark data available from concensus of agriculture or other more frequent surveys. SRS also uses data collection methods based on personal enumeration for major crop and livestock items in June and December, and measurement surveys of sample plots for estimating yields of major crops during the growing years.

In March of each year the SRS receives reports on the number of acres farmers intend to plant for 16 principal crops and a wide variety of minor crops. Data are used to estimate the total number of acres intended to be planted for each of the principal crops. In June, reports are obtained from farmers on acreage actually planted, and preliminary re-estimates of production are prepared for about 20 major crops. Thereafter, the acreage estimates along with monthly reports on crop condition, are used in forecasting production throughout the growing season. Monthly forecasts are also made of fruit production. (For some of the earlier crops, such as winter and spring wheat, the monthly forecasts being earlier than July.)

At the end of the growing season, the SRS gets reports on number of acres harvested, yield per acre, and production for most crops, including field crops, vegetables, fruits and nuts. From these reports, SRS prepares production estimates for about 135 crops, on a national, regional and state basis. Weekly reports are issued on weather/crop conditions.

Yearly changes in gross volume of crop production are measured and an index of volume of crop production computed from production data for the crop year. All production is included, regardless of its final disposition. This index is published monthly from July through December in "Crop Production". Year to year changes in average yield level of 28 crops are measured as an index of crop yields per acre harvested, subdivided into yield indexes of field and fruit crops. The series is published in the annual summary of "Crop Production" issued each December.

Publications of the U. S. Department of Agriculture are given in Appendix A .

1.5 USDA DATA SAMPLING METHODS AND THE MASTER SAMPLE

The mechanics of collecting data for the development of the USDA statistics is a complicated, expensive and time consuming task. Furthermore, the methods of collecting the data should satisfy the sampling requirements of statistical probability theory and/or the appropriate adaptation or modification of past methods which solve a problem satisfactorily for the user.

In general, four sampling methods which are currently being used or have been in the past are[6, 7]:

1. Mailed Inquiry
2. Random Point
3. Quota Method
4. Area Sampling

Of these four, the first three give biased samples of the population or universe under study and usually depend upon historical information. In general, there are two basic frames, area and list, for the organization or identification of each element of the population to be sampled. The list frame is a listing of the population elements with appropriate identifying data. Subclassification of these may be done with supplementary information. The area frame consists of identifiable units or segments of land area which may be sampled by drawing subsamples from the segments.

The random point method involves locating a random distribution of points on a map and a fixed number of elements, farms, are associated with each sample point. The survey can be quickly designed, but the returns are liable to be biased because sample points are more likely to fall upon large rather than small farms.

The quota method is primarily used for public opinion polls, marketing surveys, and election forecasts. The population is divided into a number of strata or cells and a proportionate sample is drawn from each cell. Quotas are set up for each cell usually based upon census information and filled by enumerators. Quota sampling has the disadvantage of being biased by selective filtering of the enumerators and the usually historical information of non-current census. The quota is simple to prepare.

Area sampling requires the division of a region into small areas or cells containing the unit for observation. The region ideally encompasses the population, hence a proportionate sample or sample rate is known. An unbiased sample of units is made by enumerating all units within each cell. In the case of farms, the headquarters are selected within the cell regardless of whether or not the farm boundaries extend outside the cell. Unbiased selection of land area is made by selecting only that land within the cell or whose fields have their northwest corner within the cell. Area sampling has the advantage of clustering the units of observation, reducing travel time and cost. The method is adaptable to stratification, double sampling and subsampling for the reduction of error. Area sampling may be biased because the number of farms within the cell can change with time. A disadvantage of area sampling is that detailed maps are required for definition of sample areas in the field. Aerial photographs are used to supplement detailed maps. The logistics of obtaining appropriate aerial coverage can be a problem.

A Master Sample Plan was begun in 1943 in part because the area method cannot be designed quickly. Costs are incurred when map areas must be sufficiently delineated for identification in the field.

The master sample in the early forties consisted of over 67,000 areas which identify over 300,000 farms located in nearly every county in the United States. There are about 5 farms per area which averages about 2.5 square miles. The largest and smallest areas are 108 and .71 square miles respectively. To date, sample areas have been selected for all of the 3070 counties in the United States. The total sample areas contain 1/18 of the land area of the United States, 1/18 of the farms, 1/18 of the rural population, etc.

Three primary strata were defined upon the basis of incorporation and density of population, e.g., incorporated, unincorporated and densely populated, open country and sparsely populated.

Master sample materials consist of one inch per mile scale maps of all counties with a tabulation of cultural content including members of farms and dwellings and complete aerial coverage.

1.6 AREAL STRATIFICATION STRUCTURE OF THE UNITED STATES FOR PREPARATION OF AGRICULTURE STATISTICS

Areal stratification of the United States or any other region of the earth is important operationally to functional system definition and to utilization of satellite obtained imagery.

The United States is divided into 10 farm production regions based upon a geographical stratification as shown in Figure 2. Each state is divided into several crop reporting districts (Figure 3) which roughly separates different farming characteristics, but does not cut across county boundaries. Every county in the United States is included in the Master Sample Plan and over 300,000 individual farms are identified in the United States.

For other land usage, 18,323 (1962) special natural resource districts have been established to manage and direct the use and development of land and water resources. Table 3 gives the type of district and the number in the United States.

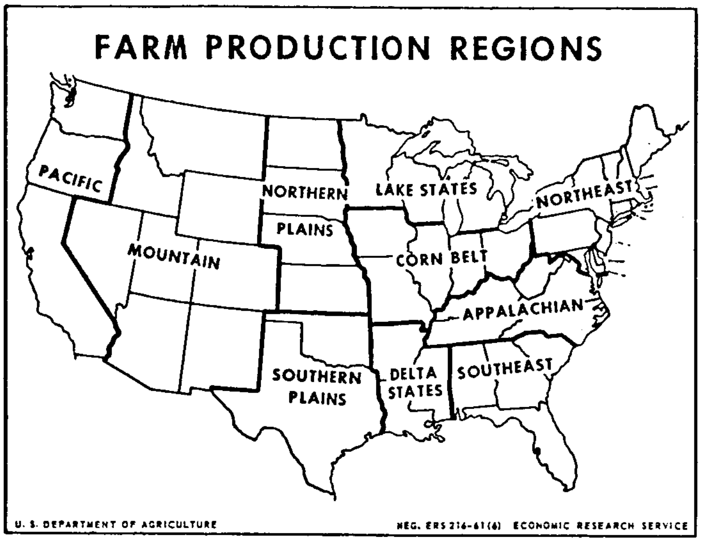


Figure 2[36]

Two important facts may be acknowledged from the preceding discussions. The USDA has established a functional communication network throughout the United States reaching to individual farms. A large amount of areal land usage information pertinent to specification and maximum utilization of satellite obtained data is available.

TABLE 3

LAND USAGE DISTRICTS

Type of District	1962	1957	1952	1942
Total number special districts	18,323	14,423	12,319	8,299
Total number natural resource districts	8,458	7,323	4,740	3,627
Drainage	2,240	2,132	2,174	1,955
Soil conservation	2,461	2,300	571	-
Irrigation and water conservation	781	564	641	523
Flood control	500	209	206	200
Parks and recreation	488	316	194	128
Water supply	1,502	787	665	357
Other natural resources	176	353	222	386
Multifunction natural resources	310	662	67	78

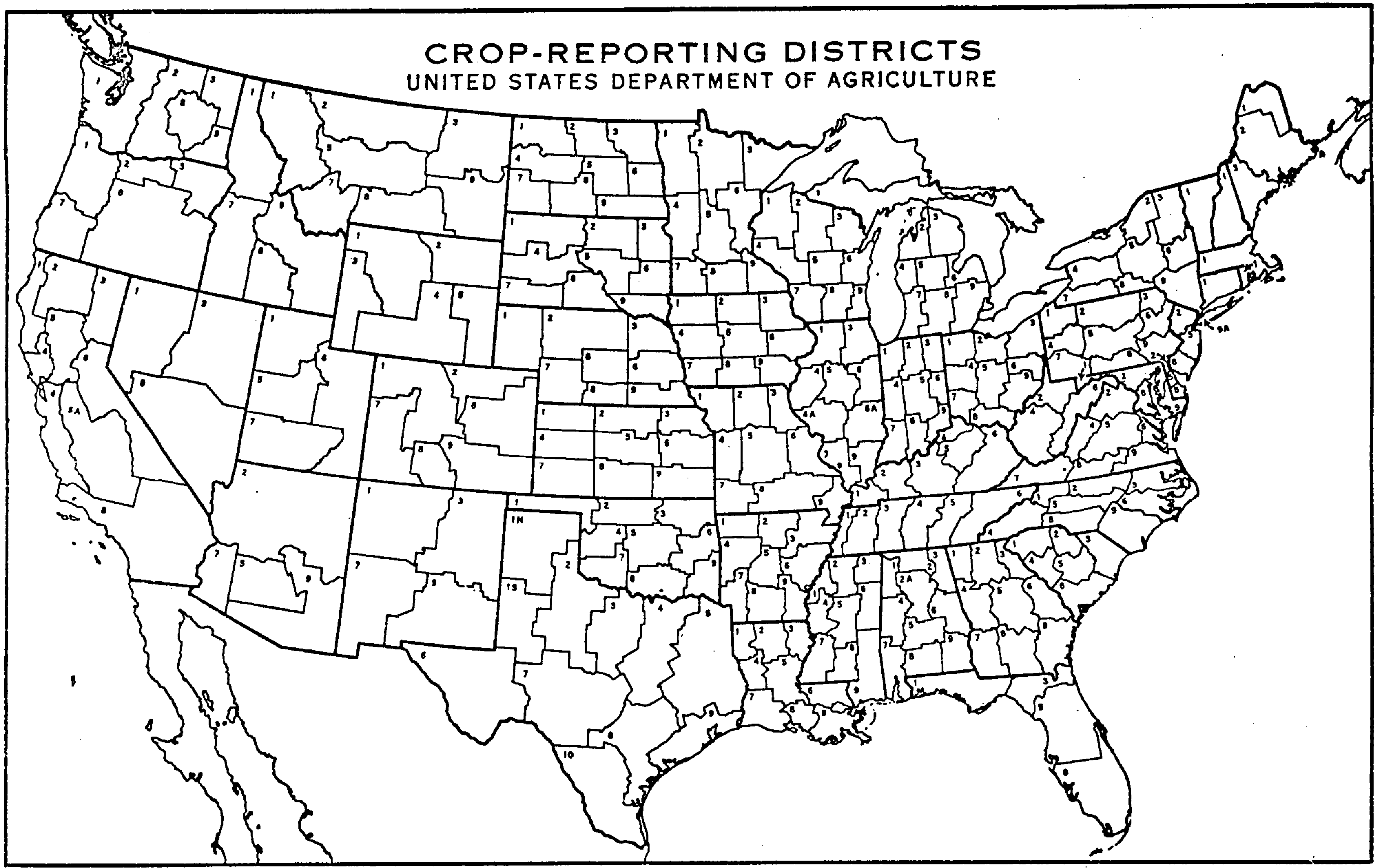

CROP-REPORTING DISTRICTS
UNITED STATES DEPARTMENT OF AGRICULTURE

Figure 3

CHAPTER 2

TARGET DEFINITION, SPACIAL & TEMPORAL DISTRIBUTION

2.1 GENERAL INTELLIGENCE REQUIREMENTS FOR ORBITING SENSORS

Data obtained from satellite sensing systems must be transformed into intelligence. The effectiveness of a total system for this purpose depends upon:

- The ability to identify the target.
- Compatibility of different target classes with a limited system flexibility.
- Temporal dispersion of target members.
- Spacial dispersion of target members.

Systems designed for optimum detection, location and identification of target class (X) is unlikely to be optimum for class (Y) . The "ideal" system for maximum identification capability of all possible target classes is one which performs spectrophotometric measurements from the visual to the microwave region of the electromagnetic spectrum. At this point in time, the earth can be imaged in any portion of the electromagnetic spectrum from ultraviolet to radar frequencies. Any image of the terrain in all likelihood will contain in some manner a representation or manifestation of most target classes of interest subject to theoretical electromagnetic interaction constraints which are primarily a function of wavelength. Every target class has some optimum frequency band or bands within which it must be sensed for maximum enhancement. A visual, infrared, or radar satellite-borne imaging system cannot accommodate all possible filter/frequency combinations required for the target classes discussed in this section as a practical satellite sensing system for a worldwide or national survey.

Any target has an electromagnetic signature which can be expressed as a function of frequency, e.g., a target has more than one "color" (frequency response) associated with its electromagnetic interaction properties, permitting greater discrimination and classification as the "number" of classification tags increase. To separate the subclasses of vegetation by other than geometry, wheat, for example, must have a "color" distribution associated with its mass effect different from a background of grass. (Note: mass effect is due to integrating the plant response over an area containing many plants.) The color distribution (frequency response) of wheat must be measurably different from that of corn or the two cannot be separated by other than photointerpretation techniques relying on pattern recognition and associative information relative to the field in question. Equally important the signature of other crops or vegetation must be sufficiently different to reduce the "false alarm" rate. A system with a limited fixed frequency response or filtered in such a manner as to separate and identify wheat from corn may not be applicable for identification of soil groups.

A photographic system with a few film/filter combinations is not adaptable to identification of all target classes where the frequency response of the target is required for identification based upon a comparative grey scale. It is important to recognize the subtle difference between relative and absolute correlation of a known with the unknown by the spectral response of a natural aggregate. Spectral response is an amplitude function of frequency. Frequency measurements are absolute. Amplitude is the relative response integrated over some frequency interval. The amplitude or intensity of emitted or reflected energy is quite variable due to analytically unknown environmental and geometric influences. To correlate amplitude system response between two like systems requires measurement standards and the elimination of system parameter differences (for example, system gain settings).

The majority of the possible applications for orbiting sensors require an identification based upon substance dependent electromagnetic spectral reflectance properties. It seems reasonable to expect that nature has provided considerable variability and inhomogeneity of the reflectance properties among target classes and their members. (See Figures 4 & 5) This suggests that much experimentation with systems and targets must be done from aircraft before being attempted from spacecraft. It seems reasonable to assume that systems requirements for transformation of soil characteristics into intelligence may not be adaptable except by secondary inference to plant vigor. Systems for the detection of mineral deposits are, in all likelihood, not applicable to soil moisture measurements (if any). It appears reasonable at this time and most certainly in the near future to utilize existing systems for mapping purposes. The entire United States can be reduced to 629 photographic frames with a ground resolution of approximately 10 to 20 feet. By appropriate reduction of the imagery, regional trends ranging from several hundred thousand square miles to a few square miles can be studied for whatever target distribution of interest can be identified.

Temporal dispersion of targets influence recognition by altering target signatures or visible associative ancillary information. For example, the spectral reflectance of crops is a function of the growth stage. Optimum sensing periods for one crop may be different for another giving rise to overflight time conflicts.

Spacial dispersion of target members is of primary importance to systems development and procedures for identification using automatic and/or photointerpretative techniques. A target class containing many members distributed over a large region or a single target whose location is unknown requires an areal search of the region data even on a sample basis. Locating a small areal target on a photographic or television frame with a coverage of 3600 square nautical miles and 10 ft ground resolution is difficult unless the target is extremely enhanced on the imagery. As the number of target members (small in area relative to a finite region) increases, time and cost of an enumeration increases. Approximately 92.8% (53 million acres) of the

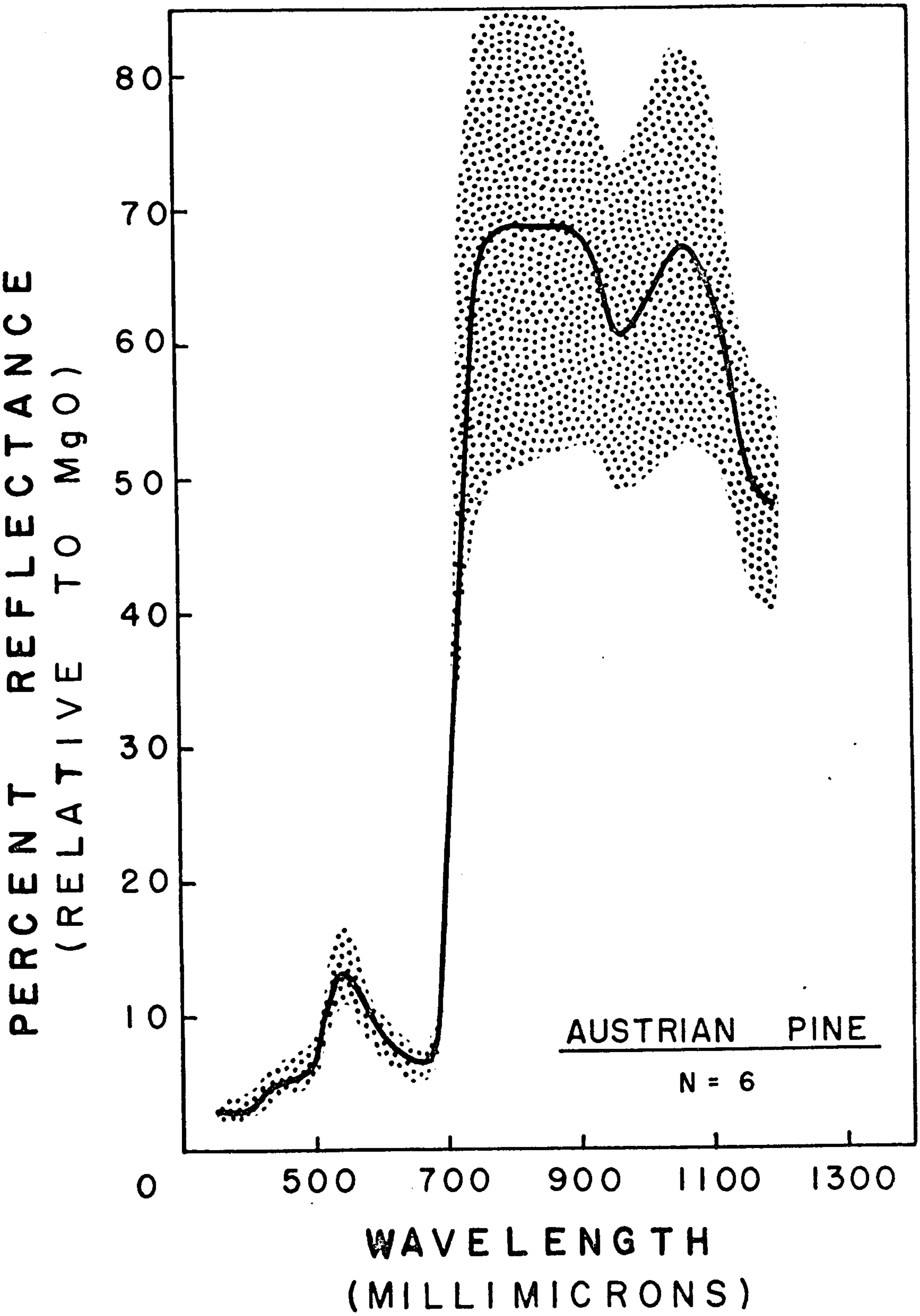


Figure 4.[31] Average curve of reflectance from needles of Austrian pine (Pinus nigra) collected near Dexter, Michigan, on August 29, 1963. (Shaded area represents the 96 percent confidence interval for the average curve.)

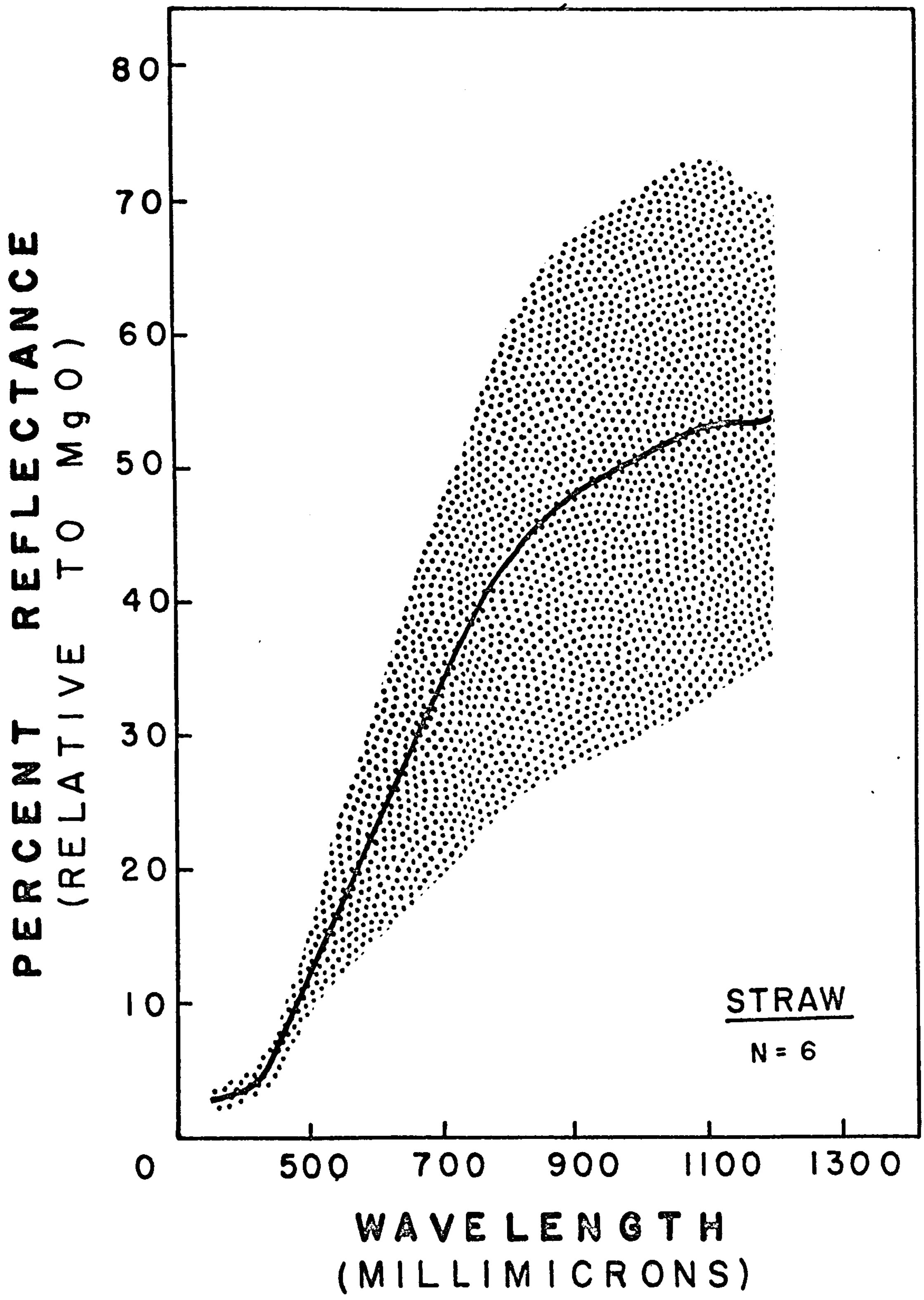


Figure 5.[31] Average curve of reflectance from cut straw collected from a field near Dexter, Michigan, on August 29, 1963. (Shaded area represents the 96 percent confidence interval around the average curve.)

planted wheat acreage in the United States was distributed among 17 states with a combined area of nearly 1 billion acres. A target such as wheat might require the location and identification of $\frac{1}{2}$ million target members (fields). Statistical sampling may be required subject to the questionable hypothesis that the statistics of one portion of the region is the same in another. The location of a single local target may be known eliminating automatic identification systems and search requirements. In this case, if the target can not be identified with 100% reliability, a ground check or ancillary information is available at a reasonable cost for substantiating the identification hypothesis.

The probability of detecting a "reasonable" single target located a priori in space and time from one satellite is 100%. Two targets may require either an increased field of view or multiple satellites.

The Continental United States exclusive of Alaska is 3 million square miles or approximately 2 billion acres in area. The advantage of high altitude imagery is the scale of observation. Satisfactory ground resolution (less than 50 ft.) permits a variable scope of observation ranging from thousands of square miles to less than one acre from one primary data base. The scale of observation capability of satellite imagery versus the scale of interest is important. We are faced on one hand with an enormous areal coverage and on the other, areal targets of interest which may be smaller than one acre. The entire United States can be imaged on 629 9"x9" frames each with a ground coverage of 3600 square nautical miles at any specified hour ± 2 hours in 22 days with no allowance for cloud cover. The ground scale on the aerial photo in Chapter 1 is about 1" = .91 miles. An enlargement of about 8.42X would give the same scale (1" = .91 miles) to the satellite imagery. Each enlarged master frame would be 75.6 x 75.6 inches. For a map scale of 1" = .91 miles = 4805 ft., the eye can resolve an area about 20 x 20 square feet.

There are approximately five major overlapping divisions of interest to earth science for which terrestrial high altitude remote sensing may be useful, e.g., agriculture/forestry, geology, hydrology, oceanography, and geography. Table 4 lists these general areas, the nature of the targets and applicable sensing modes. Visual photography, multiple spectral photography and infrared imagery/spectroscopy provide a data base of universal interest and across-the-board capability. The nature of the targets listed is interesting in view of the preceding discussion.

It is difficult to associate "detection of acres cooled by evaporation" with 3 million square miles of data for just the Continental United States. It seems somewhat awkward to map the wheat acreage of the earth from just the timing or triggering sequence requirements for a satellite system exclusive of other targets dispersed among the 52 million square miles of land area (less Antarctica). Spacial dispersion of many targets is the primary problem in transforming data (relating to an image of the earth) into intelligence.

TABLE 4[30]

POSSIBLE APPLICATIONS FOR ORBITING SENSORS

Experimental Technique	Agriculture Forestry	Geology	Hydrology	Oceanography	Geography
Visual Photography	Crop and soil identification, identification of plant vigor and disease	Identification of surface structure	Identification of drainage patterns	Identification of sea state, beach erosion, offshore depth and turbidity	Urban and rural land use, transportation routes and facilities; terrain and vegetation characteristics
Multispectral Photography		Identification of surface features	Soil-moisture content	Sea color as indicative of living organisms	
IR Imagery and Spectroscopy	Terrain composition, plant vigor and disease condition	Mapping thermal anomalies, mineral identification	Detection of areas cooled by evaporation	Mapping of ocean currents, sea-ice investigations	Surface-energy budgets, near-shore currents and land use
Radar Imagery	Soil characteristics	Surface roughness, tectonic mapping	Measurement of soil-moisture content, identification of run-off slopes	Sea state, ice flow and ice penetration, Tsunami warning	Land and ice mapping, cartographic and geodetic mapping
RF Reflectivity		Subsurface layering, mineral identification	Moisture content of soils	Sea ice thickness and mapping, sea state	Land/ice mapping and thickness, penetration of vegetation cover
Passive Microwave Radiometry and Imagery	Brightness-temperature map of terrain	Dielectric constant measurement indicative of subsurface layering	Snow and ice surveys	Sea ice and ocean-current mapping	Snow and ice measurements
Absorption Spectroscopy (Remote Geochemical Sensing)		Detection of mineral deposits, trace metals, and oil fields		Detection of concentrations of surface marine flora	

The advantage of increasing altitude is the over-view. The fact that systems are capable of imaging thousands of square miles on one frame with tens of feet ground resolution implies the simultaneous existance of a macroscopic and microscopic capability; the available amount of microscopic data analyzed over the macroscopic can be an impossible barrier. The data must be transformed into intelligence if it is to be useful. Problems of spacial dispersion, target variety, and a scale of coverage never before available to man are perhaps best handled by individuals and groups relating only small segments of the satellite obtained data to their specific researches. Since any image is "useful" and the worthiness of discussion of the imagery is subject to many points of view, project selection by scientists in close coordination with system engineers will be extremely important in the transformation of the data into useful intelligence.

There has been considerable effort given to target definition and to just what is being sought through multispectral remote sensing. Table 5 lists such an analysis for a functional associative correlation with Table 4. The reader should also refer to Table 7 in the next section listing the agricultural/ forestry subjects of interest for satellite sensor experimentation. The magnitude and significance of the body of information contained or inferred in these tables for practical purposes is infinite. For science, technology and civilization, it represents all of the past, present and future. If meaningful programs are to be established without obtaining masses of redundant data for the sake of taking data, then perhaps it is time to take a good look at man's ability to synthesize the spacial and temporal dispersion of areal observations and islands of intelligence from the macroscopic to the microscopic. For example, suppose the agricultural productivity of soil and environment was assessed upon a 1 square foot grid basis for the entire land area of the world. What could be done with this knowledge? A statement implying the agricultural productivity of the world could be increased is meaningless, short of total dictatorial control by the state. It takes capital for fertilizer to increase the yield and if the yield is increased capital and technology is required for harvesting, processing and distribution.

Furthermore, there are substantial regions of the world which have not been isolated by the advance of technology where the producer has available all the necessary information to maximize yield subject to soil requirements and environmental (rainfall, temperature, etc.) limitations. Most nations have a university capable of gaining access to man's knowledge and applying it. From a practical point of view, there is the question of grid size for analysis of spacial variations or changes relative to what is already known about the region. Assuming all other requirements would be met in increasing the agricultural productivity of the land, what is the ideal minimum grid size upon which the data is to be obtained? If it is sufficiently large (thousand square miles) the data may already exist in such a detail as to prescribe for the region. Geographers employ macroscopic classification procedures extending in varying degrees toward the microscopic relative to the land masses of the earth. The

TABLE 5[1]

BASIC AND APPLIED DATA SOUGHT THROUGH MULTISPECTRAL REMOTE SENSING BY WORKERS IN VARIOUS DISCIPLINES

I. FORESTERS AND AGRICULTURISTS

  A. BASIC

    1. Amount and distribution of the "biomass"
    2. Nature and extent of important "ecosystems"
    3. Amount and nature of energy exchange phenomena

  B. APPLIED

    1. The species composition of vegetation in each area studied
    2. Vigor of the vegetation
    3. Where vegetation lacks vigor, the casual agent
    4. Probable yield per unit area and total yield in each vegetation type and vigor class
    5. Information similar to the above for livestock, wildlife and fish

II. GEOLOGISTS

  A. BASIC

    1. Worldwide distribution of geomorphic features
    2. Energy exchanges associated with earthquakes and volcanic eruptions

  B. APPLIED

    1. Location of certain or probable mineral deposits
    2. Location of certain or probable petroleum deposits
    3. Location of areas in which mineral and petroleum deposits of economic importance probably are lacking

III. OCEANOGRAPHERS

  A. BASIC

    1. Diurnal and seasonal variations in sea surface temperatures and subsurface temperatures
    2. Vertical and horizontal movements of ocean currents and individual waves

TABLE 5 (Cont.)

3. Global, regional and subregional shoreline characteristics with time
4. Diurnal and seasonal movements of fish, algae and other marine organisms

B. APPLIED

1. The exact location, at a given time, of ships, icebergs, tsunamis, storms, schools of fish and concentrations of kelp
2. The location of ocean beaches suitable for recreational development
3. The rate of spread of water-pollutants and the kind and severity of damage caused by them

IV. METEOROLOGISTS

A. BASIC

1. Diurnal and seasonal variations in cloud cover, wind velocity and air temperature and humidity in relation to topography and geographic locality
2. Accurate statistical data on the points of origin of storms, the paths followed by them, their intensities, and their periods of duration

B. APPLIED

1. Early warning that a specific storm is developing
2. Accurate tracking of the storm's course
3. Accurate periodic data on air temperatures, humidity and wind velocity
4. Accurate quantitative data on the response of the atmosphere to weather modification efforts

V. HYDROLOGISTS

A. BASIC

1. Quantitative data on factors involved in the hydrologic cycle (vegetation, snow cover, evaporation, transpiration, and energy balance)
2. Quantitative data on factors governing climate (weather patterns, diurnal and seasonal cycles in weather related phenomena)

TABLE 5 (Cont.)

B. APPLIED

1. The location of developable aquifers
2. The location of suitable sites for impounding water
3. The location of suitable routes for water transport
4. The moisture content of soil and vegetation

VI. GEOGRAPHERS

A. BASIC

1. Global, regional and subregional land use patterns
2. The nature and extent of changes in vegetation, animal populations, weather, and human settlement throughout the world

B. APPLIED

1. The exact location, at any given time, of facilities for transportation and communication
2. The interplay of climate, topography, vegetation, animal life and human inhabitants in specific areas
3. The levels of economic activity and the purchasing habits of inhabitants in specific areas

individual farmer or forester treats the microscopic in their local immediate environment.

Perhaps what is needed in the utilization of satellite remote sensing is the development of a practical environmental classification based upon an analysis ranging from the macroscopic to the microscopic, weighted not by value, but by spacial dispersion based upon the fact that any member of a class occupies space and if the space is small, there can be a very large number of members.

2.2 AGRICULTURAL/FORESTRY TARGETS OF INTEREST FOR ORBITAL SENSING

The general nature of agricultural/forestry subjects of interest and their sensing requirements have been established[8]. Table 6 summarizes the findings. The table includes sensing modes, spectral band and resolution requirements for imaging or sensing the respective targets or target associated attributes. The premise of this work is that the transformation of the data into the desired intelligence, e.g., discrimination and identification, can be done within the stated sensing modes, spectral bands and system resolutions at orbital altitudes. It has been shown[1] that multispectral differentiation of crops, for example, is feasible, but the large variations within a species requires measurements subjected to all parameter variation (crop variety, maturity, size, soil type, moisture content, etc.) which influence the response.

All targets have a signature or response which can be sensed at some frequency or band of frequencies. The response can be used for discrimination and identification by methods other than pattern or form recognition, e.g., analysis of the information contained in the spectral reflectance. Unfortunately, the substance dependent properties of an electromagnetic energy exchange process can be infinitely variable through some range. Therefore, to identify and establish a reliability for identification of a terrain target, a complete set of empirical signatures need be obtained which encompass the range of variability found within nature. Quantitative causal relationships for predicting inhomogeneous substance dependent electromagnetic energy exchanges or signatures as found in nature can have marginal value because of the unknown inhomogeneities of both natural substance and geometry which influence the exchange[9]. The inhomogeneities of natural things as found within a terrain complex will be a major obstacle to identification by spectral response to the extent of automatic transformation of data into intelligence on the observational scale of satellites.

In all likelihood the aggregate of satellite obtained data will be analyzed using photointerpretive techniques, e.g., primary spacial pattern recognition and secondary inference involving the use of ancillary information associated with the target area and the nature of the electromagnetic energy exchange process being sensed. The information content (usefulness is relative)

TABLE 6

Agriculture/Forestry Subjects of Interest and Sensing Requirements[8]

Selected Knowledge Requirements	Indicative Phenomena	Estimated Sensing Requirements		
		Mode	Spectral Band	Resolution
1. Location and identification of major cultivated crops.	a. Boundaries and topographic features	I	0.4-3 mu	20'-100'
		P	1 mu	10'
	b. Planting patterns	I	0.4-3 mu	5'- 50'
	c. Color, texture, and contrast	I	0.4-3 mu	20'-100'
		P	3. -35 gc	10' ht
	d. Spectral signature	S	0.4-3 mu	10'- 50'
2. Location of forest resources and identification of composition by type.	a. Color, texture, and color contrast	I	0.4-3 mu	20'-100'
		P	3. -35 gc	10' ht
	b. Boundaries and topographic features	I	0.4-3 mu	20'-100'
		P	1 mu	10' ht
	c. Spectral signature	S	0.4-3 mu	10'- 50'
3. Location and identification of gross characteristics of range areas.	a. Boundaries and topography	I	0.4-0.9 mu	20'-100'
		P	1 mu	10' ht
	b. Related cultural features	I	0.4-0.9 mu	50'-200'
		R	10 gc	20'-100'
4. Estimation of crop vigor and yield.	a. Boundaries and topographic features	I	0.4-3 mu	5'- 50'
		P	1 mu	10' ht
	b. Planting pattern	I	0.4-3 mu	5'- 50'
	c. Color, texture, and color contrast	I	0.4-3 mu	10'- 50'
	d. Crop symmetry and density	I	0.4-3 mu	0.1'- 5'
	e. Spectral signature	S	0.4-3 mu	5'- 50'
5. Estimation of vigor and potential forest yield.	a. Color, texture, and color contrast	I	0.4-3 mu	20'-100'
	b. Individual and group geometric symmetry	I	0.4-3 mu	5'- 50'
		R	0.4-10 gc	5'- 50'
	c. Crown diameter	I	0.4-0.9 mu	1'- 10'
	d. Crown closure	I	0.4-0.9 mu	10'- 50'
	e. Height	P	1 mu	1'- 5' ht
	f. Spectral signature	S	0.4-3 mu	10'- 50'

I = passive imagery S = spectroscopy
R = illuminated imagery P = non-imaging reflectometry
T = telemetry

TABLE 6 (Cont.)

		Estimated Sensing Requirements		
Selected Knowledge Requirements	Indicative Phenomena	Mode	Spectral Band	Resolution
6. Estimation of foraging potential of ranges.	a. Color, texture, and color contrast of herbaceous cover	I	04.-3 mu	20'-100'
	b. Related potential water resources	I	0.4-14 mu	100'-500'
	c. Related cultural and topographic features	I	0.4-0.9 mu	50'-200'
		P	1 mu	10' ht
		R	10 gc	20'-100'
	d. Spectral signature	S	0.4-14 mu	50'-200'
7. Discovery of ecological relationships.	a. Related features of plant site/habitat and correlative topographic features	I	0.4-14 mu	10'- 50'
		S	0.4-14 mu	10'- 50'
		P	1 mu	10' ht
		R	10 gc	10'- 50'
	b. Plant/plant relationships	I	0.4-3 mu	5'- 20'
		S	0.4-3 mu	5'- 20'
	c. Seasonal periodicity and climatic tolerance of vegetative cover	I	0.4-3 mu	10'- 50'
		S	0.4-3 mu	10'- 50'
	d. Thermal energy budget	I	3. -14 mu	20'-100'
8. Location, identification, count and determination of migration patterns of important wildlife.	a. Color and pattern contrast	I	0.4-14 mu	0.1'- 5'
	b. Thermal discontinuity	I	3. -14 mu	0.1'- 5'
	c. Tracking of tagged specimens	T	-	1 mile
9. Location, identification, and determination of migration patterns of animal pests and insects.	a. Color, pattern of swarms	I	0.4-14 mu	0.1'- 5'
	b. Color, pattern of infested crops	I	3. -14 mu	0.1'- 5'
	c. Spectral signature	T	-	1 mile

TABLE 6 (Cont.)

Selected Knowledge Requirements	Indicative Phenomena	Estimated Sensing Requirements		
		Mode	Spectral Band	Resolution
10. Assessment of infestation damage.	a. Changes in previously established color/patterns	I	0.4-3 mu	10'-100'
	b. Changes in spectral signature	S	0.4-3 mu	10'-100'
11. Identification and location of forest fires.	a. Temperature discontinuity	I	3. 14 mu	100'-1000'
	b. Color, pattern of smoke, fire	I	0.4-3 mu	500'-1000'
12. Assessment of damage of forest fires.	a. Color, pattern of burned areas	I	0.4-3 mu	100'-500'
	b. Temperature	I	3. 14 mu	100'-1000'
	c. Spectral signature	S	0.4-14 mu	100'-500'
13. Cataloging of features of reclaimable areas, and assessment of reclamation measures.	a. Boundaries and topography	I P	0.4-3 mu 1 mu	100'-500'
	b. Color, texture of associated soils	I	0.4-3 mu	100'-500'
	c. Spectral signature of associated soil and vegetative cover	S	0.4-14 mu	20'-100'
	d. Soil moisture/salinity/reflectivity	S P	0.4-14 mu 0.3-0.6 gc	20'-200' 20'-200'
	e. Associated meteorological phenomena	R T	0.5-10 gc -	20'-200' -
14. Location and survey of potentially usable lands.	a. Boundaries and topography	I P	0.4-3 mu 1 mu	10'-200' 10'-200'
	b. Color, texture of associated soil and vegetative cover	I	0.4-3 mu	100'-500'
	c. Spectral signature of associated soil	S	0.4-14 mu	100'-500'
	d. Soil moisture/salinity reflectivity	S P	0.4-14 mu 0.3-0.6 gc	100'-1000' 100'-1000'
	e. Associated meteorological phenomena	R T	0.5-10 gc -	100'-1000' -

TABLE 6 (Cont.)

Selected Knowledge Requirements	Indicative Phenomena	Estimated Sensing Requirements		
		Mode	Spectral Band	Resolution
15. Cataloging of soil fertility and environmental characteristics.	a. Color, tone texture	I	0.4-3 mu	50'-500'
	b. Physiographic, cultural related features	I	0.4-3 mu	50'-500'
	c. Associated vegetative cover, type, and vigor	I	0.4-3 mu	10'-100'
		S	0.4-3 mu	10'-100'
	d. Slope, drainage pattern, moisture content, dielectric constant	I	0.4-3 mu	20'-200'
		R	0.5-10 gc	10'-100'
		P	0.3-0.6 gc	20'-200'
	e. Energy budget	I	3. 14 mu	100'-500'

of any terrain complex is extensive. The quantity of positive or negative evidence which can be obtained by a skilled interpreter can provide answers or at least a basis for judgement of many questions. For example, a study was undertaken by the University of California to evaluate the feasibility of identifying significant wildland terrain features from aerial photography[27]. Table 7 lists the targets and their photo-identification capability as a function of photo scale (1:10,000; 1:30,000) and film. Nearly all of the targets were identifible using Ekta Aero IR film. Considerable terrain information could be obtained regarding vegetation, rocks and minerals, and even soil types. The classification of targets ranged from the "precise" (Dubakella soil series) through the "intermediate" (hardwoods) to broad (Aquatic vegetation). Occasionally a broad classification was tightened temporally or functionally, e.g., vegetation not in leaf or aquatic vegetation. The reader should note the classification of targets and what can be reasonably deduced from imagery with some experience in the world. There is a preponderance of geometric or form/pattern recognition and secondary inference. For example, the term granitic could be assigned by inference from visual observation knowing something of the geology of the region, e.g., whether granitic, metamorphic, or sedimentary structure is dominant. Interpreters knowledgeable in the earth sciences for exploration purposes are quite use to associating ancillary information with anomalous terrain conditions which can be traced to some extent in three dimensions and sometimes in the fourth and arriving at a reasonable valid judgement of nature. The point being, if a terrain complex can be seen, a great deal can be said - experience and ancillary information associated with the targets and environment being primary factors in judgement. The next section presents the planned experiments in target discrimination and identification for the Orbiting Research Laboratory (ORL).

TABLE 7[27]

FEASIBILITY OF IDENTIFYING SIGNIFICANT WILDLAND TERRAIN FEATURES ON AERIAL PHOTOGRAPHY

	Photo Scale and Film								
	1/10, 000					1/30, 000			
Terrain Features	Code	Pan	Aero IR89B	Ekta	Aero IR	Pan	Aero IR	Ekta	Aero IR
VEGETATION									
Mature conifers	11	++	++	++	++	+	+	++	++
Intermediate-aged conifers	12	++	++	++	++	+	+	+	++
Young conifers	13	++	++	++	++	-(+)	+	+	++
Hardwoods	14	+	++	++	++	-	-(+)*	-(+)*	+(++)*
Open brushfields	15	++	+	++	++	++	+	++	++
Riparian vegetation	16	+	++	++	++	+	+	+	++
Aquatic vegetation	17	+	++	++	++	+	++	++	++
Meadow or grassland	18	++	++	++	++	+	+	+	++
Sparse or drying vegetation less than 3' high	19	-	-	+	++	-	-	-	+
Vegetation not in leaf	21	-	-	+	++	--	--	+	++
Herbaceous vegetation in standing water	22	-	++	+	++	-	+	+	++
Sprayed brushfields	23	+	0	++	++	0	-	++	++
Dead or dying vegetation greater than 3' high	24	-	+	+	++	-	-	+	++
Snags or other downed timber	25	+	--	++	++	+	--	+	++
Burned areas	26	+	++	+	++	-	+	+	++
Windrowed brush	27	++	++	++	++	++	++	++	++

Legend: ++ generally and easily identifiable   - inconsistently identifiable
+ generally identifiable, but often   -- unidentifiable
requiring a trained interpreter   0 no example

*Larger stands of hardwoods are more readily identified

TABLE 7[27] (Cont.)

	Photo Scale and Film								
	1/10,000					1/30,000			
Terrain Features	Code	Pan	Aero IR89B	Ekta	Aero IR	Pan	Aero IR	Ekta	Aero IR
WATER: STANDING WATER, RIVERS, SNOW									
Deep ponds or lakes	31	++	++	++	++	+	++	++	++
Shallow lakes or marshy ponds	32	+	++	+	++	+	++	+	++
Streams, rivers, ditches	33	+	++	+	++	-(+)	++	+	++
Snow	34	++	++	++	++	++	++	++	++
ROCK & MINERAL									
Granitic outcrop covered with black lichens	41	+	++	+	++	-	+	-	++
Granitic outcrop without lichen cover	42	++	-	++	++	+	+	-	++
Granitic talus	43	++	-	++	++	+	-	+	++
Serpentine rock or peridotite outcrop	44	+	-	+	++	-	-	-	+
Gravel bars	45	++	-	++	++	++	-	++	++
SOILS									
Black meadow soil	51	+	-	+	++	-	-	+	++
Cornutt series	52	-	-	++	+	-	-	+	+
Dubakella series	53	+	-	++	++	-	-	+	+
Forward series	54	+	+	+	+	-	+	-	-
Cohasset series	55	+	-	+	+	-	-	-	-
Josephine series	56	-	+	+	+	-	-	-	-
Corbett series	57	-	-	+	+	-	-	-	-

TABLE 7^{27} (Cont.)

		Photo Scale and Film							
		1/10, 000				1/30, 000			
Terrain Features	Code	Pan	Aero IR89B	Ekta	Aero IR	Pan	Aero IR	Ekta	Aero IR
CULTURAL FEATURES									
Paved asphalt roads	61	++	+	++	++	+	+	++	++
Dirt surface roads	62	++	+	++	++	+	-	++	++
Areas of harvested timber	63	++	-	++	++	+	-	+	++
Dams	64	++	++	++	++	+	+	++	++
Irrigated pastures	65	+	++	++	++	+	+	+	++
Dredge mine tailing	66	++	+	++	++	+	-	+	++

2.3 PLANNED AGRICULTURAL/FORESTRY REMOTE SENSING EXPERIMENTS

As part of the Orbiting Research Laboratories (ORL) experimental program of NASA the following experiments[8] for agricultural/forestry target discrimination and identification evaluation have been planned.

Experiment 1:[8]

Identification of Wheat - Location and Identification of Major Cultivated Corps

Objective: To recognize and identify different species of wheat in selected ground truth sites, principally in the U. S., and to measure area of wheat fields. This is the first phase in achieving the capability of surveying wheat on a global basis.

Expected Results: (1) Measures of effectiveness and limitations -- probability of detection, false alarm rate, sensitivity of obliquity and atmospheric conditions -- of black and white and multispectral sensing, from orbit, of wheat fields of different species. (2) Variations in effectiveness of identification and field area measurement, as a function of stage of growth. (3) Perfected procedures for pointing sensors and for quick-look, on-board analysis of data.

Relation to Other Experiments: Other experiments cover oats, barley, rice, corn potatoes, and other crops determined to be economically significant.

Description of Experiment: Collect multispectral imagery, spectrometry, and photometry data over at least two ground truth sites in the U. S. Perform observations at obliquities from 0° to 45°, at selected sun angles from 5° to 90°. Evaluate astronaut-assisted sensor pointing and cloud dodging. Imagery and data will be partially processed aboard ORL, looking for unusual effects requiring immediate checking of conditions of ground truth sites. Evaluate automatic spectral-matching techniques.

Mission and Orbital Characteristics:

Inclination: 45°; 30° acceptable

Altitude: 150 to 250 n.m.

Orbital Eccentricity: Circular orbit preferred

Flight Duration: 45 days preferred; two weeks marginally acceptable

Equipment:

Unit	Aperture	Characteristics Frequency/ Spectral Band	Wt(lb)	Vol(ft^3)	Power (W)
Photographic camera	38"	0.4-0.9 mu	1500	100	500
Multispectral camera	2"	0.4-1.2 mu	75	2.5	75
Panoramic camera	4.3"	0.4-0.9 mu	300	18	620
Visible spectrometer	16"	0.3-3 mu	100	3	30
IR spectrometer	16"	3-15 mu	80	3	30
Synthetic aperture radar	300"x36"	0.5, 8 Gc	1050	60	17,500
Laser altimeter	41"	1.061 mu	200	15	1,200
Total			3305	201.5	19,955

Experiment: 2

Identification of Major Coniferous Forest Stands, Location of Forest Resources and Identification of Composition by Type

Objective: To recognize, identify and differentiate different species of conifers over selected ground truth sites in the U. S. and North America and to determine the areal extent of the specific conifer stands. Currently selected ground truth sites include forests in the Buck's Lake, California, conservation area. This is a preparatory phase to the achievement of a global inventory of major forests and estimation of the value of global forest resources.

Expected Results: (1) Experimental verification of the techniques and equipment required for the identification and estimate of the areal extent of major stands of coniferous forests. (2) Determination of the effect of coniferous tree species, seasonal variation, time-of-look, and illumination on sensor effectivity. (3) Verification and specification of optimal sampling sizes as a function of forest species content. (4) Perfected procedures for pointing/tracking, quick-look and on-board data reduction analysis. (5) Delineation of the relation of species composition of forest stand to spectral signature and the limitations imposed by orbital characteristics on spectral differentiation techniques. (6) Relationship between forest types and synoptic correlative measures not discernible from the ground or aircraft.

Relation to Other Experiments: Other experiments involve deciduous stands, tropical hardwood stands, and other forest classifications of economic import.

Description of Experiment: Collect data by multispectral imagery, spectrometry, and photometry over at least two selected ground truth sites in North America. This information is required to determine the areal extent and composition of major coniferous forests by determining color, texture, color contrast, spacing pattern, elevation and spectral signatures. The observations are to be obtained with variations in sensor obliquity from 0-45° and at selected sun angles from 10°-90°. Simultaneous information on the climatology of the ground truth sites, particularly cloud cover, will be obtained to assess the capability of the astronaut to effectuate sensor pointing, cloud dodging, and optimal data acquisition from "targets of opportunity". Images and data will be partially processed on board the ORL.

Mission and Orbital Characteristics:

Inclination: 50° preferred; 30° acceptable

Altitude: 100-300 n.m.

Orbital Eccentricity: Circular orbit preferred

Flight Duration: 45-day flight desired to include maximum data on foliage change due to seasonal variations. Minimum of two flights required, one in local summer and one in local winter.

Equipment:

		Characteristics			
Unit	Aperture	Frequency/ Spectral Band	Wt(lb)	Vol(ft^3)	Power (W)
Photographic camera	16"	0.4-0.9 mu	420	35	300
Multispectral camera	2"	0.4-1.2 mu	75	2.5	75
Panoramic camera	4.3"	0.4-0.9 mu	300	18	620
Visible spectrometer	Share 16"	0.3-3 mu	100	3	30
IR spectrometer	Share 16"	3-15 mu	80	3	30
Synthetic aperture radar	2 Freq 300"x36"	0.5, 8 Gc	1050	60	17,500
Laser altimeter	41"	1.061 mu	200	15	1,200
Total			2225	136.5	19,755

Experiment: 3

Estimate of Vigor Loss in Oats Due to Disease/Infestation, Estimation of Crop Vigor and Yield

Objective: To recognize and identify various strains of oat diseases and determine the areal extent, and rate of growth of diseased plants/fields. To verify deployment and operation previously investigated by conventional aircraft to several disease inoculated test sites in the U. S. and South America.

Expected Results: (1) Experiment verification of the ability to detect major oat and other cereal crop diseases from orbit by remote observation techniques. (2) Evaluation of the effect of ORL operation on the sensitivity of the assessment of oat diseases (e.g., Puccinia Graminis, Phytophthora Citrophthora) by inversion of the IR reflection characteristics of the leafy structure of the plants. (3) Determination of the functional effectiveness of the sensor/experimental techniques -- probability of detection, false indication, areal precision, specific disease indication, climatological interference, and sensitivity of obliquity/illumination and atmospheric interence. (4) Variations of feasibility of detection as a function of season species, and stage of growth. (5) Estimates of the optimal sampling areas.

Relation to Other Experiments: This experiment is one of a large number to determine a global inventory of agricultural productivity. The experiment is also directly related to damage assessment of infestations. Other similar experiments include determination of vigor loss in the other cereal crops -- wheat, barley -- as well as other economically significant cultivated crops.

Description of Experiment: Loss of vigor in cereal crops, particularly oats, is conventionally determined by photographically recording foliage reflectance in the near IR region. Eventually cereal diseases lead to reduction in chlorophyll content of the leafy structure and to correlative unmasking of the yellow pigments. The experiment would consist of obtaining data by multispectral imagery, photometry, and spectrometry from at least four distributed, disease inoculated test sites in the U. S. and two sites in South America (probably Argentina, with the compliance of the Argentine government). Later experiments would consist of variations in the inoculated pathogenic disease agent to evaluate the feasibility of determining the agents responsible for loss of oat crop vigor. Equipment sensor variations within each experiment would consist of variations of sensor obliquity (0-45°), sun angle at time of observation (5-90°). Simultaneous assessment of test site climatological conditions would be required to aid in later data reduction and to permit evaluation of the effectiveness of the astronaut as regards on-board data reduction/analysis.

Mission and Orbital Characteristics

Inclination: 30°

Altitude: 100-300 n.m.

Orbital Eccentricity: Circular orbit preferred

Flight Duration: 30 days, to include variations due to growth stages

Seasonal Dependence: July 15 - August 1 northern latitudes;
December 15 - February 1 southern latitudes

Equipment:

		Characteristics			
Unit	Aperture	Frequency/ Spectral Band	Wt(lb)	Vol(ft^3)	Power (W)
Photographic camera	16"	0.4-1.2 mu	420	35	300
Panoramic camera	4.3"	0.4-1.2 mu	300	18	620
Multispectral camera	2.0"	0.4-1.2 mu	75	2.5	75
IR spectrometer	Share 16"	3-15 mu	80	3	30
IR scanner/ radiometer	12"	4-14 mu	250	13	400
Spectral matcher	12"	4-14 mu	250	13	400
Total			1375	84.5	1825

Experiment: 4

Estimation of Yield of the Douglas Fir Component of Major Coniferous Forests, Estimation of Vigor and Potential Forest Yield

Objective: To establish the quantity of the Douglas Fir constituency of major coniferous forests in selected ground truth sites in the U. S. and to estimate the growth level, stratification and quality of trees making up the forest stand.

Expected Results: (1) Experimental verification of the operations and techniques required for the identification and yield mensuration of the Douglas Fir component of coniferous forests. (2) Determination of the masking effect of closely related species, seasonal variations, time-of-look, and illumination on sensor effectiveness. (3) Verification and specification of optimal sampling size as a function of forest constituency. (4) Perfected procedures for pointing/tracking, quick-look, and on-board data reduction/analysis. (5) Delineation of the relation of species composition of forest stands to spectral signature, particularly of Douglas Fir species, and limitations imposed by orbital characteristics on spectral differentiation. (6) Relationship between forest type and synoptic correlative measures not discernible from the ground or aircraft.

Relation to Other Experiments: This experiment is one of the experiments which are jointly required to determine the forest product potential of the world. Other experiments include similar techniques for the determination of yield of forest components such as Ponderosa Pine, Oak, Hemlock, Maple. This experimental technique must be preceded by successful demonstration of the orbital capability to identify specific forest constituents, particularly Douglas Fir.

Description of Experiment: There are four reliable indicators of timber stand volumes: (1) photogrammetrically estimating the volume of each species constituting forest stands, (2) photogrammetrically estimating the volume/unit area of the timber stand, (3) ocularly or photogrammetrically comparing the image of an individual tree or stand with previously calibrated volume standards, (4) delineating on remote sensing imagery the boundaries of timber stands within which conditions indicative of volume appear to be homogeneous. Canopy height and density, respectively, are the best primary and correlative indicators of Douglas Fir timber content. Remote measurement requires a wavelength which (a) is sufficiently short (approximately 60 cm) to resolve the dimensions of a mature tree, (b) is sufficiently short to bounce off canopy top (approximately 5 cm), and (c) is sufficiently long to penetrate the canopy and bounce off the ground (approximately 50 cm.). The experiments will consist of collecting multi-spectral imagery, spectrometry, and photometry over at least two ground truth sites in North America. The observations will be performed with variations in sensor obliquity (0-45°) and at selected sun angles (5-90°). Images and data will be partially processed on-board ORL.

Mission and Orbital Characteristics:

Inclination: 50°, 30° acceptable

Altitude: 100-300 n.m.

Orbital Eccentricity: Circular orbit preferred

Flight Duration: 45-day flight desired to include maximum data on foliage change due to seasonal variation. Minimum of two flights required, one in local summer, one in local winter.

Equipment:

		Characteristics			
Unit	Aperture	Frequency/ Spectral Band	Wt(lb)	Vol(ft^3)	Power (W)
Photographic camera	38"	0.4-0.9 mu	1500	100	500
Multispectral camera	2"	0.4-1.2 mu	75	2.5	75
Panoramic camera	4.3"	0.4-0.9 mu	300	18	620
Visible spectrometer	16"	0.3-3 mu	1100	3	30
IR spectrometer	16"	3-15 mu	100	3	30
Synthetic aperture radar	300"x36"	0.5, 8 Gc	1050	60	17,500
Laser altimeter	41"	1.061 mu	200	15	1,200
Total			3305	201.5	19,955

Experiment: 5

Forest Energy Budget, Discovery of Ecological Relationships

Objective: To investigate by synoptic data gathering the gross ecological relationships which govern the distribution of biological materials and energy balance relations of the environment in loco.

Expected Results: (1) Assessment of the capability to remotely gather data concerning energy interchanges within forested areas. (2) Variations in effectiveness of identification of factors involved in ecological energy interchanges via remote PI means. (3) Perfected procedures for pointing/tracking and for quick-look, on-board analysis of data.

Relation to Other Experiments: This experiment is one of several principal experiments which, if successful, will yield greater insight into problems related to the understanding of global ecological phenomena. Other principal experiments include determination of total biomass and determination of the rate of change of insolative pressures relative to latitude and seasonal variation.

Description of Experiment: Collect multispectral imagery, spectrometry, and photometry data over at least two ground truth sites in the U. S. Perform observations at obliquities from 0-45°, at selected sun angles from 5-90°. Evaluate astronaut-assisted pointing of sensors and cloud dodging. Images and data will be partially processed on board the ORL, looking for unusual effects requiring immediate checking of conditions of ground truth sites. Of particular importance is the evaluation of automatic spectral-matching techniques.

Mission and Orbital Characteristics:

Inclination: 45°, 30° acceptable

Altitude: 100-300 n.m.

Orbital Eccentricity: Circular orbit preferred

Flight Duration: 14 days

Equipment:

		Characteristics			
Unit	Aperture	Frequency/ Spectral Band	Wt(lb)	Vol(ft^3)	Power (W)
Photographic camera	16"	0.4-1.2 mu	420	35	300
Panoramic camera	4.3"	0.4-1.2 mu	300	18	620
Multispectral camera	2"	0.4-1.2 mu	75	2.5	75
IR scanner/ radiometer	12"	4-14 mu	250	13	400
IR spectrometer	Share 16"	3-15 mu	80	3	30
Spectral matcher	12"	.35-14 mu	200	12	500
Total			1325	83.5	1925

Experiment: 6

Detection of Major Herds of Migrating Caribou, Location, Identification, Count, and Determination of Migration Patterns of Important Wild Life

Objective: To detect and locate major migrating herds of caribou and to determine appropriate methods of search, minimum size of group that can be detected, and ability to estimate herd size.

Expected Results: (1) Measures of the effectiveness and limitations of the experimental techniques -- probability of detection, false identification rate, species differentiation, sensitivity to obliquity, and prevailing atmospheric conditions. (2) Variations in the effectiveness of identification as a function of season and herd size. (3) Determination of related measures of herd migration, e.g., forage availability, ice/snow conditions. (4) perfected techniques for astronaut visual search and on-board data reduction/analysis.

Relation to Other Experiments: This experiment is related to experiments on mapping and identification of vegetation, observation of vegetation and moisture conditions of water -- fowl wintering and breeding areas, rangeland, etc., and provides associated information to assess breeding conditions and range carrying capability. This experiment is also related to other experiments such as location of musk oxen and geese.

Description of Experiment: Photographic multispectral scanners and infrared mappers will be used for identification of migrating caribou herds. Caribou herds could be observed by photo interpretation techniques, but multispectral and infrared sensors could possibly provide enhanced indication of the presence of caribou herds in estimating herd size and further provide negative detection capability. Methods of restricting search areas to likely locations are also required.

Mission and Orbital Characteristics:

Inclination: Polar preferred; greater than 50° acceptable

Altitude: 100-300 n. m.

Orbital Eccentricity: Circular orbit preferred

Flight Duration: 30 days during migration period.

Equipment:

Unit	Aperture	Characteristics Frequency/ Spectral Band	Wt(lb)	Vol(ft^3)	Power (W)
Photographic camera	38"	0.4-1.2 mu	1500	100	500
Panoramic camera	4.3"	0.4-1.2 mu	300	18	620
Multispectral camera	2"	0.4-1.2 mu	75	2.5	75
Microwave radiometer	360"	10 Gc	450	30	50
IR scanner/ radiometer	12"	4-14 mu	250	13	400
IR spectrometer	16"	3-14 mu	80	3	30
Spectral matcher	12"	.35-14 mu	200	12	500
Total			2855	178.5	2175

Experiment: 7

Insect Infestation of Major Forest Stands, Location, Identification, and Determination of Migration Patterns Of Animal Pests and Insects

Objective: To recognize and identify different insect infestation prevalent in the major forest stands, principally in North America, and to measure the area of infestation and rate of growth of the infested area.

Expected Results: (1) Experimental verification of the capability to detect pertinent insect infestation, of which the major forests are prey, from orbit via remote means. (2) Evaluation of the effect of ORL operation on the sensitivity of the determination of the particular infesting agent by direct observation of swarm characteristics where possible and by indirect indicators such as inversion of IR reflectance. (3) Determination of the functional effectiveness of the sensor/experimental techniques -- probability of detection, false indication, climatological interference, areal precision identify of specific infesting agent, and sensitivity to obliquity/illumination and atmospheric interference. (4) Variation in the feasibility of detection as a function of season, forest constituency, and forest stage of growth. (5) Estimates of optimum sampling requirements.

Relation to Other Experiments: This experiment is one of several experiments which are required for making a continuous global inventory of agriculture/forestry productivity. It contributes to a general category in which all insect infestations in forests are combined. Similar experiments for insect infestation of cultivated crops are also required.

Description of Experiment: Collect multispectral imagery, spectrometry over at least two insect inoculated ground test sites in the North American continent. Perform observations with variations in sensor obliquity (0-45°), sun angle 5-90°, and insect infesting agent. Evaluate astronaut-controlled pointing/tracking, cloud dodging, and on-board data reduction/analysis. Evaluate automatic spectral matching techniques.

Mission and Orbital Characteristics:

Inclination: 50° preferred; 45° acceptable

Altitude: 100-300 n.m.

Orbital Eccentricity: Circular orbit preferred

Flight Duration: 14 days

Equipment:

		Characteristics			
Unit	Aperture	Frequency/ Spectral Band	Wt(lb)	Vol(ft^3)	Power (W)
Photographic camera	38"	0.4-1.2 mu	1500	100	500
Panoramic camera	4.3"	0.4-1.2 mu	300	18	620
Multispectral camera	2"	0.4-1.2 mu	75	2.5	75
Microwave radiometer	360"	10 Gc	450	30	50
IR spectrometer	16"	3-14 mu	80	3	30
Spectral matcher	12"	.35-14 mu	200	12	500
Total			2605	165.5	1775

Experiment: 8

Forest Fire Detection, Identification and Location of Forest Fires

Objective: To determine the feasibility of early detection, location and surveillance of forest fires by use of infrared scanners. Test should include sleeper fires and small fires, as well as large fires. Capability of early detection of forest fires could result in substantial reduction of fire losses. Need for forest fire detection is greatest in developing countries, but must be accompanied by improved fire fighting capability. These experiments should be performed over selected North American ground truth sites.

Expected Results: (1) Measures of the probability of detection of small and/or sleeper fires. (2) Assessment of detection sensitivity as affected by obliquity, cloud cover, illumination cycle, day-night observation. (3) Determination of false alarm rates as a function of fire size, temperature, coverage of adjacent foliage. (4) Determination of capability to measure fire growth rate and areal extent. (5) Perfected on-board procedures for pointing/tracking, quick-look, and ground reporting.

Relation to Other Experiments: This experiment constitutes one of the four major elements of the ORL subobjective - Reduction of Loss due to Meteorological and other Calamitous Events.

Description of Experiment: Infrared mappers will detect infrared energy radiated by forest fires. Detection of "sleeper" fires or small fires, especially with forest canopy interference, may limit the effectiveness of infrared detection. Small fires are estimated to have spot diameters of about 60 feet with average temperature gradients of 2°K. Infrared mapping should be supplemented with radiometry to provide a more thorough analytical basis for interpretation. Use of the 4.5 - 5.5μ wavelength band should reduce thermal noise associated with natural backgrounds.

Mission and Orbital Characteristics:

Inclination : 50°

Altitude: 100-300 n.m.

Orbital Eccentricity: Circular orbit preferred

Flight Duration: 14-45 days

Equipment:

		Characteristics			
Unit	Aperture	Frequency/ Spectral Band	Wt(lb)	Vol(ft^3)	Power (W)
Photographic camera	6"	0.4-1.2 mu	250	12	200
Multispectral camera	2"	0.4-1.2 mu	75	2.5	75
Spectral matcher	12"	3-14 mu	250	13	400
IR scanner radiometer	12"	3-15 mu	250	13	400
IR spectrometer	16"	5-14 mu	80	3	30
Total			905	43.5	1105

Experiment: 9

Forest Fire Burn Survey, Assessment of Damage of Forest Fires

Objective: To identify and measure the areas of forests burned by forest fires in selected ground truth sites in the U. S. This is a preliminary phase in achieving the capability of forest yield determination on a global basis. Tests should include the determination of damage due to recent and past fires and the assessment of orbital and local environmental masking factors.

Expected Results: (1) Determination of the effectiveness of orbitally measuring the burn damage caused by small and large forest fires as indicators of potential yield decrease and as a direct aid in planning for reforestation measures. (2) Assessment of detection sensitivity as affected by obliquity, cloud cover, smoke masking, illumination angle and day/night observation capability. (3) Determination of the capability of measuring regrowth rate and areal extent. (4) Perfected on-board procedures for pointing/tracking, quick-look and ground reporting.

Relation to Other Experiments: This experiment constitutes one of the four major elements of the ORL subobjective - Reduction of Loss due to Meteorological and Other Calamitous Events.

Description of Experiment: Collect multispectral imagery, spectrometry, and photometry data over at least two ground truth sites in North America. Perform observations at obliquities ranging from 0-45° and at selected sun angles from 5-90°. Evaluate astronaut assisted pointing of sensors and cloud dodging. Imagery and data will be partially processed aboard the ORL, looking for unusual effects requiring immediate checking of conditions of ground truth sites. Evaluate automatic spectral matching techniques.

Mission and Orbital Characteristics:

Inclination: 50°

Altitude: 100-300 n.m.

Orbital Eccentricity: Circular orbit preferred

Flight Duration: 14-30 days

Equipment:

		Characteristics			
Unit	Aperture	Frequency/ Spectral Band	Wt(lb)	Vol(ft^3)	Power (W)
Photographic camera	6"	0.4-1.2 mu	250	12	200
Multispectral camera	2"	0.4-1.2 mu	75	2.5	75
Spectral matcher	12"	3-14 mu	250	13	400
IR scanner/ radiometer	12"	3-14 mu	250	13	400
IR spectrometer	16"	3-14 mu	80	3	30
Total			905	43.5	1105

Experiment: 10

Identification of Vegetative vs Non-Vegetative Areas, Cataloguing Features of Reclaimable Areas, and Assessment of Reclamation Measures

Objective: To develop techniques for differentiating vegetation and soil types, identifying gross crop and tree species, and grossly determining approximate areal extent. The techniques developed as a result of this experiment can be used as economic measures for obtaining data for agricultural census of reclaimable land areas both for domestic, but more importantly for agricultural planning in developing countries. Techniques developed will also be of direct use in determining energy budget and water budget data required in current studies by botanists, hydrologists and climatologists.

Expected Results: (1) Evaluation of photo interpretation and spectral matching techniques for distinguishing types of land use (woodlands, farmland, etc.) tree/crop species. (2) Methods for obtaining optimum sampling coverage of large, previously undifferentiated land areas relative to natural vegetative cover will be evaluated. (3) Measure of effectiveness and limitations on sensor performance, required sampling procedures. (4) Perfected procedures for pointing/tracking, quick-look and astronaut on-board data reduction/analysis.

Description of Experiment: Multilens cameras and optical-mechanical scanners will acquire multispectral imagery which will be used to test and evaluate photo interpretation and spectral matching methods for distinguishing types of land use (woodland, rangeland, farmland), tree and crop species, crop vigor, and moisture conditions. Radar and high resolution photography will also be used. Medium and high resolution photography will be evaluated as means for obtaining "sample" coverage of vegetated areas. Infrared scanners and radiometers will provide data for energy budget studies. Vegetation is to be identified primarily by spectral characteristics in the UV, visible and IR regions; microwave reflectivity is also a possible indicator. Recognition by shape or texture via radar is an attractive alternative. Observations will be performed at at least four ground truth sites in the U. S. Performance will be evaluated at various sensor obliquities $0-45^\circ$ and sun angles $5-90^\circ$.

Mission and Orbital Characteristics:

Inclinations: 45° preferred; 30° acceptable

Altitude: 100-300 n.m.

Orbital Eccentricity: Circular orbit preferred

Flight Duration: 30 days preferred; 14 days marginally acceptable

Equipment:

		Characteristics			
Unit	Aperture	Frequency/ Spectral Band	Wt(lb)	Vol(ft^3)	Power (W)
Photographic camera	16"	0.4-0.9 mu	420	35	300
Panoramic camera	4.3"	0.4-0.9 mu	300	18	620
Multispectral camera	2"	0.4-1.2 mu	75	2.5	75
IR scanner/ radiometer	12"	4-14 mu	250	13	400
Synthetic aperture radar	300"x36"	0.5, 8 Gc	1200	180	4000
Spectral matcher	12"	.35-14 mu	200	12	500
Dual channel reflectometer	2700"	300 & 600 mu	2660	260	185
Total			5105	520.5	6080

Experiment: 11

Determination of Soil Moisture Content of Agricultural Sites Related to Reclamation, Cataloging Features of Reclaimable Areas and Assessment of Reclamation Measures

Objective: To estimate the moisture content of soil and provide maps of soil moisture areal distribution over selected ground truth sites, principally in North America. This is an experiment which would provide the eventual capability of assessing adequate growing conditions for crops. It is also useful for hydrologic studies.

Expected Results: (1) Measurements of total moisture content of selected soil sites and depth of moisture penetration. (2) Measures of effectiveness and limitations of selected sensor systems -- probability of detection, capability for determining moisture penetration, sensitivity to orbital sensor constraints (illumination, obliquity), decreases in sensor effectiveness due to vegetative cover. (3) Variation of the sensor techniques as a function of time and season. (4) Perfected procedures for pointing/tracking and for on-board participation in data reduction/analysis.

Related to Other Experiments: Other experiments include boundary and topographic mapping, assessment of types and quality of associated vegetation and correlative climatology of reclaimable areas.

Description of Experiment: Soil moisture is measured by means of passive/active microwave techniques -- emission and reflection of microwave signals are influenced by soil moisture content. Direct observation of soil by multispectral imaging devices determines surface wetness. Indirect indication of moisture content by observation of color/condition of vegetation. Lists of soil/vegetation types, climatology, seasonal dependence, and range of moisture levels for each site will be done partially aboard ORL by astronaut direct observation and photo interpretation. Simultaneous direct measurement of soil moisture content at test site and correlative climatological measurements are required.

Mission Orbital Characteristics:

Inclination: 50° preferred; 45° or 30° acceptable

Altitude: 100-200 n.m.

Orbital Eccentricity: Circular orbit preferred

Flight Duration: 45 days

Equipment:

Unit	Aperture	Characteristics Frequency/ Spectral Band	Wt(lb)	Vol(ft^3)	Power (W)
Photographic camera	6"	0.4-1.2 mu	250	12	200
Multispectral camera	2"	0.4-0.9 mu	75	2.5	75
IR scanner/ radiometer	12"	4-14 mu	250	13	400
Spectral matcher	12"	.35-14 mu	200	12	500
Synthetic aperture radar	300"x36"	3, 10, 35 Gc	1050	60	17,500
Total			1725	99.5	18, 675

Experiment: 12

Survey of the Agricultural Effects of Soil Erosion, Cataloging of Soil Fertility and Environmental Characteristics

Objective: To estimate the effects of soil erosion on potential agriculture lands in selected sites in the U. S. This is an experiment which would ultimately provide the capability for assessming and preassessing adequate growing conditions for crops. It is also directly applicable to hydrologic surveys and studies.

Expected Results: (1) Measurement of the total moisture content, moisture inclination capability, and surface effects due to drainage and runoff. (2) Measures of effectiveness and limitations of selected sensor systems. Capability to determine moisture penetration, sensitivity to orbital constraints (illumination/obliquity), decreases in sensor effectiveness due to vegetative cover. (3) Variation of the sensor techniques as a function of time/season. (4) Perfected procedures for astronaut-controlled pointing/tracking and for on-board participation in data reduction/analysis.

Relation to Other Experiments: Other experiments include boundary and topographic delineation and temporal determination of the features of local climatology. It is also directly applicable to similar experiments in Geology/Hydrology.

Description of Experiment: Soil erosion effects and soil moisture can be measured by passive/active microwave techniques. Direct observation of soil and moisture/erosion sensitive vegetative cover by multispectral techniques is also feasible. Indirect indication of erosion action and moisture content by observation of color/condition of associated vegetation. Enumeration of associated soil types, vegetation types, climatology, seasonal variations and range of moisture level/erosion progress for each site can be partially determined aboard the ORL by astronaut direct observation and photo interpretation techniques. Simultaneous direct measurement of soil moisture/erosion progress at the test site and correlative climatological measurements are also required.

Mission and Orbital Characteristics:

Inclination: 45°

Altitude: 100-300 n.m.

Orbital Eccentricity: Circular orbit preferred

Flight Duration: 45 days

Equipment:

Unit	Aperture	Frequency/ Spectral Band	Wt(lb)	Vol(ft^3)	Power (W)
Photographic camera	6"	0.4-1.2 mu	250	12	200
Multispectral camera	2"	0.4-1.2 mu	75	2.5	75
IR scanner radiometer	12"	4-14 mu	250	13	400
Spectral matcher	12"	.35-14 mu	200	12	500
Synthetic aperture radar	300"x36"	10 Gc	1050	60	17,500
Total			1825	99.5	18, 675

2.4 TARGET RESOLUTION REQUIREMENTS FOR PHOTOINTERPRETATION

Considerable research effort is being given to human function in the photo-optical systems[10] for target discrimination and identification. Factors influencing the interpretation of imagery are:

- scale
- acuteness (sharpness)
- contrast
- ground resolution (spacial resolution)

It has been shown that the interpretability of imagery depends primarily upon scale and ground resolution and to a lesser extent, sharpness and contrast[2]. The effect of scale and ground resolution are approximately equal since both are a function of altitude.

The spacial resolution requirements for interpretation of terrain features and agricultural targets have been established by the U. S. Department of Agriculture[4]. Interpretation is taken to mean primarily discrimination and to some lesser extent identification (the latter by pattern recognition, secondary inference or the use of ancillary information). The targets and resolution requirements are given as follows:

- Resolution - 100 feet

  Timberline
  Waterline
  Snowline
  Grassland - brushland interface
  Brushland - timberland interface
  Grassland - timberland interface
  Bare soil - vegetation
  Individual fields ≥ 10 acres
  Major roads, railroads, waterways

- Resolution - 30 feet

  Mature orchard trees
  Dominant rain forest trees
  Fields ≥ 1 acre
  Farmstead
  Fence lines
  Damaged areas > 30 feet in diameter

- Resolution - 7 feet

  Woody vegetation density
  Tree counts
  Species of dominant trees
  Damaged areas $\gtrsim$ 7 feet in diameter
  Species of cover crops $\gtrsim$ 20 ft^2 (questionable)
  Drainage patterns
  Soil series boundaries
  Major soil series
  Soil moisture (difficult)
  Planimetric detailed mapping

An important aspect of these target ground resolution requirements are the limiting conditions imposed by resolution limits of the human eye as related to areal coverage on the film (Appendix B).

Using the Rayleigh criteria, the human eye can resolve two points with 100% contrast separated by approximately 1/254 inches or 10 lines/mm at a distance of 25 cm. A 9"x9" photographic frame could be divided by the eye into 9 x 254 or 2286x 2286 bits. Considering the 100 foot resolution limit, the effective limiting linear ground dimensions would be 2286 times 100 feet or 43.29 statute miles. Since system resolutions in excess of 100 lines/mm are available, the 9"x9" negative could cover an area 432.9 x 432.9 statute miles which would be enlarged at least 10 times to accommodate the limit of resolution of the eye. The ground coverage on a 9"x9" negative with ground resolution limits of 30 and 7 feet would be 130 x 130 and 30.3 x 30.3 statute miles respectively for a system resolution of 100 lines/mm and an enlargement of 10X to accommodate the limit of resolution for the unaided eye. These estimates of ground coverage compare favorably with those in Table 10, Chapter 4. In Chapter 5, swath widths for complete coverage of the United States at 200 nautical miles altitude polar orbit, are 1 degree longitude. One degree of longitude is 54.9 nautical miles and 38.7 nautical miles at 25° and 50° North latitude. A 60 nautical mile swath or field of view is compatible with a system ground resolution limit of 7-30 ft., reasonable photographic enlargement, and the over-all resolution requirements for the majority of targets discussed in this chapter.

Table 8 lists some approximate ground resolutions including stereoscopic requirements for a variety of forestry applications[28]. Resolution less than one foot at orbital altitudes are impractical requirements for an orbital sensing system since 1 ft. at 200 nautical miles altitude is .17 seconds of arc. Systems are film limited currently to one second of arc with a possible reduction to .1 arc second in 1975.

The preceding sections provide insight as to what can be seen or expected to be seen from orbital altitudes and the nature of the interpretive

TABLE 8[37]

APPROXIMATE GROUND RESOLUTIONS REQUIRED FOR VARIOUS FORESTRY APPLICATIONS OF REMOTE SENSING

Forestry Application	Required Ground Resolution		
	Gross Features 10 ft. diam.	Intermediate Features 1-10 ft. diam.	Detailed Features 1-12 in. diam.
Orientation Aids to Administration	X	x	x
Regional Inventories			
Estimates or maps of extent of forest only	x	x	---
Comprehensive estimates, area, volume and growth of timber	---	x 3d	---
Resource Management Inventories	x	X 3d	x 3d
Land Classification	x	X 3d	---
Development Plans	---	x 3d	x 3d
Product Volume Estimates	---	---	x
Protection Plans	---	x 3d	---
Damage Detection	x	x	X 3d
Pest Control	---	x 3d	x 3d
Timber Salvage Plans	---	x 3d	---
Timberland Value Appraisals	---	x 3d	---

Note: Where "3 d" is indicated, 3rd-dimensional resolution through measurable parallaxes is necessary to provide height determinations of trees and/or other vegetation, and/or microrelief. In such situations stereoscopic photography from relatively low altitudes is necessary. A large "X" indicates the most frequently desired resolution.

procedures for many of the possible applications. There remains the question of spacial dispersion of target members, the scale of potential observation available from orbital sensors,and the problems in transforming data into intelligence. Therefore, the next section will treat the spacial distribution of a primary potential target of importance - the major agricultural crops, worldwide distribution and specifically their distribution in the United States.

2.5 MAJOR AGRICULTURAL CROPS AND WORLDWIDE DISTRIBUTION

The earth has 52 million square miles of land excluding Antarctica. Crops are cultivated on about 5.5 million square miles or approximately 10% of the land mass. An estimated 15% to 20% or 9.4 million square miles is meadowland, pasture and rangeland available for livestock. The agricultural crops of interest distributed over this enormous area present a difficult data base for transformation into intelligence.

The ten major crops and their relative percentage of total 1964 yield is given in Figures 6 & 7 for the United States[12] and the World [11]. Appendix C shows the spacial distribution of these crops throughout the world. Figures 8, 9 and 10 show the distribution of the crops and cumulative value as a function of latitude. The latitude ranges are important to orbital specifications (Chapter 5), specifically the orbital inclination which defines the maximum latitude of coverage.

2.6 MAJOR CROP DISTRIBUTIONS IN THE UNITED STATES

There are four types of cropland acreage of interest to the USDA:

1. Crop acreage harvested
2. Crop acreage failure
3. Summer fallow
4. Cropland used for pasture

Corn, cotton, wheat and hay account for half the total value of U. S. crops. Grazing is the single largest use of agricultural acreage. To accommodate the census of this and other information, the United States is divided geographically into 10 farm production regions. Each state is divided into several crop reporting districts. Every county is included in the master sample plan and over 300, 000 farms are identified. Table 9 lists the region, states, state area, area in crops (1959), and per cent of state area in crops. The per cent in crops is important for preliminary estimates of target density with no allowance for geographical subclassification of the cropland within a state.

Target density information is presented in Figures 11 - 16 showing the acreage planted in corn, oats, barley, rye and potatoes. The totality of crop acreage need be determined as a primary intelligence of interest to the USDA and to the economy of the nation. The data representation of the figures

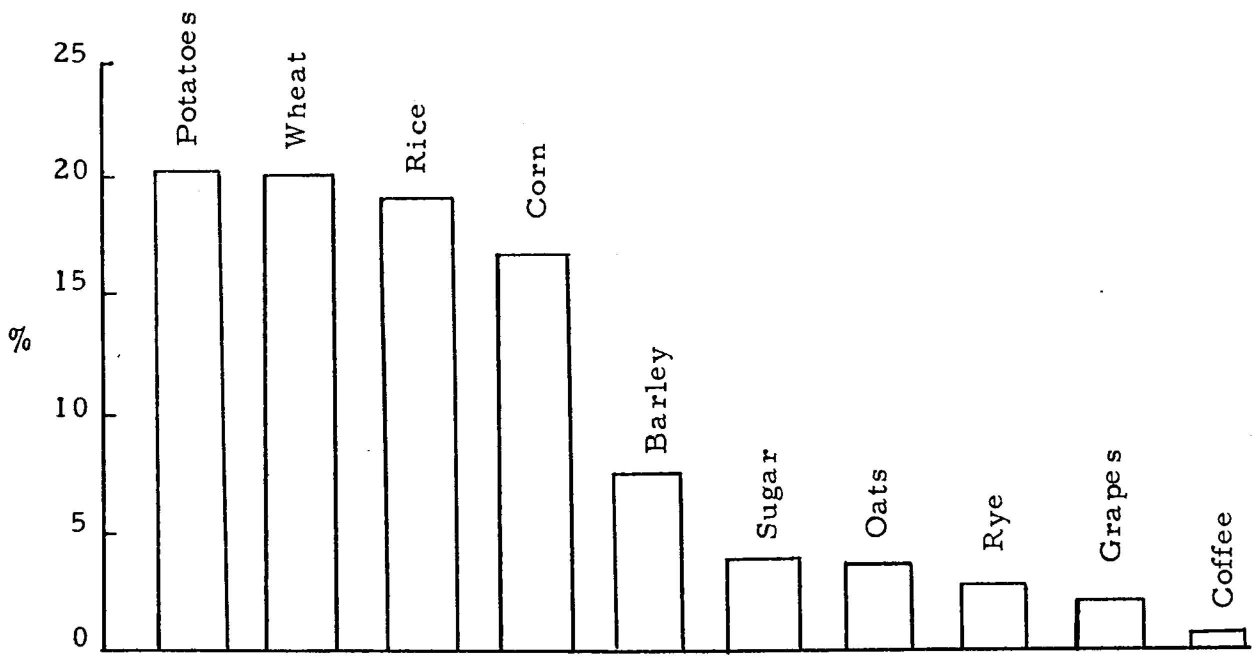


Figure 6 . The World's Ten Major Agricultural Commodities - 1964 Basis[11]

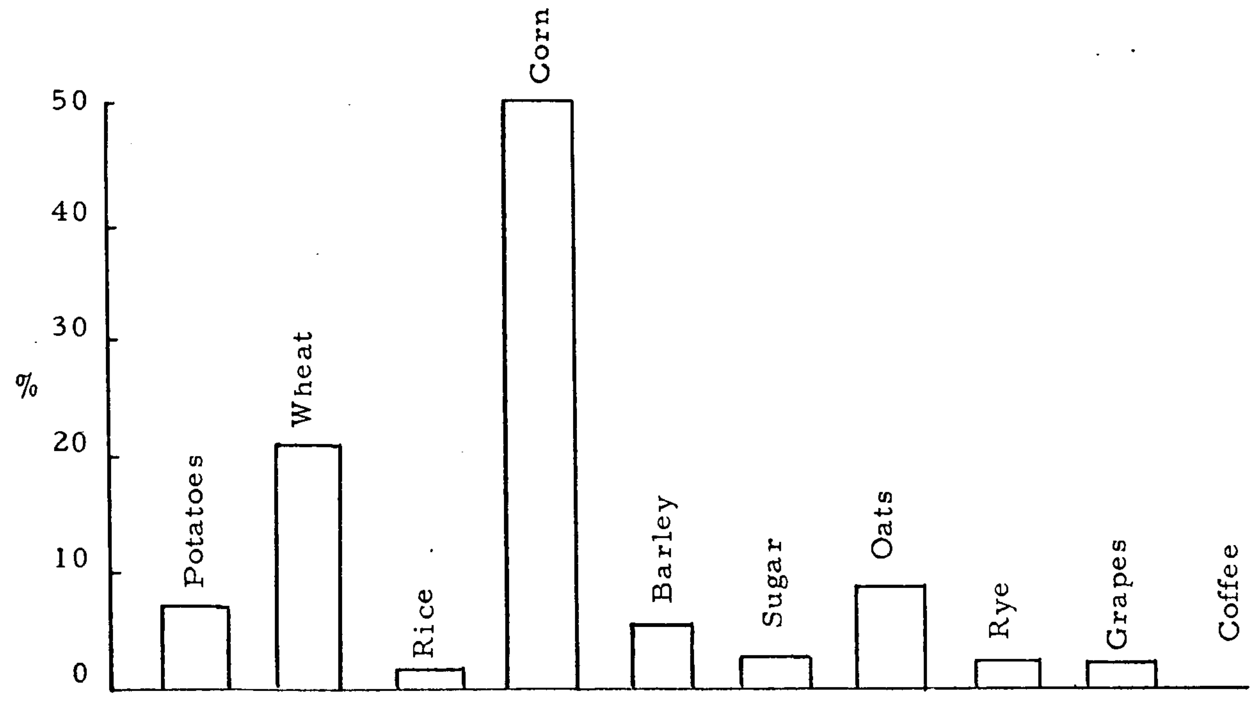


Figure 7 . U. S. Production of the World's Ten Major Agricultural Commodities (1964)[11]

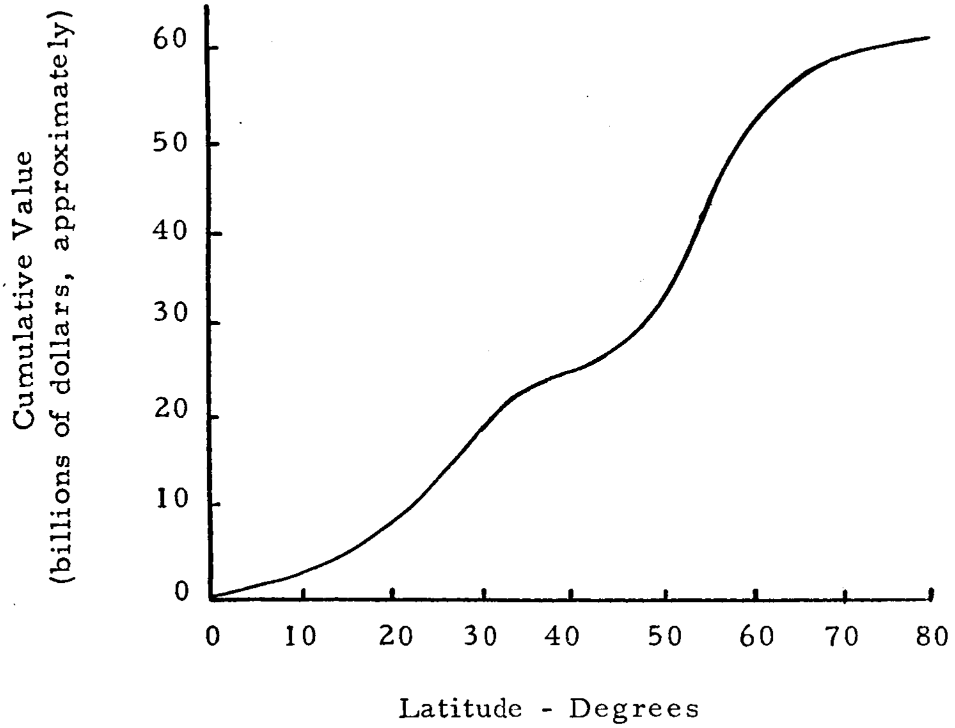


Figure 8.Cumulative Agriculture/Forestry Value vs Latitude[8]

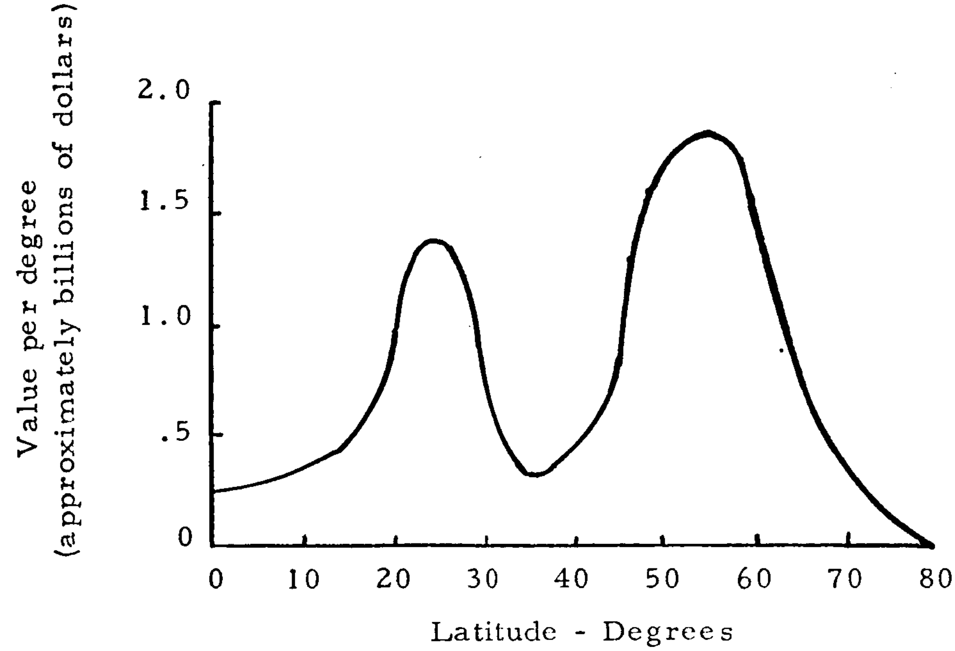


Figure 9 .Variation of Agriculture/Forestry Products Value with Latitude[8]

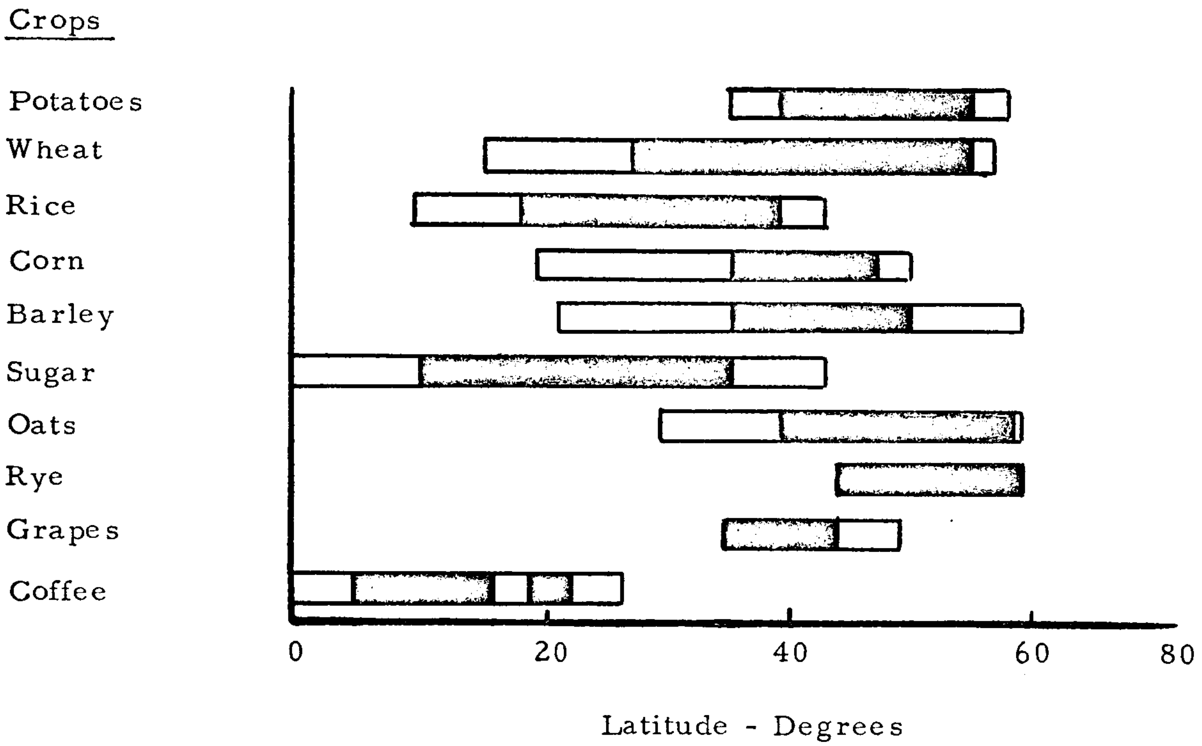


Figure 10. Agriculture Products as a Function of Latitude[8]

TABLE 9

FARM PRODUCTION REGIONS

	Total Acres 1000 acres	Cropland 1000 acres	% Area
PACIFIC			
Washington	43,643	6,914	15.8
Oregon	62,068	4,184	6.7
California	101,564	9,366	9.2
MOUNTAIN			
Montana	94,168	14,052	14.9
Idaho	53,476	5,004	9.4
Wyoming	62,665	2,075	3.3
Nevada	70,746	363	.5
Utah	54,346	1,362	2.5
Colorado	66,718	9,014	13.5
Arizona	72,902	1,258	1.7
New Mexico	77,862	1,275	1.6
NORTHERN PLAINS			
N. Dakota	45,226	26,480	58.6
S. Dakota	49,310	16,021	32.5
Nebraska	49,432	21,450	43.4
Kansas	52,657	27,218	51.7
SOUTHERN PLAINS			
Oklahoma	44,748	11,088	24.8
Texas	171,097	26,563	15.5
LAKE STATES			
Minnesota	53,804	19,404	36.1
Wisconsin	35,939	9,876	27.5
Michigan	37,258	7,388	19.8

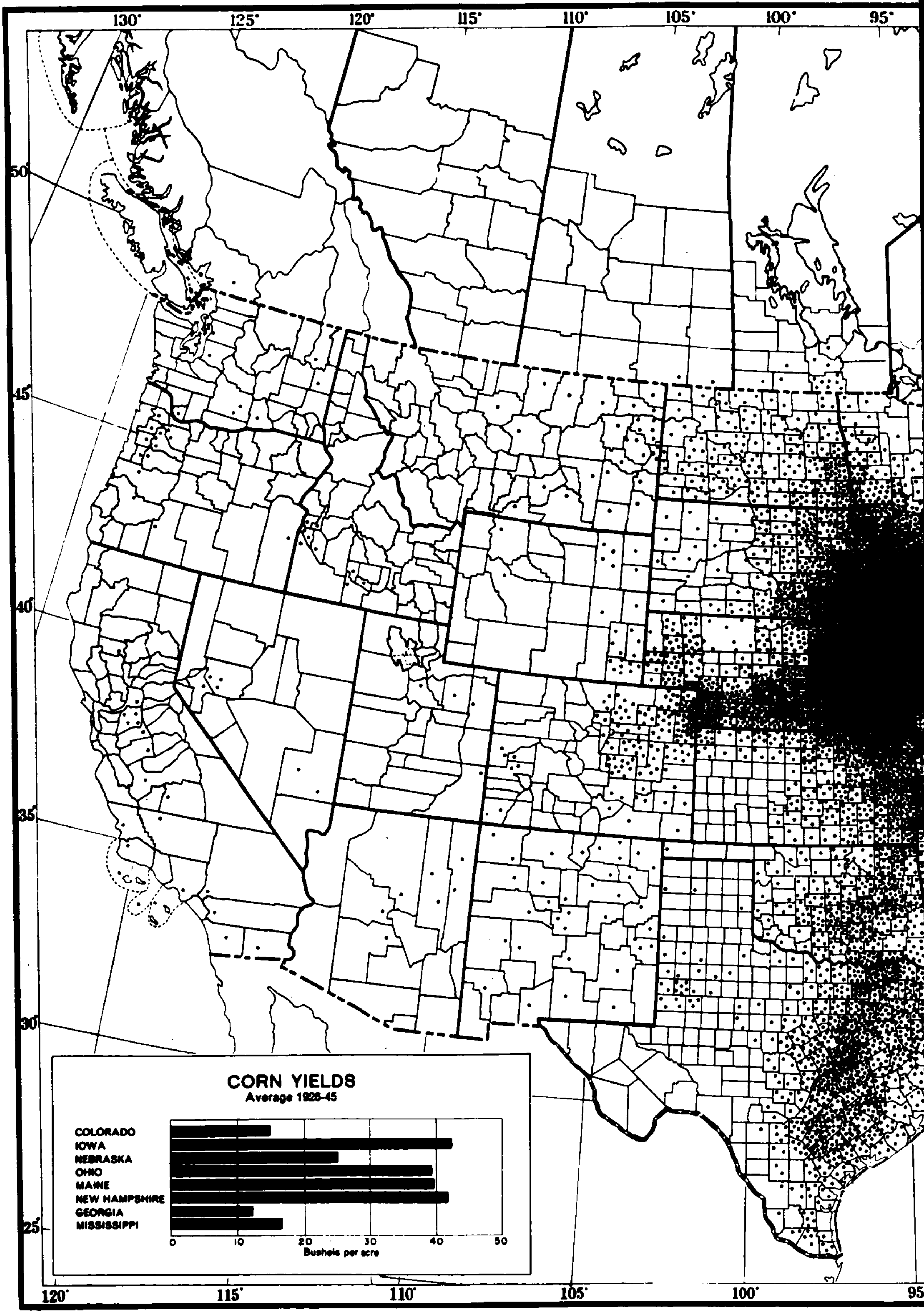
TABLE 9 (Cont.)

	Total Acres 1000 acres	Cropland 1000 acres	% Area
CORN BELT			
Iowa	36,019	23,424	65.0
Missouri	44,591	12,541	28.1
Illinois	36,096	21,380	59.2
Indiana	23,226	11,424	49.2
Ohio	26,382	10,045	38.1
DELTA STATES			
Arkansas	33,985	5,627	16.6
Louisiana	31,055	2,585	8.3
Mississippi	30,538	4,858	15.9
NORTHEAST			
Maine	21,258	717	3.4
New Hampshire	5,955	211	3.5
Vermont	6,150	761	12.4
Massachusetts	5,284	298	5.6
Rhode Island	777	35	4.5
Connecticut	3,206	246	7.7
New York	31,729	5,198	16.4
Pennsylvania	29,013	5,091	17.5
Maryland	6,769	1,504	22.2
Delaware	1,316	440	33.4
District of Columbia	44	---	---
New Jersey	5,015	688	13.7
APPALACHIAN			
West Virginia	15,476	863	5.6
Kentucky	25,853	4,209	16.3
Tennessee	27,037	4,280	15.8
Virginia	26,122	2,978	11.4
N. Carolina	33,736	5,101	15.1

TABLE 9 (Cont.)

	Total Acres 1000 acres	Cropland 1000 acres	% Area
SOUTHEAST			
Alabama	33,030	4,106	12.4
Georgia	37,681	5,451	14.5
S. Carolina	19,875	2,965	15.0
Florida	37,478	2,044	5.5

CORN



UNIVERSITY OF MARYLAND, DEPARTMENT OF GEOGRAPHY

70-1

FOLD-OUT #1

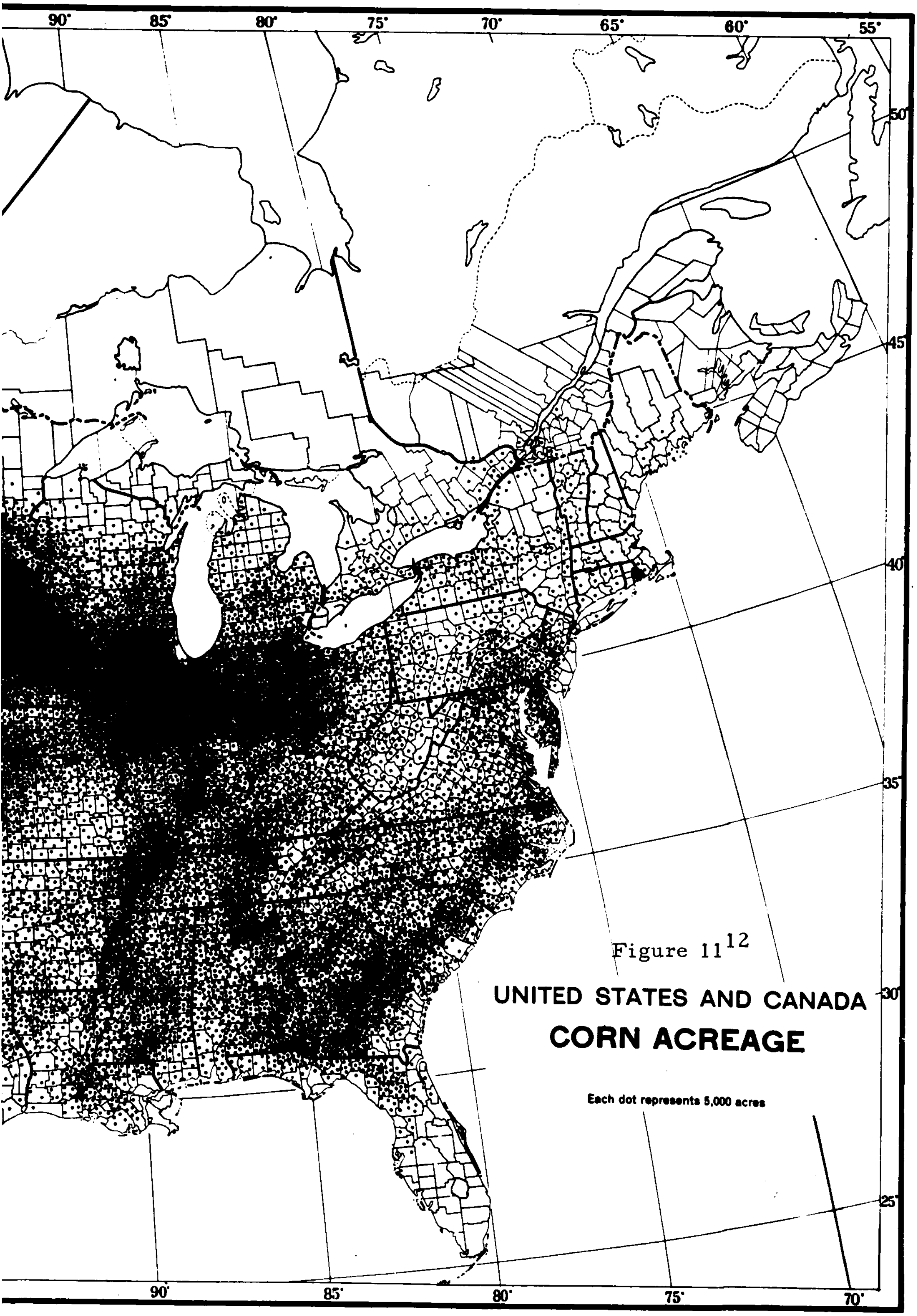
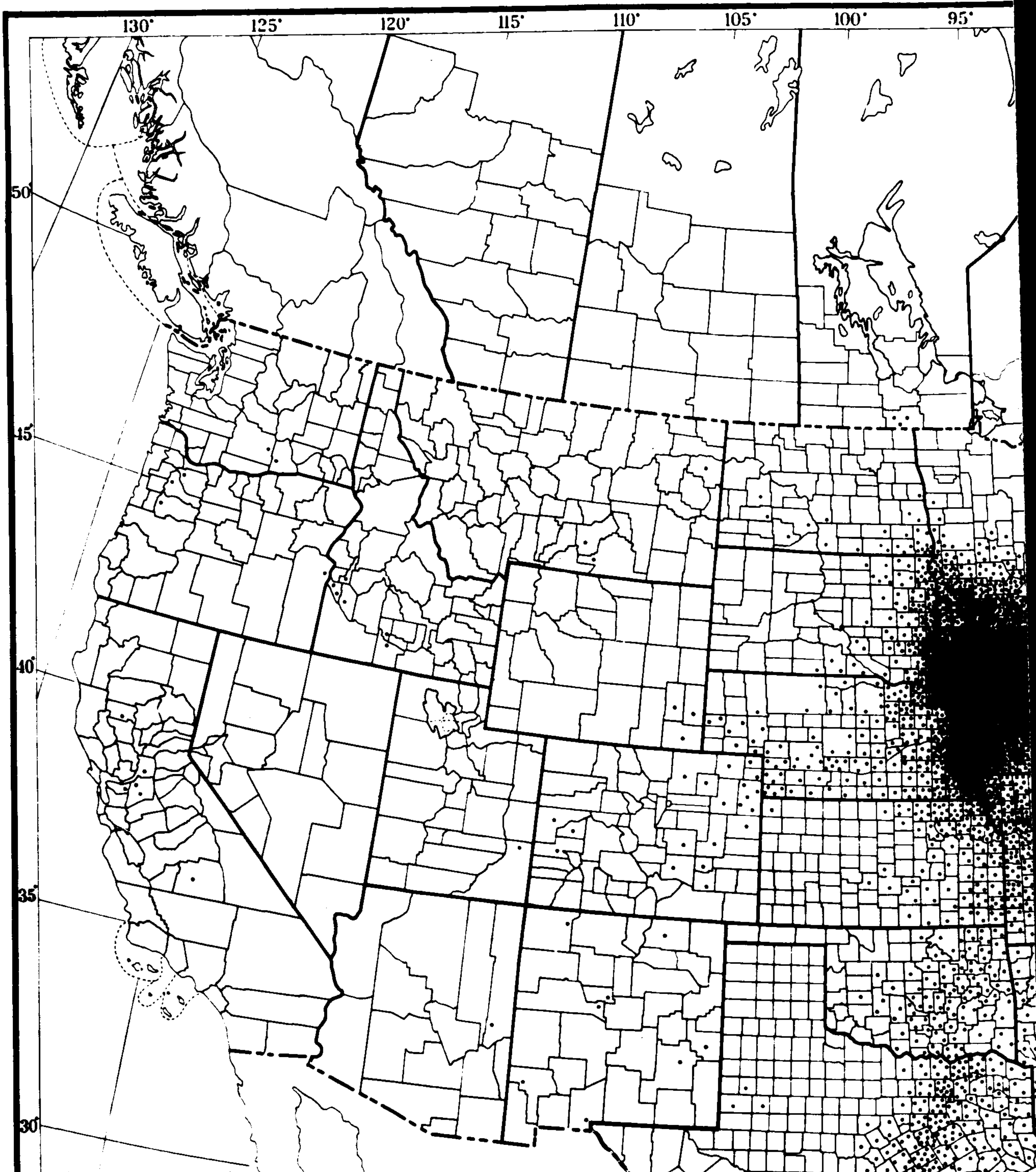


Figure 11[12]

UNITED STATES AND CANADA
CORN ACREAGE

Each dot represents 5,000 acres

FOLD-OUT #2



UNIVERSITY OF MARYLAND, DEPARTMENT OF GEOGRAPHY

FOLD-OUT #1

7/-1

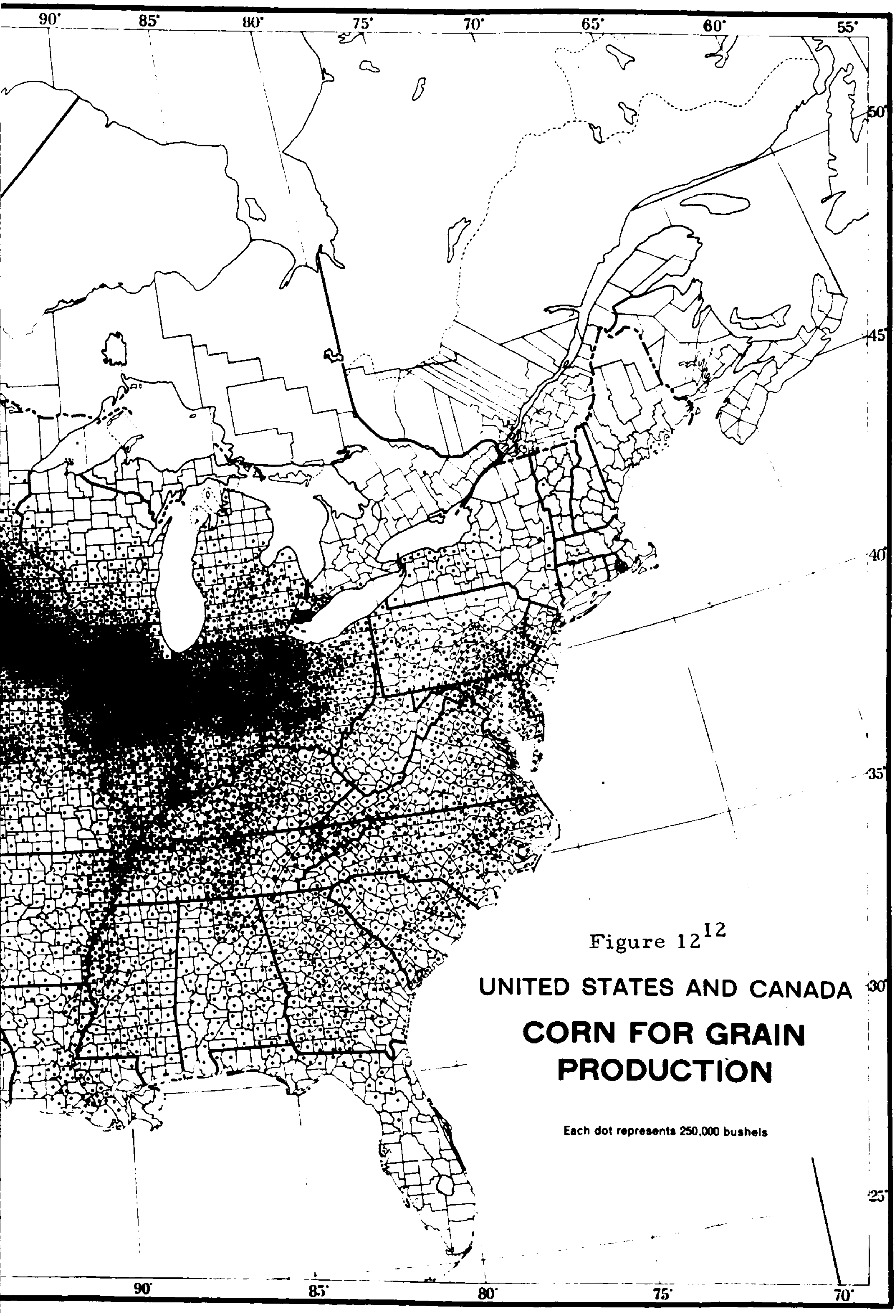


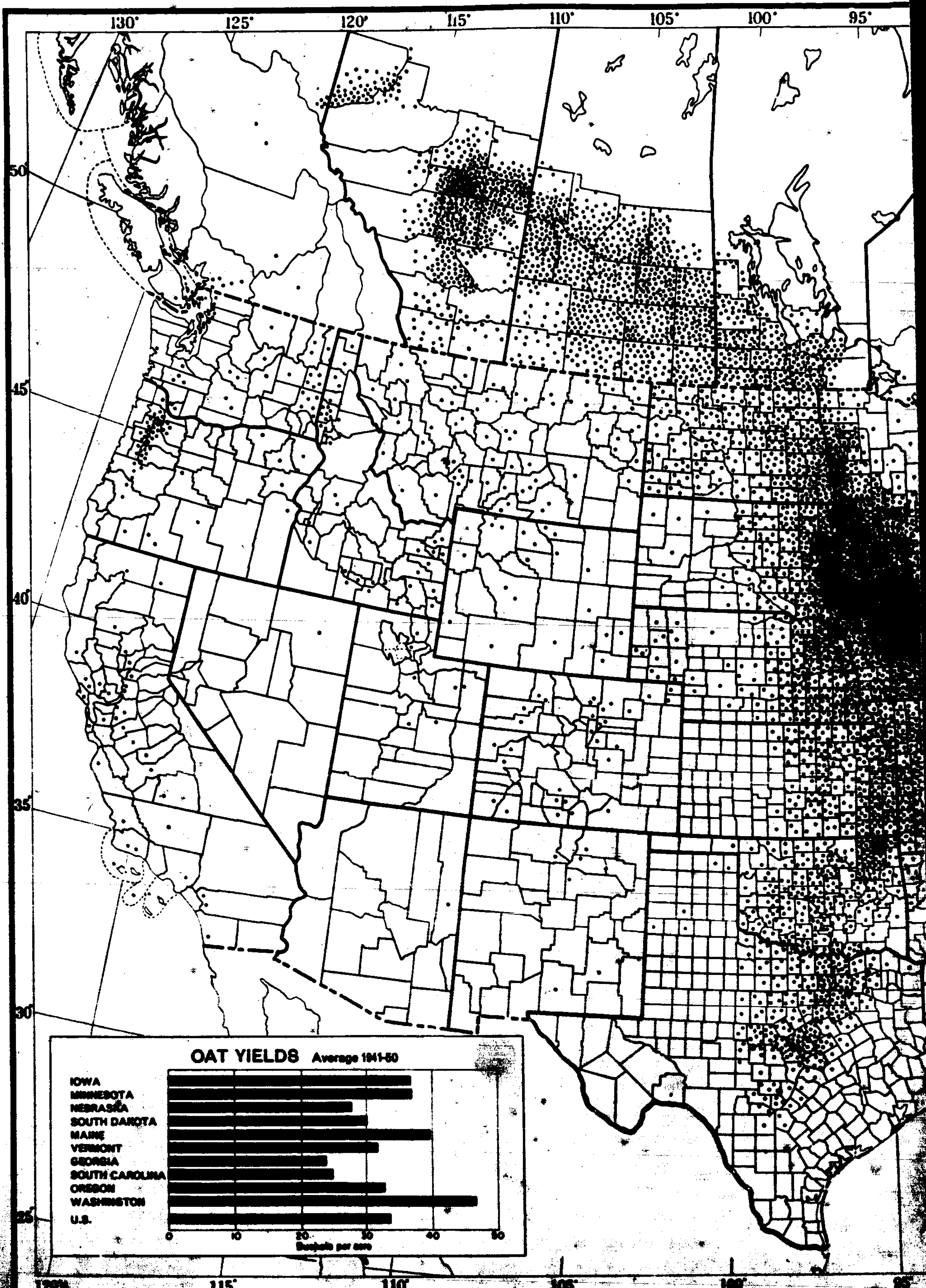
Figure 12[12]

UNITED STATES AND CANADA

CORN FOR GRAIN PRODUCTION

Each dot represents 250,000 bushels

FOLD-OUT #2



[illegible], DEPARTMENT OF GEOGRAPHY

FOLD-OUT #1

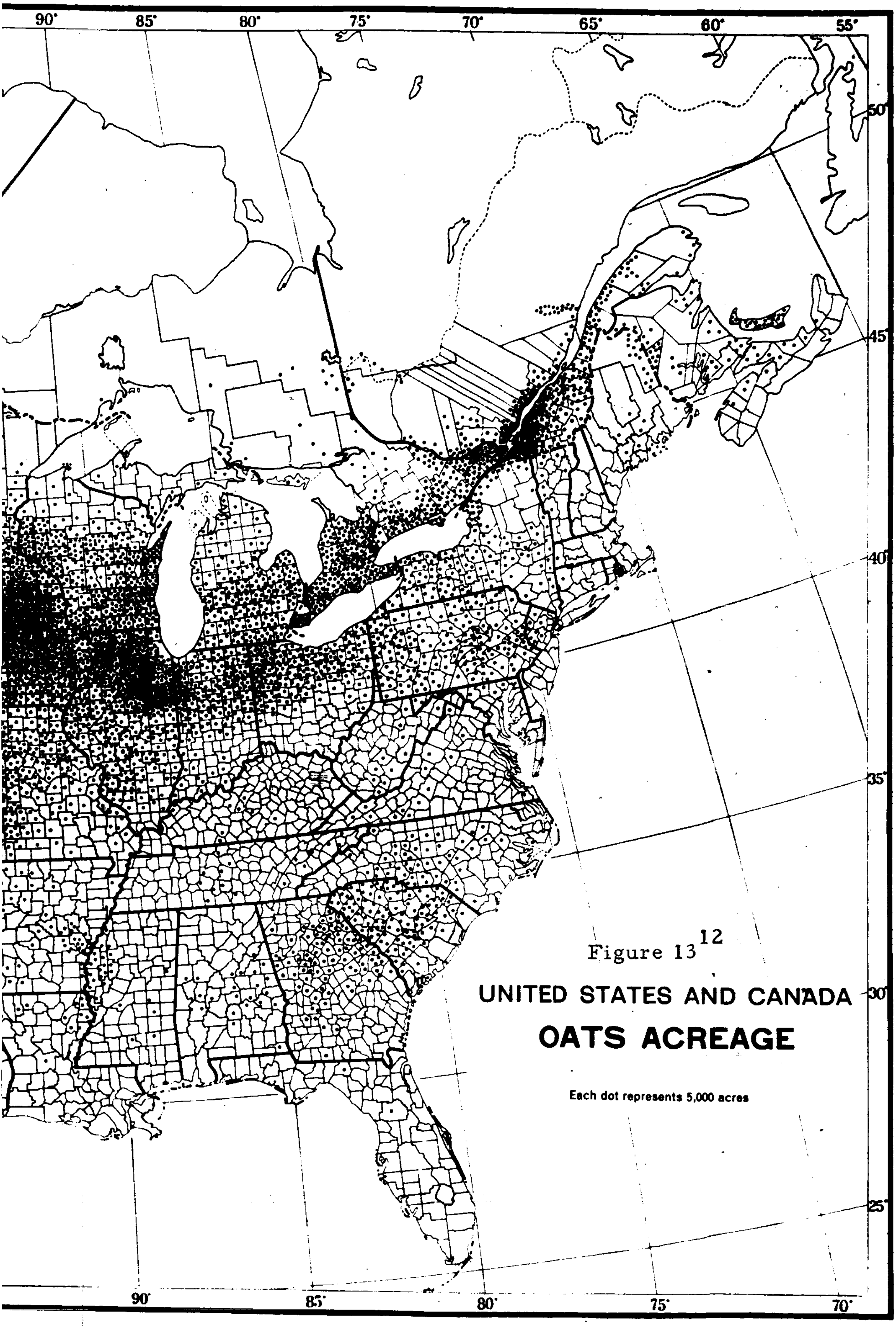


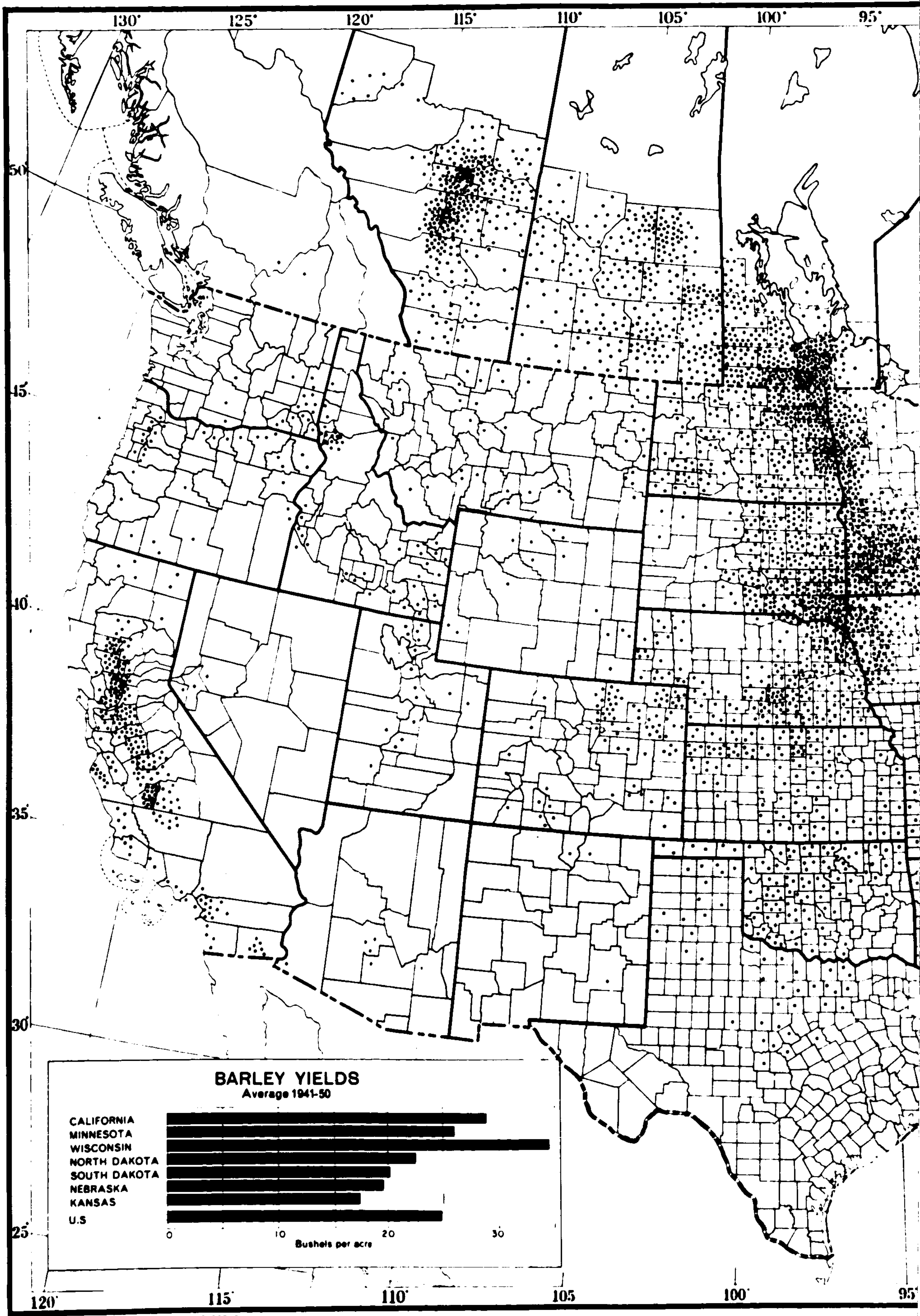
Figure 13 12

UNITED STATES AND CANADA

OATS ACREAGE

Each dot represents 5,000 acres

FOLD-OUT #2



UNIVERSITY OF MARYLAND DEPARTMENT OF GEOGRAPHY

FOLD-OUT #1

73-1

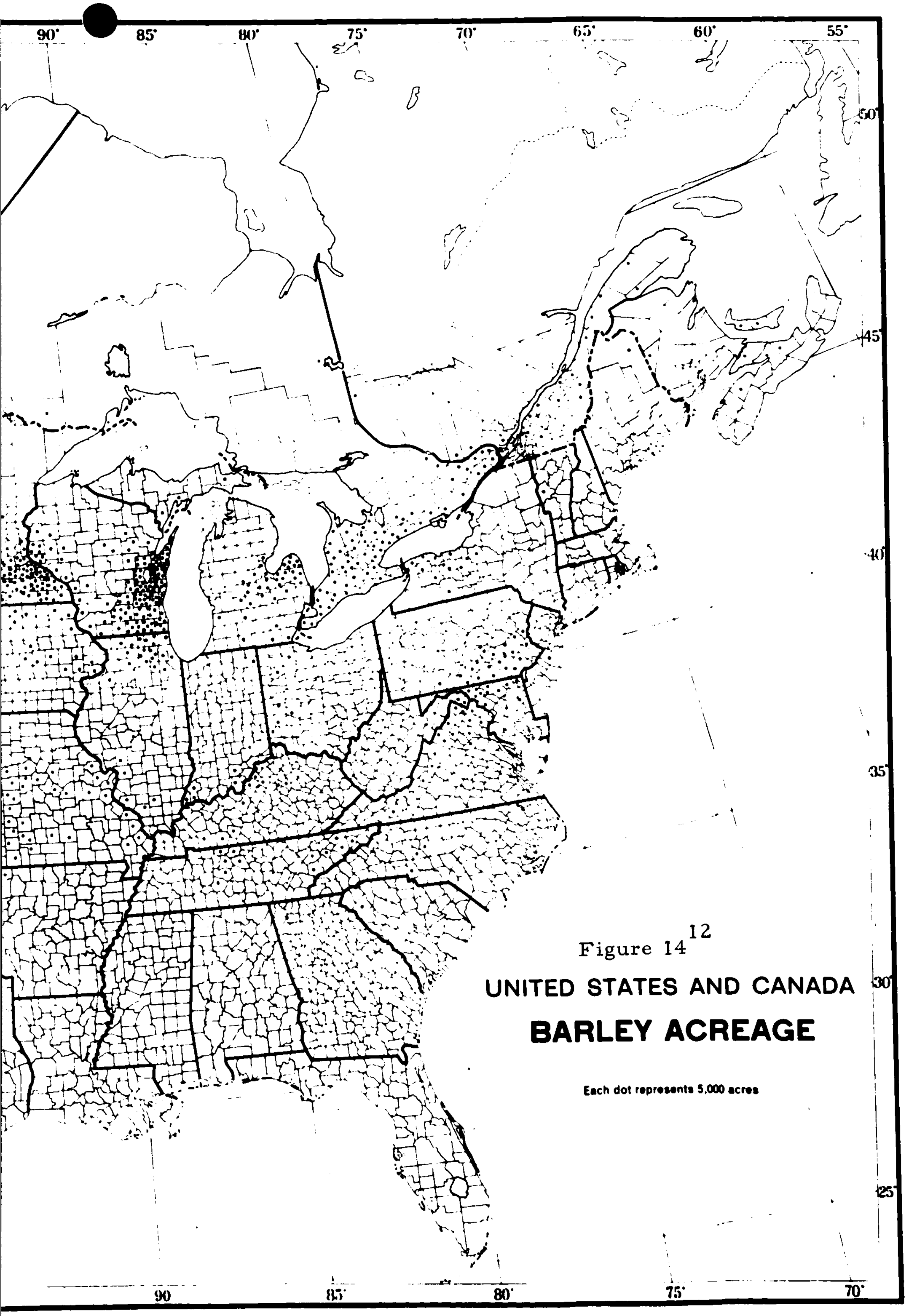


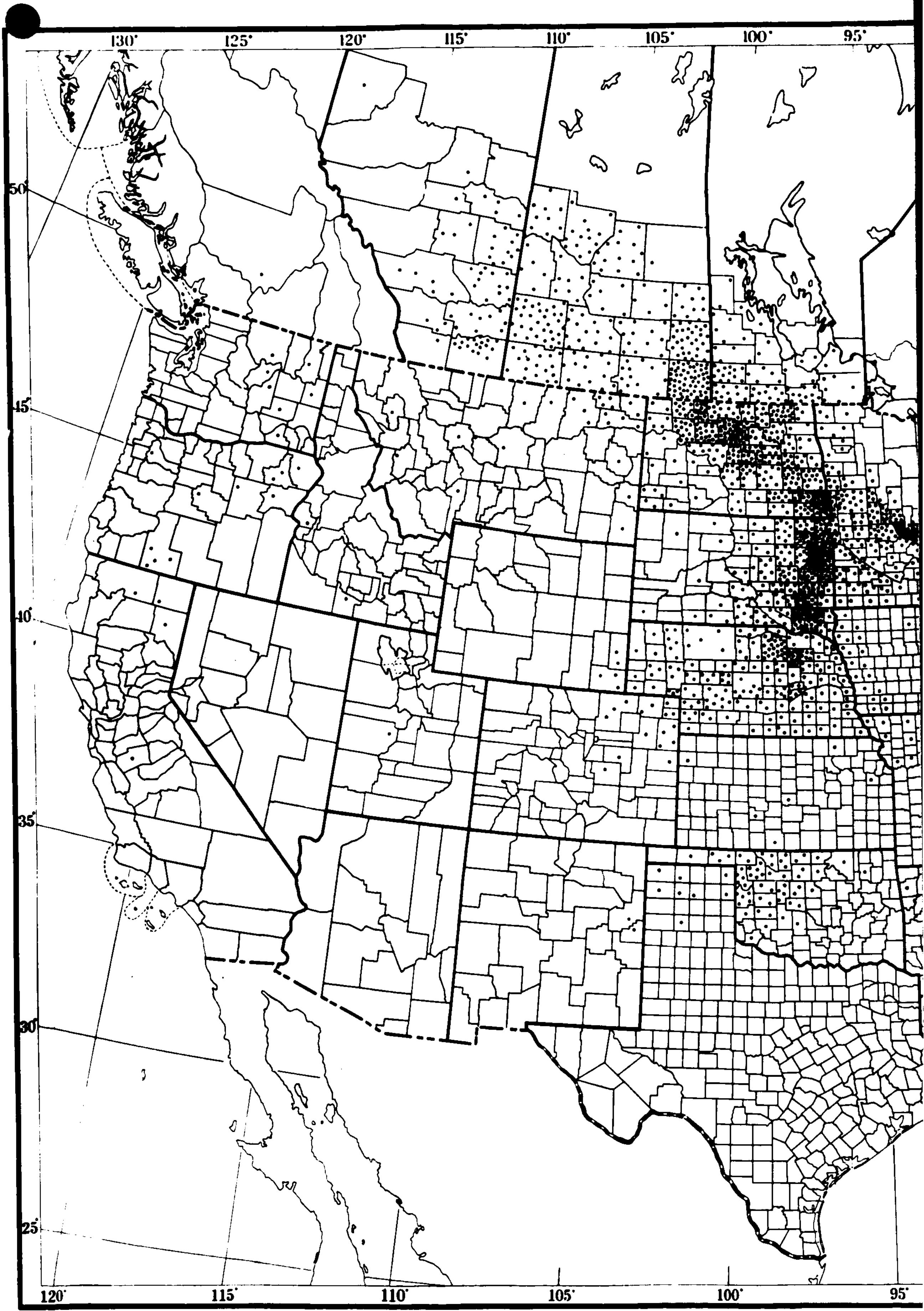
Figure 14 12

UNITED STATES AND CANADA

BARLEY ACREAGE

Each dot represents 5,000 acres

FOLD-OUT #2



UNIVERSITY OF MARYLAND, DEPARTMENT OF GEOGRAPHY

FOLD-OUT #1

74-1

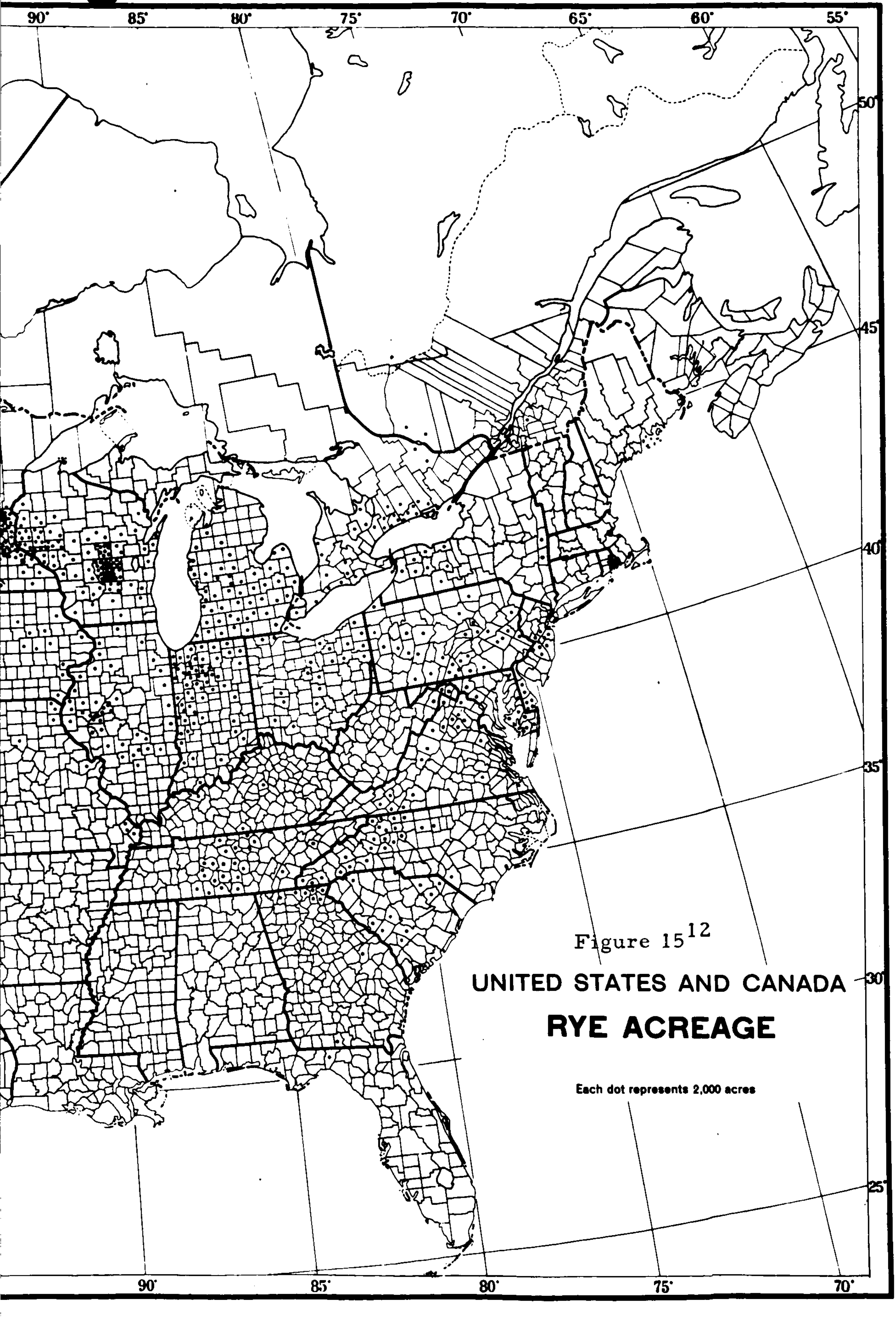


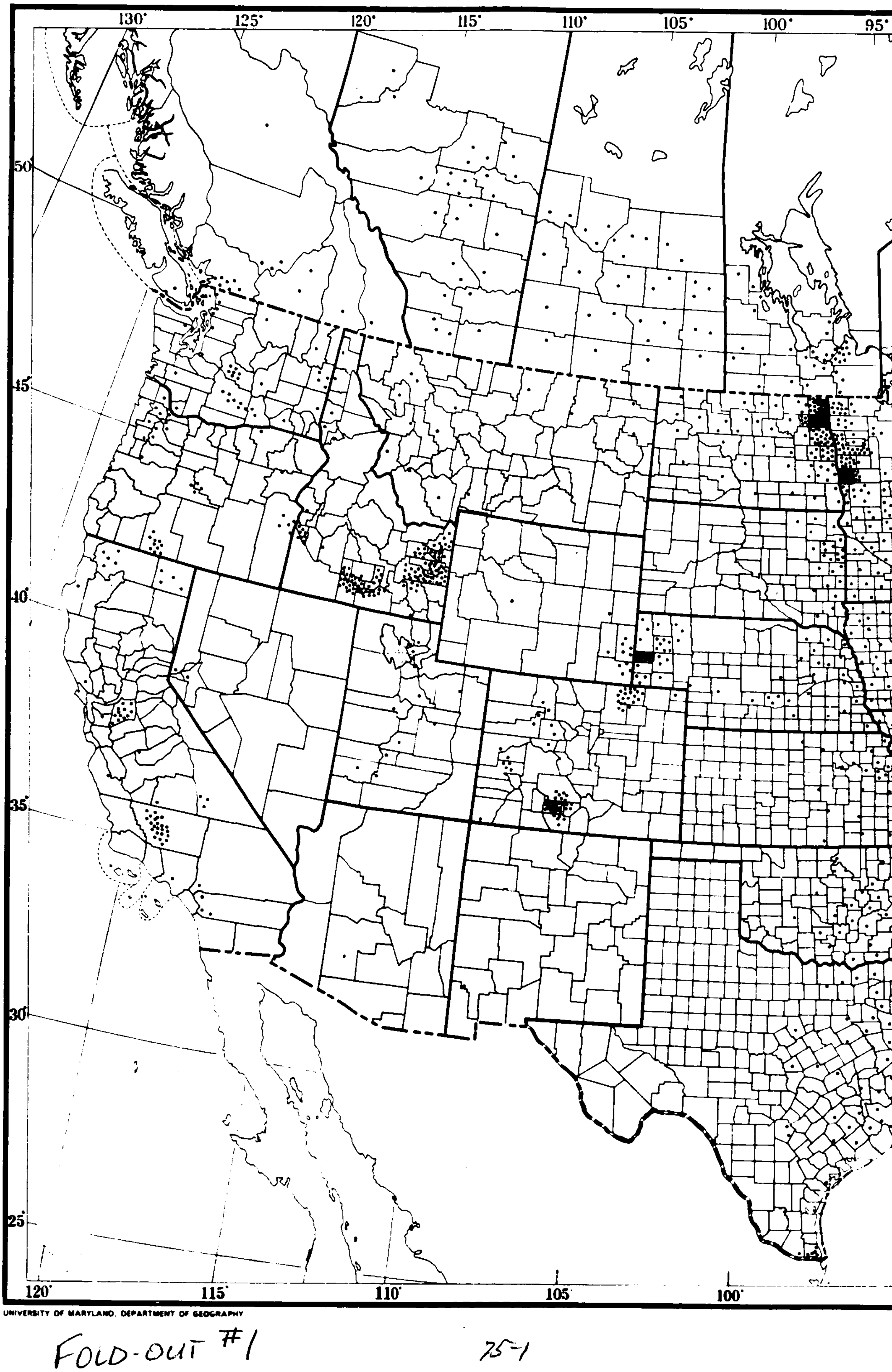
Figure 15[12]

UNITED STATES AND CANADA

RYE ACREAGE

Each dot represents 2,000 acres

FOLD-OUT #2



UNIVERSITY OF MARYLAND, DEPARTMENT OF GEOGRAPHY

FOLD-OUT #1

75-1

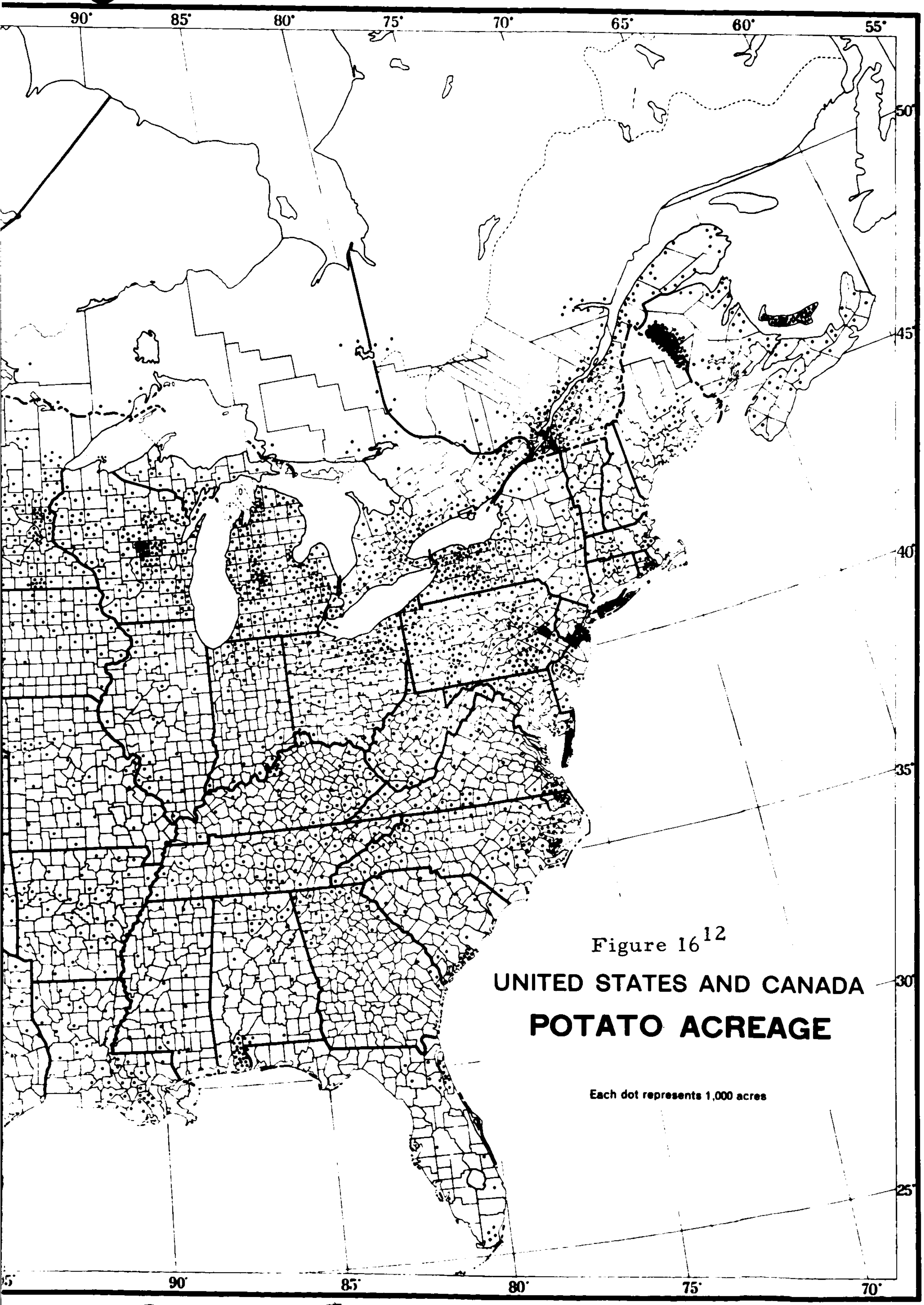


Figure 16[12]

UNITED STATES AND CANADA

POTATO ACREAGE

Each dot represents 1,000 acres

FOLD-OUT #2

can be mapped in 22 days (less cloud cover) from a 200 nautical mile altitude satellite in polar orbit. Swath widths or ground track separation are 1 degree longitude; 629 9"x9" photographs each 3600 square nautical miles with a ground resolution of approximately 20 feet can provide the data base.

There are two boundary conditions within which the objective of aggregate crop acreage measurements can be accomplished.

1. If the crop is 100% identifible from the data base alone without the application of photointerpretation techniques and the use of ancillary data, then the enumerative process can be completely automated, e.g., the transformation of areal targets data into the intelligence represented by the sum of its individual member areas.

The important advantage of ultra-high altitude sensing is the overview. If target classes are selected such that small individual member areas are involved, the enumerative process of hundreds of thousands of spacially dispersed members can present difficult cost barriers and result in historical intelligence. Such barriers can be alleviated by automation of the location, detection and identification process, but not in the immediate future.

2. If a crop can be identified only by photointerpretation techniques as a human analytical function, then for those regions of the earth possessing a national agricultural agency and a network of intelligence units on a state, district, county and local level, the spacial dispersion and enumerative process may best be handled by the smallest unit, e.g., each unit concerned only with its area imagery. Generally the number of associative units increases as the size of the unit decreases within an organizational complex. Therefore, the problem of target dispersion may best be dealt with by the maximum number of smallest units associated with the smallest area.

The enumeration of crop acreage doesn't require each of the 3070 counties to be treated. Probably less than 1500 counties need be analyzed for many specific crops. Analysis on a county level presupposes no prior photographic mosaics of the county continually being updated by the USDA for land usage. Complete aerial coverage of the United States is available and being used for this purpose, but for many targets, results in historical information. The rapid areal coverage of satellite sensing systems is an important survey capability subject to cost analysis.

The presentation of spacial distribution of crops in the preceding figures is an important reminder of the problems in practical integration of satellite sensing systems and procedures with a dispersed areal aggregate of target members.

For practical purposes when the number of targets becomes large, applicable statistical procedures need be established to estimate the enumerative sum within the region of interest by sampling. The problems and requirements for areal sampling are discussed in Chapter 3. The pictorial presentation of crop acreage in this section and the variable spacial density of the crops serve to associate statistical requirements with the scale of observation available from satellites. Furthermore, the variable density of the crop acreage aggregate at the observational scale of the figures exhibits at all levels of observation, e.g., crop acreage density variances in 100 acre lots within a 150 x 150 square mile region can show equivalent spacial complexity even when subject to fairly rigorous geographic constraints within the region.

2.7 WHEAT DISTRIBUTION IN THE UNITED STATES

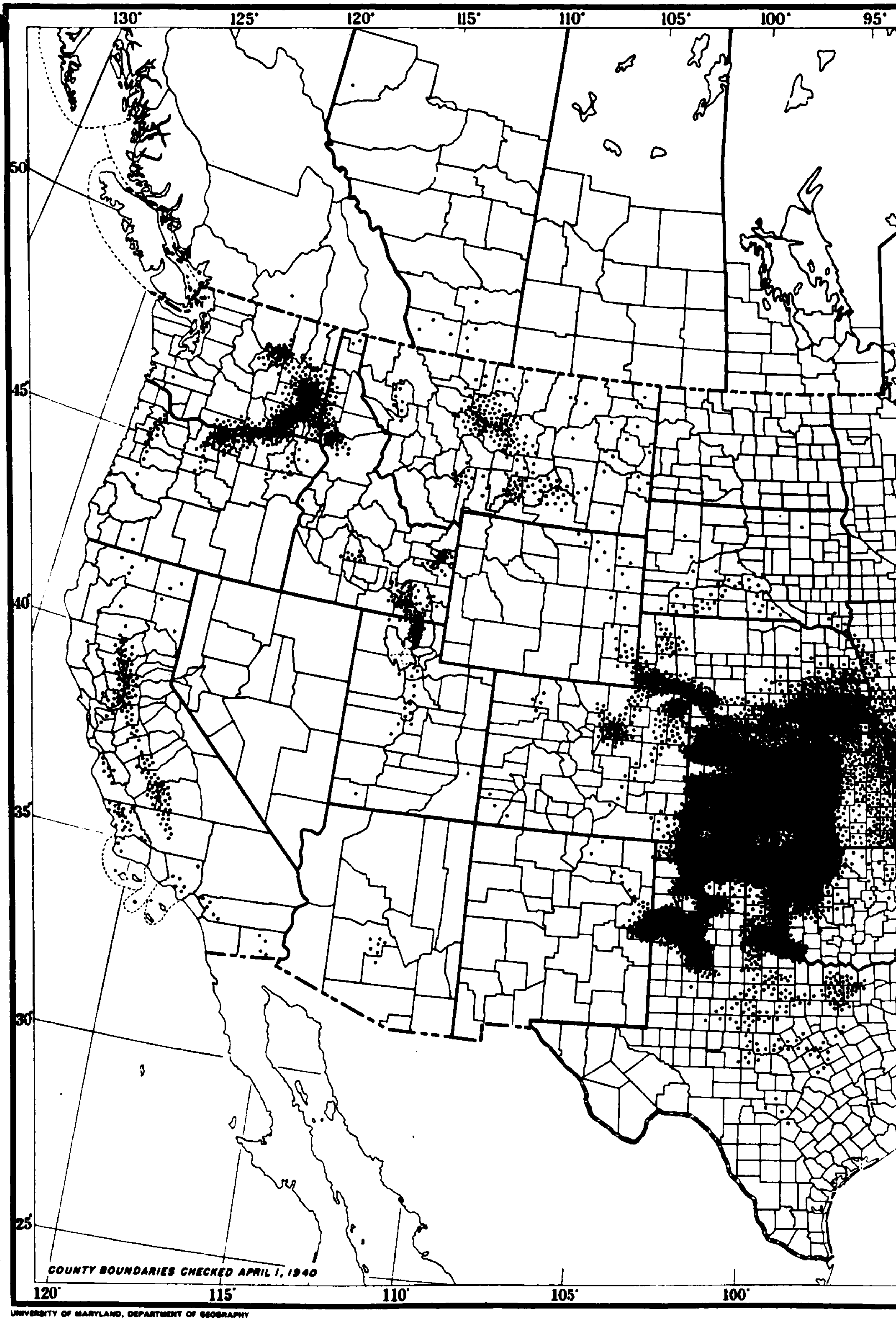
The spacial and temporal distribution of planted wheat acreage is presented in the accompanying figures for a specific target definition. Figures 17 & 18 show the areal distribution of wheat acreage over the United States in lots of 5000 acres.

A primary intelligence of interest to the USDA is an estimate of the total planted acreage in the United States. Table 10 shows the wheat acreage by state, per cent area of the state in the crop, and the per cent of the total wheat acreage in the United States. The 17 states listed contain approximately 92.8% of the total acreage in wheat or 53.02×10^6 acres distributed among 953.84×10^6 acres. Wheat acreage represents 5.5% of the combined 17 state area. Table 11 gives the planted acreage for all crop reporting districts in each state. Planting and harvest times versus state for Winter & Spring Wheat are given in Table 12. Table 12 is important since it associates the spacial and temporal distribution for one target class and therefore is suggestive of the dispersion which must be contended with.

Spacial distribution of areal targets require an areal data search predicated upon some identification criteria. If the criteria is a correlation of relative frequency response, then the response will be a function of the wheat growing period. Therefore, the response must be measured as a function of time and furthermore, the location/environment. Instead of one known signature for correlation continuously with an unknown, there will be several discrete signatures each having a spread in possible amplitudes and differing in frequency characteristics.

The above paragraph represents the major "problem" in practical achievable acquisition of intelligence at orbital altitudes and the remote sensing of substance dependent properties in general. The feasibility of correlating a known electromagnetic signature with an unknown has been established under certain conditions localized in space and time. The feasibility of identifying different members of a target class distributed in space and time as related to the complete coverage of the United States has not been shown.

WHEAT



UNIVERSITY OF MARYLAND, DEPARTMENT OF GEOGRAPHY

78-1

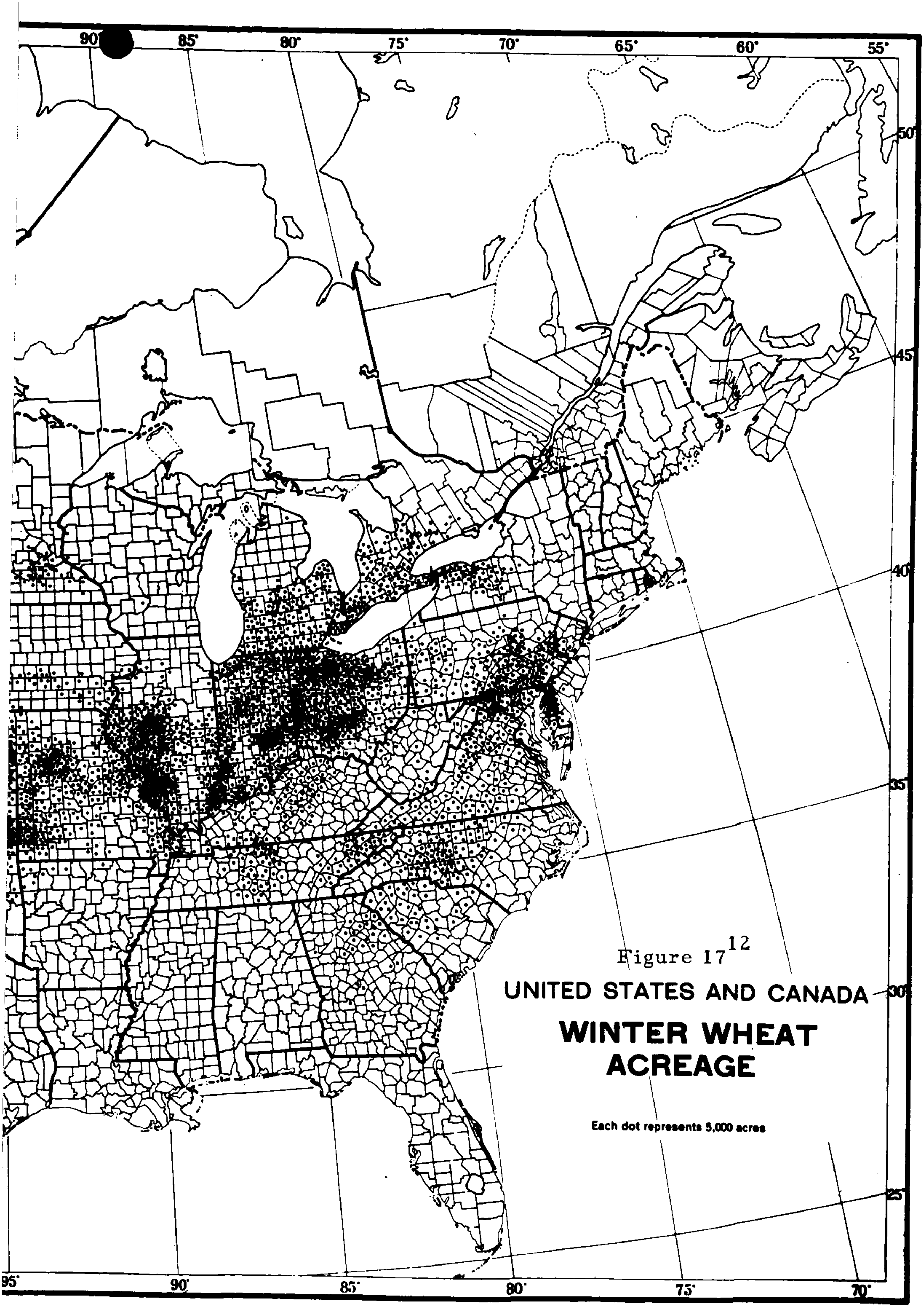
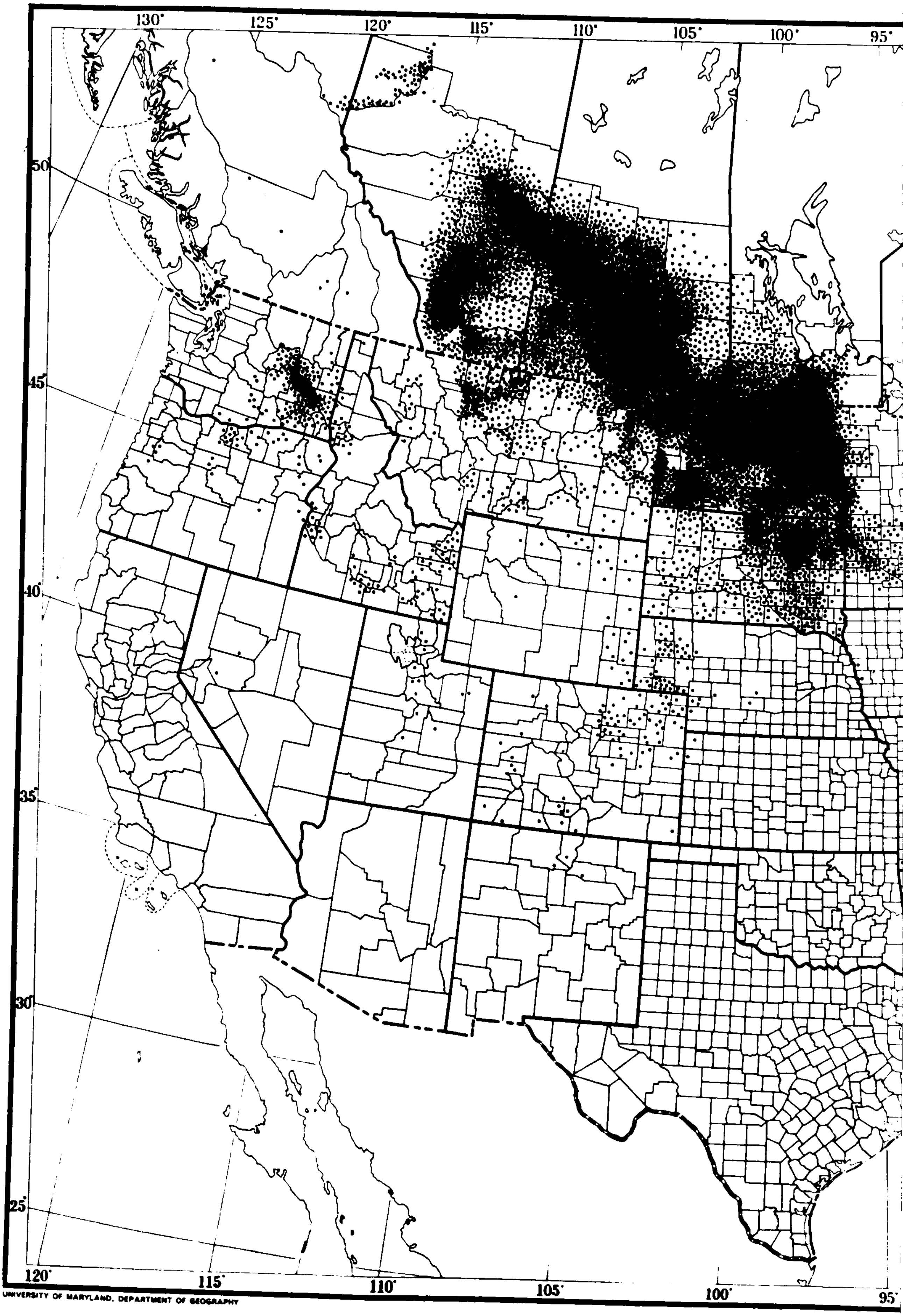


Figure 17[12]

UNITED STATES AND CANADA

WINTER WHEAT ACREAGE

Each dot represents 5,000 acres



UNIVERSITY OF MARYLAND, DEPARTMENT OF GEOGRAPHY

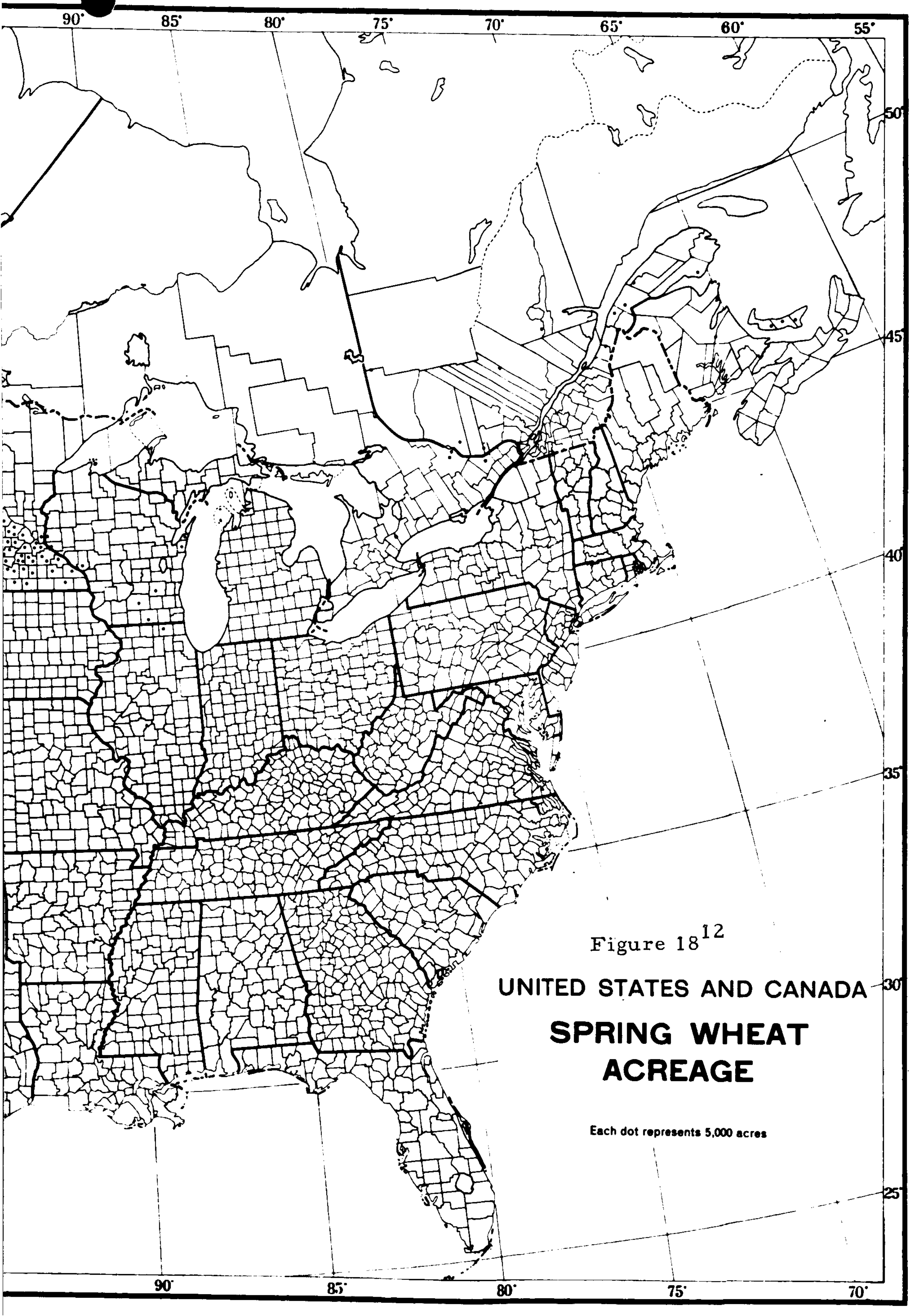


Figure 18[12]

UNITED STATES AND CANADA

SPRING WHEAT ACREAGE

Each dot represents 5,000 acres

TABLE 10

WHEAT PLANTED ACREAGE - 1965 (in 1,000 acres)

State	State Area (acres)	Wheat (acres)	% by State Area	% Total Wheat Acreage	Accum. Total
Kansas	52.66×10^6	11.39×10^6	21.6%	20%	20%
North Dakota	45.23×10^6	6.93×10^6	15.3	12	32
Oklahoma	44.74×10^6	5.32×10^6	11.9	9.3	41.3
Montana	94.16×10^6	4.41×10^6	4.7	7.7	49.0
Texas	171.10×10^6	4.16×10^6	2.4	7.3	56.3
Nebraska	49.43×10^6	3.36×10^6	6.8	5.9	62.2
Colorado	66.71×10^6	3.00×10^6	4.5	5.3	67.5
Washington	43.64×10^6	2.50×10^6	5.7	4.4	71.9
South Dakota	49.31×10^6	2.23×10^6	4.5	3.9	75.8
Illinois	36.09×10^6	1.72×10^6	4.8	3.0	78.8
Missouri	44.59×10^6	1.56×10^6	3.5	2.7	81.5
Ohio	26.38×10^6	1.29×10^6	4.9	2.3	83.8
Indiana	23.22×10^6	1.27×10^6	5.5	2.2	86.0
Idaho	53.47×10^6	1.22×10^6	2.3	2.1	88.1
Oregon	62.06×10^6	$.94\times10^6$	1.5	1.7	89.8
Michigan	37.25×10^6	$.91\times10^6$	2.4	1.6	91.4
Minnesota	53.80×10^6	$.81\times10^6$	1.5	1.4	92.8

TABLE 11

WHEAT - PLANTED ACREAGE - 1965

State & Region	Crop - Reporting Districts 1	2	3	4	5	6	7	8	9	10	State Total
NORTHEAST											
Maine	.1	.07	.03								.2
New Hampshire	.06										.06
Vermont	.5										.5
Massachusetts	2										2.
Rhode Island	.7										.7
Connecticut	2										2.
New York	1	1	146	25	4	9	5	3	6		200.
New Jersey		13			28			6			47.
Pennsylvania	17	13	6	30	100	33	19	103	123		444.
Delaware	21										21.
Maryland	1	91						16	27		135.
LAKE STATES											
Michigan	1	7	17	17	91	201	103	268	200		905.
Wisconsin	1	1	1	3	1	12	1	10	25		55.
Minnesota	562	4	1	193	20	1	4	17	12		814.
CORN BELT											
Ohio	325	214	80	212	245	34	111	47	21		1289.
Indiana	133	168	176	147	259	102	194	39	51		1269.
Illinois	21		52	379/ 139	158	407/ 144	259		159		1718.
Iowa	1	2	1	20	2	1	24	5	28		84.
Missouri	183	152	224	174	221	168	142	25	267		1556.

TABLE 11 (Cont.)

WHEAT - PLANTED ACREAGE - 1965

State &	Crop - Reporting Districts										State
Region	1	2	3	4	5	6	7	8	9	10	Total
NORTHERN PLAINS											
North Dakota	1142	824	1287	650	658	587	725	504	548		6925.
South Dakota	324	807	243	160	296	28	102	233	37		2230.
Nebraska	925	15	29		178	473	695	425	624		3364.
Kansas	1173	1295	354	1256	1733	432	2119	2386	638		11386.
APPALACHIAN											
Virginia		36		10	48	33	9	36	32		204.
West Virginia		2		3		18					23.
North Carolina	4	38	33	3	41	26		41	14		200.
Kentucky	24	93	44	16	57	6					240.
Tennessee	55	13	26	34	12	20					160.
SOUTHEAST											
South Carolina	18	3	5	8	26			8			68.
Georgia	3	4	16	6	15	11	5	11	1		72.
Florida	26		6		3						35.
Alabama	7	1/16	3	1	2	2	23	6	1		62.
DELTA STATES											
Mississippi	81	21	3	78	4	5	4	2	1		199.
Arkansas	8	1	256	15	9	87	1	1	15		393.
Louisiana	3	2	65	2	12	1	4	1			90.
SOUTHERN PLAINS											
Oklahoma	1008	1631	186	759	646	25	996	65	5		5321
Texas			250	400	.5	.5	74				
North	2400	474						24		1	
South	86	450						1		1	4162

TABLE 11 (Cont.)

WHEAT - PLANTED ACREAGE - 1965

State & Region	Crop - Reporting District										State Total
	1	2	3	4	5	6	7	8	9	10	
MOUNTAIN											
Montana	62	1740	1449		513		93	266	289		4412.
Idaho	301						62	204	650		1217.
Wyoming	3	68	3	6	214						294.
Colorado	72	551				1820	78	2	486		3009.
New Mexico	11		282				2		1		296.
Arizona		2			18		7		1		28.
Utah	141				51	32	7				231.
Nevada	8		10					1			19.
PACIFIC											
Washington	5	251	128		1315				799		2498.
Oregon	108	485	279				1	68			941.
California	1	10	15	88	96/69	9		38			326.
											56, 942.

(in 1, 000 acres)

TABLE 12. U. S. WHEAT PLANTING & HARVEST PERIODS[32]

WINTER WHEAT

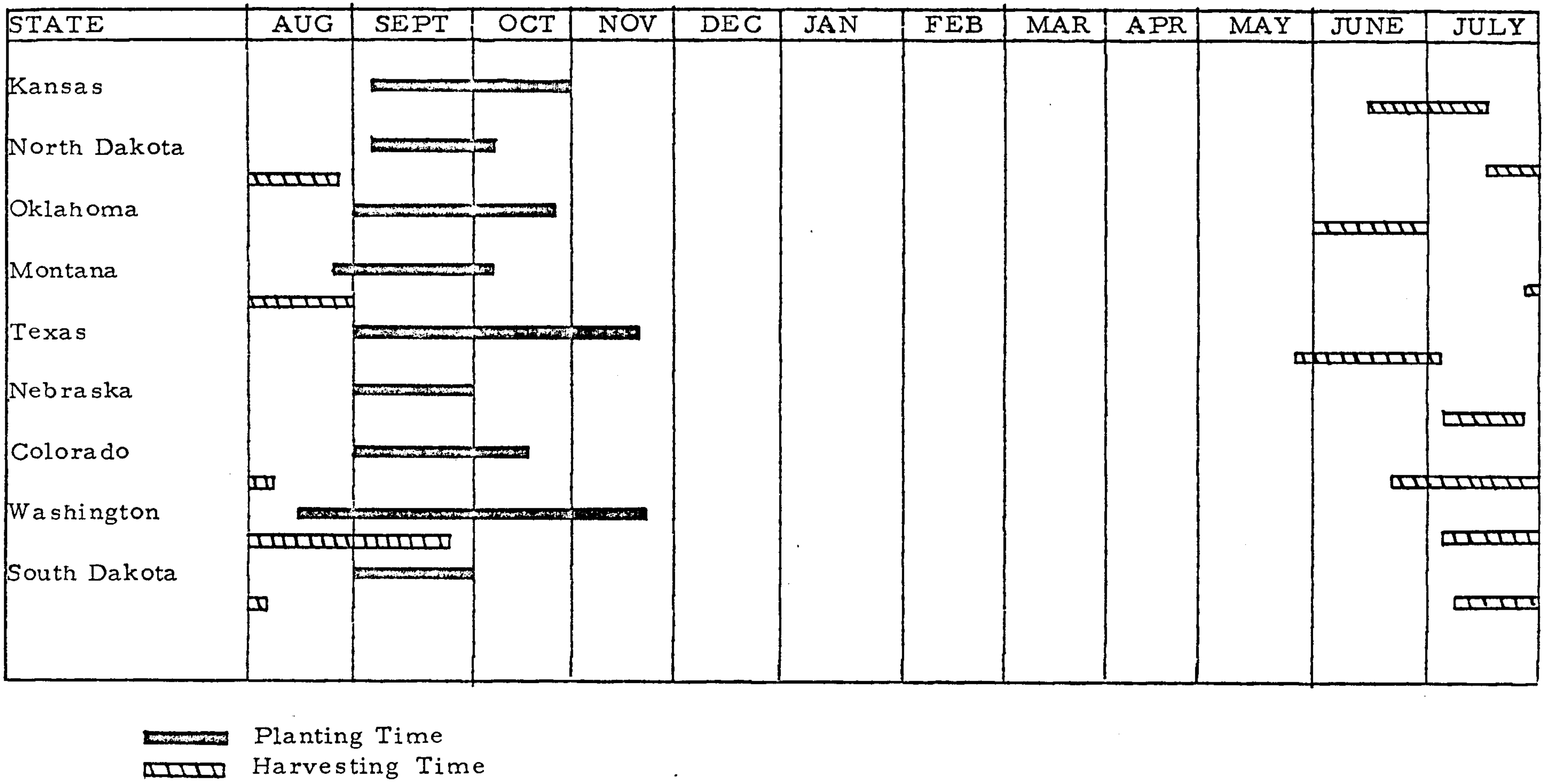


TABLE 12 (Cont.)

WINTER WHEAT

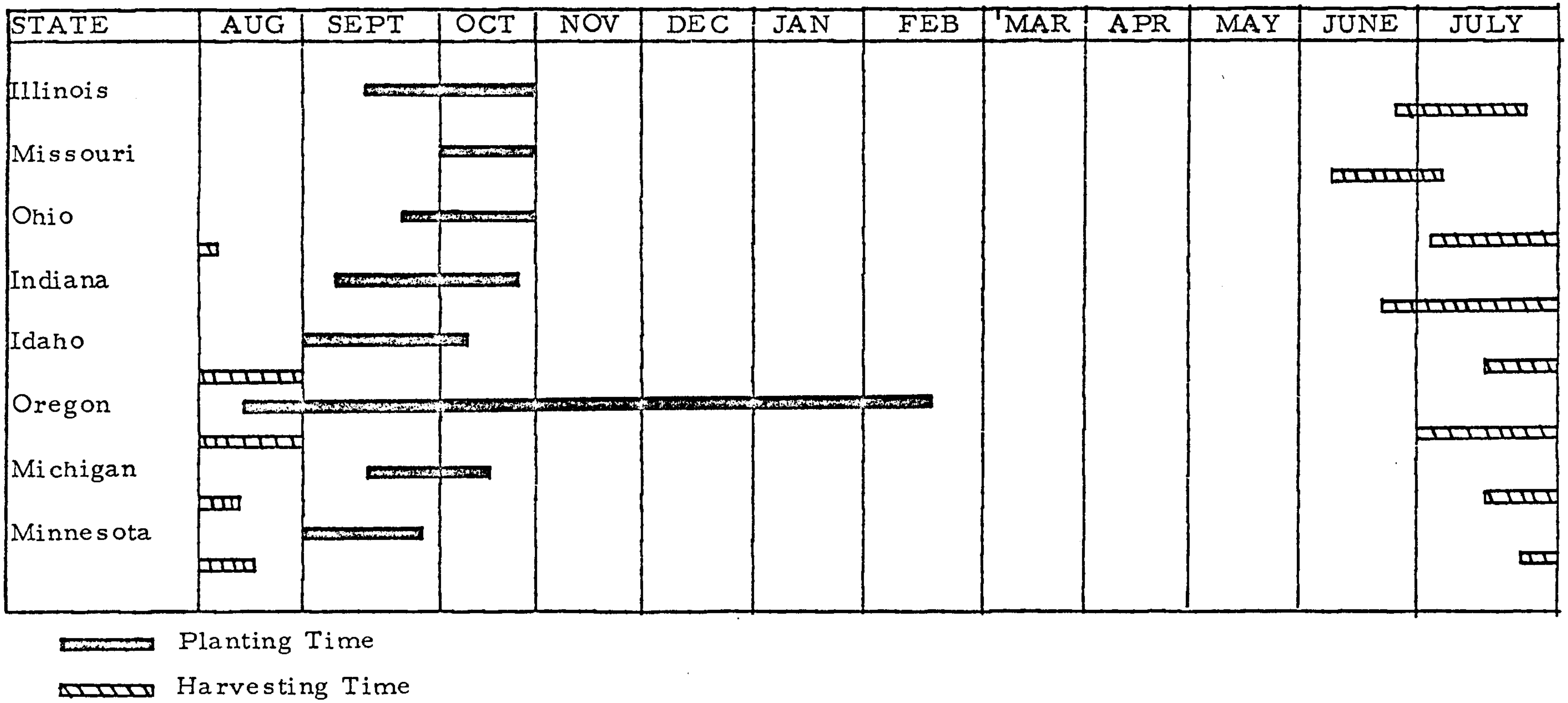
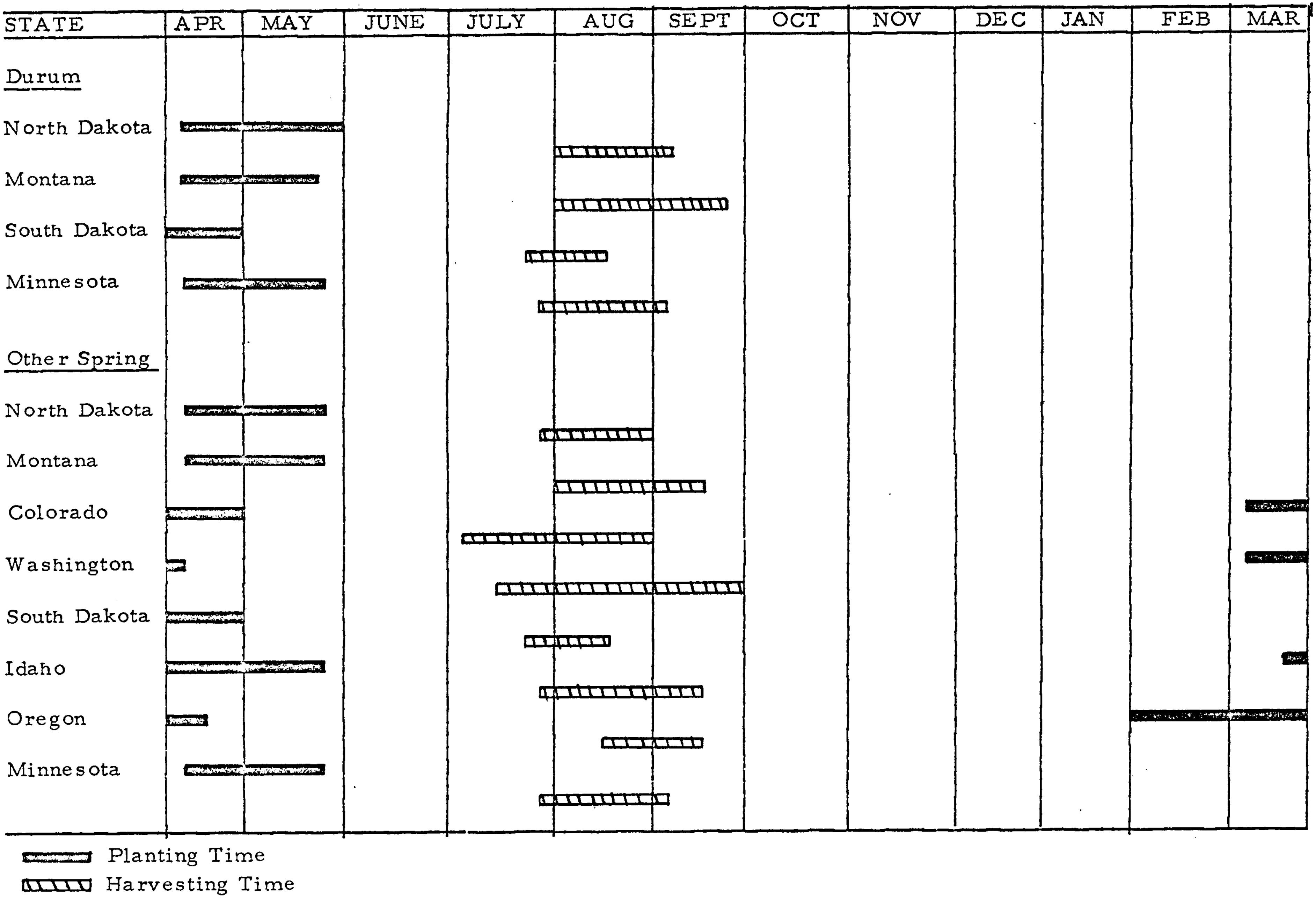


TABLE 12 (Cont.)

SPRING WHEAT



As such, it is a total remote sensing problem which must include and integrate all requirements and constraints in systems, vehicle, orbits, data retrieval, data analysis and mission. From another point of view, the capability exists for an orbital photographic survey of the entire United States with a ground resolution in tens of feet. A photograph can be useful as a mapping base. It may not be optimum for all targets, but it is a reasonable record of a terrain complex.

CHAPTER 3

AREAL SAMPLING

3.1 INTRODUCTION

Good high altitude photographic coverage of the nation satisfying the requirements for crop classification and associated area measurements can be used in a variety of ways. For example, in the United States the appropriate imagery could be processed, magnified and fragmented for dissemination to the appropriate USDA control group on a regional and local basis. Everyone of the 3070 counties in the 48 states could be covered in this manner for both mapping and classification/enumeration purposes. Mosaics of aggregates of counties and geographical regions can be made from the imagery for interpretation, planning and control purposes. In the interest of rapid surveys in the United States and for countries with highly dispersed agriculture which do not include a network of facilities comparable to the USDA, areal sampling techniques should be investigated.

If the current research investigations develop satisfactory methods of classifying crops using color discrimination techniques applied to imaging systems then it is reasonable to assume the imagery will be used to determine crop acreage in local and extensive regions.

It must be reemphasized that the data for interpretation and measurement in all likelihood will resemble the aerial photograph shown in Figure 1. This photograph covers about 25 square miles. As shown in Figures 11 and 12, corn acreage is located primarily over 4 states, but it is distributed over approximately 25 states. Therefore an investigation of applicable sampling techniques is warranted since it is the total acreage over the nation or country of interest which is of importance to the economy of a nation and satisfactory preparation of a useful statistic.

Photographic imagery is given primary consideration throughout the report because we believe it to have the most usefulness for the greatest number of users and their targets of interest. It may not be optimum for a specific target on a target discrimination and cost basis. For example, the photometric scanning techniques and correlation of spectral reflectances for wheat crop discrimination and automatic classification are presently being investigated by the University of Michigan and Purdue University. These techniques including automatic print out by classification of a specific crop hold promise for the future. Such techniques may not be advantageous for general land usage surveys currently being conducted by the Economic Research Service of the USDA.

The primary advantage of ultra-high altitude imagery is assumed to be the large areal coverage. Condensed extensive coverage permits an over-view of the spacial distribution of many land usage populations of interest heretofore unobtainable. Such an over-view should permit statisticians to better adjust their analytical procedures to fit the actual spacial distribution as it actually is rather than what it is assumed to be.

It is the opinion of this author that the degree of spacial order of an areal aggregate and hence the statistical stationarity of areal data is dependent upon the scale of observation. Stationarity means essentially that the statistical properties of the crop areal density expressed a discrete function of linear adjacent cells of area A_0 do not change with a change in cell location. For a 2-dimensional areal distribution the condition must hold regardless of the directional orientation of the cell sequence in question. If stationarity doesn't hold, it becomes difficult to predict the value in the n^{th} cell from the preceding sequential k cell. More simply, if county X is 20% in wheat, what justification is there in assuming the adjacent county Y of same area is also 20% in wheat? Note: the specification of cell size as a "county unit" is completely arbitrary.

Areal sampling must contend with unknown variable spacial degrees of order. A given region is best sampled randomly throughout the region rather than by arbitrary selection of parallel "swaths" or linear sections of sequential cells to be subsampled. (The subsampling to provide estimates of cropdensity for the cells not sampled along a swath, and the subregions between the swaths.)

A regional statistic which provides an estimate of the sum of target areas within a bounded region is an attempt to combine all possible spacial distributions or degrees of order under one theoretical tent. Since the spacial distribution of crop area must ultimately be reduced to one number integrated over a cell area with many cells making up the region of interest, it can be seen that the statistical regularity of these numbers will depend upon the cell size.

Some idea of spacial order is provided by the spacial distribution of major crops in the United States as shown in Figures 11-18. This distribution may be referred to as a level of observation possessing a "degree" of order based upon the crop distribution in 5000 acre lots. Another level of observation and degree of order would be the spacial distribution of wheat in Kansas on a 100 acre basis. The United States can be imaged upon 629 9"x9" frames, each representing 3600 square nautical miles with a ground resolution in tens of feet. Ninety-three per cent or 53 million acres of wheat acreage in the United States is distributed among 1 billion acres. Should total wheat acreage estimates for the United States be analyzed by sampling (n) areas 1000 acres each for analysis from 1, 000, 000 possible areas or some number of 1, 000, 000 acre areas from 1000 possible areas? Ideally, planimetric measurements for thousands of fields should be eliminated and/or replaced with a simple enumeration or count. The following sections suggest a basis to accomplish this objective.

3.2 THE NATURE OF THE STATISTICAL PROBLEM IN AREAL ESTIMATES

The purpose of an areal sampling method is to estimate the total acreage of a crop within a bounded region by sampling some percentage of the area of the region. Preferably sampling should be minimal and areal measurements reduced to simple enumeration rather than planimetric measurements.

Statistical procedures for predicting the total crop acreage should provide:

- an estimate of the true value of a population characteristic (average areal density) used to predict the crop acreage in a bounded region.
- methods for determining the accuracy of the estimate, e.g., the difference between the true value and the estimate.
- a measure of the precision of the prediction which may be estimated from other information or from the sample.

Of the many possible sampling methods, those based upon the theory of probability provide an objective measure of precision[13]. The basic requirement for probability sampling is that each element of the population be drawn at random with a known and equal probability[24] or with a known and unequal probability[13]. Within this context, random sampling may be done with or without replacement; furthermore, unequal probabilities may be assigned which are proportional to a measure of some attribute, for example, size of field. Consider the spacial distribution of 25 cells occupied completely by a single crop in a region containing 70 cells as shown in Figure 19. The problem might be to estimate the number of occupied cells (M=25) in the bounded region containing N=70 cells of identical sizes.

A sample subset of n cells may be selected by numbering the cells and selecting the sample set at random without replacement, e.g., the probability of selecting the first cell is 1/N, $\frac{1}{N-1}$ for the second, etc.

This procedure is equivalent to selecting one of the possible combinations of n cells from N cells with an equal chance $1/{}_NC_n$ of being selected[24]. ${}_NC_n$ is equivalent to the number of possible spacial distributions of n occupied cells in N cells.

If $n = M = 25$ occupied cells
$N = 70$ cells in region

then the number of ways of arranging n or M in N or the number of possible "different" spacial distributions of n in N is given by:

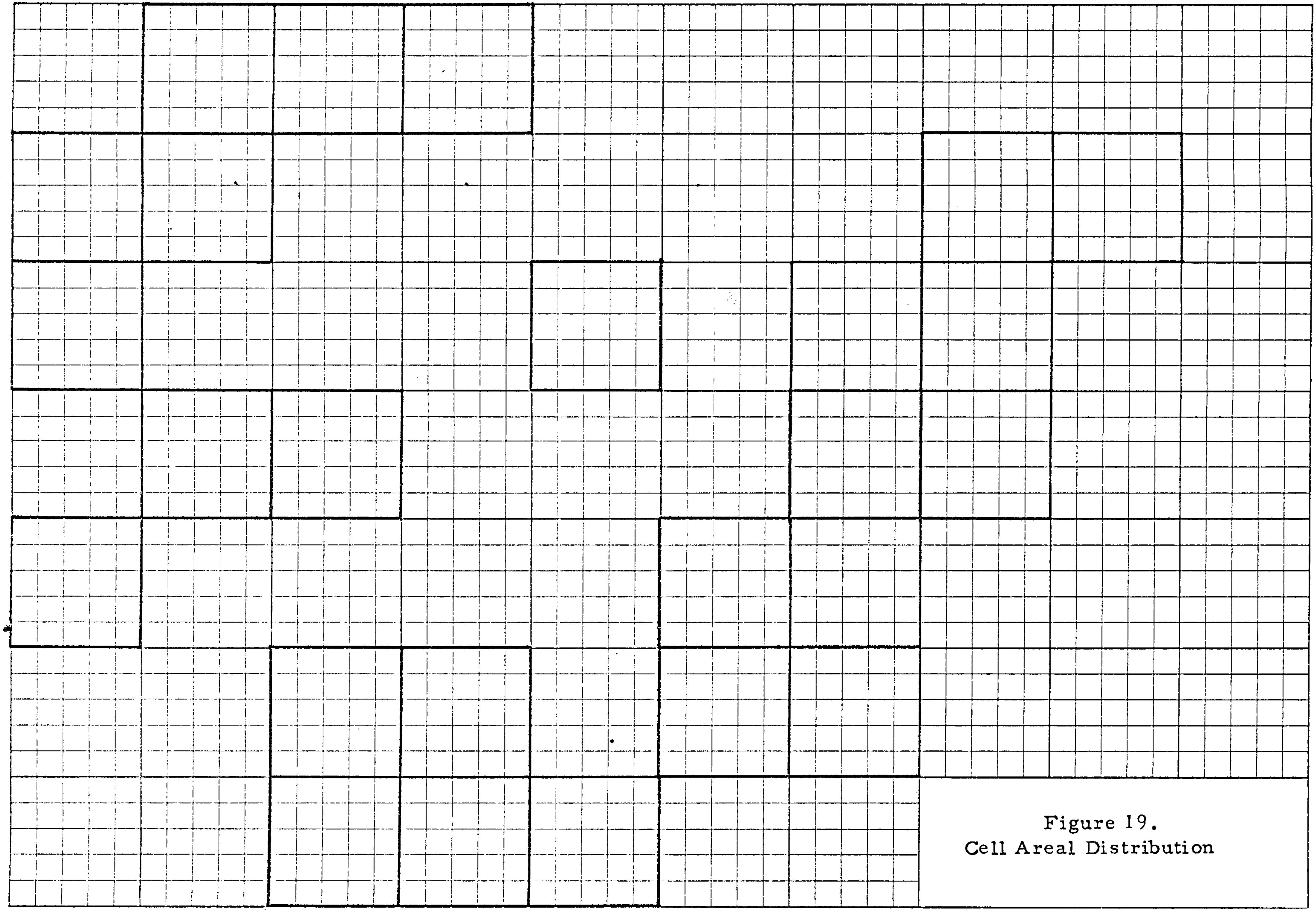


Figure 19.
Cell Areal Distribution

$$ {}_{N}C_{n} = \frac{N!}{n!(N-n)!} = 6.456 \times 10^{18} $$

Many spacial distributions of M in N will have the same pattern (say a letter in the alphabet), but will differ only in position and/or orientation (orientation meaning rotation, position change meaning horizontal or vertical displacement). It follows that the number of spacial sample distributions which may be selected is also 6.456×10^{18} if $n = M = 25$ and $N = 70$.

The probability of randomly selecting $n = 25$ cells from N cells in such a manner that the selected numbered cells form the letter L with a given position and orientation is $1/(6.456 \times 10^{18})$. The spacial distribution of the cells selected at random with or without replacement should be more or less distributed "uniformly" or "homogeneously" throughout the bounded region; however, a random selection of cells tend to cluster* and therefore the sample set may not be distributed "uniformly" or "homogeneously" throughout the region. Whether or not this is important might depend upon the degree of local spacial order as possessed by the population in the region versus the degree of local order established on a different scale by specification of cell size and random sampling.

The variable "degree of order" or spacial distribution of crops as shown over the United States in lots of 5000 acres could show the same complexity on a state basis of 100 acres. In the latter case, sampling could be a problem because of the difficulty of locating a dispersed crop which represented less than 1% of an area 150 x 150 or 22,500 square miles (represented by corn acreage in southwestern Missouri).

3.3 ELEMENTARY PROPERTIES OF AREAL SUMMATION ESTIMATES IN A BOUNDED REGION

Consider a bounded region (R) of area (A_r) containing a 2-dimensional spacial distribution of (j) incremental areas (y_i) of varying sizes (crop acreage), which, when summed, give the total crop acreage (A_c) in R.

If there are (j) incremental target areas (y_i) in (R) then there are (k) incremental non-target areas (x_i) in (R). Therefore:

$$ 1)\quad A_r = \sum_{i=1}^{j} y_i + \sum_{i=1}^{k} x_i $$

$$ 2)\quad A_r = Y_T + X_T $$

and it might appear that sampled data providing estimates of both Y_T and X_T

---

*cluster: definition of, page 92A

Cluster, Definition of:

The term cluster is used to denote a variable spacial density and order whose variability is dependent upon the scale of the observation or size of a sample cell. A single random spacial distribution of points on a two dimensional plane can be both homogeneous and non-homogeneous, constant density and variable in density depending upon the size (area) of the sample cell. Generally, increasing the cell size can result in greater homogeneity. Reliability in the prediction of the mass of an object increases with an increase in the homogeneity of its parts. Order is taken to mean two dimensional stringers, fingers, clumps, pockets, etc. exhibited visually by the point distribution possibly random in origin or possessing a local unknown spacial casuality. If the spacial dimensions of the local order is smaller than the sample cell size, sample homogeneity in point density may result. The spacial distribution of the sample cells can, of themselves, represent the same spacial complexities as the random dot distribution. An unknown spacial distribution of points and a completely arbitrary sample cell size could result in a very poor prediction of "mass" as inferred by a sample of dot areal densities.

could be checked since their sum must equal a known A_r.

Unfortunately since the sampled cells contain both y_i and x_i, or y_i and the absence of x_i, or x_i and the absence of y_i, a prediction of Y_T or X_T over a finite (R) automatically defines Y_T or X_T such that $Y_T + X_T = A_r$. We therefore, conclude that statistical theory must provide an objective measure of the precision of Y_T. The initial choice available from which such a theoretical foundation may be established which attempts to accommodate all spacial distributions of y_i is the method of selecting y_i from the population, and the notion of probability based upon the observation of statistical regularity for repeat events in nature, e.g., from what has happened in the past one may, on the average, predict to some extent what will happen in the future and its variability, but not precisely what will happen. Note that Equation 2 may be used as a ratio estimate when ancillary information provides some measure of X_T and A_r is known. (Appendix D)

A region (R) may be sampled by gridding the region into (N) square cells (S_i) of equal dimensions, and selecting (n) cells at random. From each cell the area (y_i) in crops or other land usage can be determined and a prediction made of the total acreage in crops in (R) as shown in Figure 20 by applying the method of least squares and developing a regression curve to fit data.

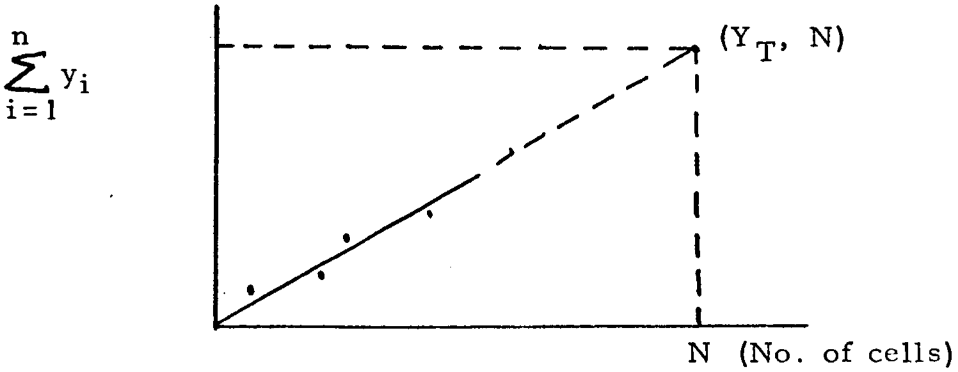


Figure 20 Linear Trend Analysis

Assuming each cell (S) to be either filled or empty would yield the graphic relationships shown in Figure 21 .

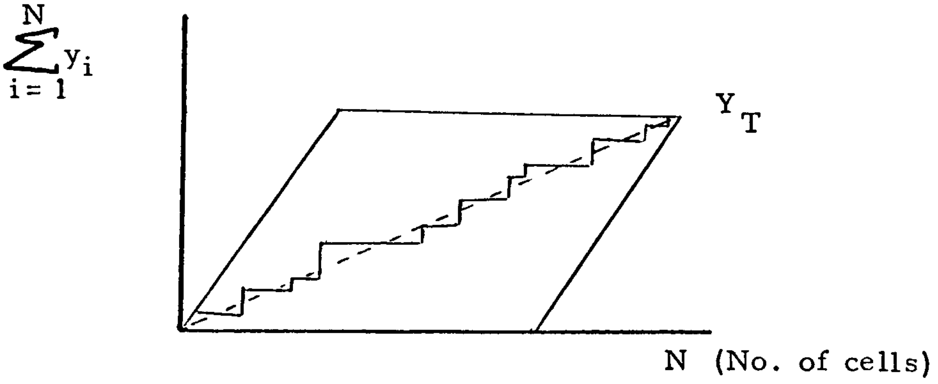


Figure 21 Random Binary Sum

Y_T may be approached along an infinite number of paths within and defined on the boundaries of the parallelogram. The probability of a random sample including (n) filled cells in the first or last (n) of N cells is a minimum.

Associated with the problem of estimating the sum are the extrinsic variables:

- regional size
- cell size (defines the number of cells in the region R)
- sampling method (cell selection)
- spacial distribution of selected cells in R

whose choice may be modified by the intrinsic variables of a specific problem:

- 2-dimensional spacial distribution of fields (population) in a region
- size distribution of fields

and/or dictated by the fundamental axioms and theorems of mathematical probability theory.

The intrinsic variables may be:

- unknown
- partially defined
- assumed

Given a suitable photographic mosaic of a region from which the crops can be identified, a rectangular grid of cells can be superimposed on the mosaic. A sample set of cells could be selected in some manner, the crops identified and areal measurements made with a planimeter (planimetric measurements should be minimal to reduce cost of data reduction). An average areal density (crop acreage/cell area) of the selected cells could be determined and assumed to be representative of the average throughout the region. Multiplication of the average crop density of the cells in the region by the number of cells in the region yields the total "mass" or crop acreage in the region.

Since the average crop density $p(y)$ (crop area/cell area) is:

$$0 \leq p(y) \leq 1$$

a skewed distribution about the mean is to be expected since it is unlikely the average density will be exactly .5. If the crop acreage is "homogeneous" throughout the cells, the variance of the density about the mean will be small. The size of the cells relative to the crop spacial distribution can influence the degree of similarity or homogeneity of crop density within the cells and hence the variance.

3.4 REGULAR ESTIMATION PROCEDURES AND CELL VARIANCE

Let the areal density $p_i(Y)$ be some property Y (wheat field area) belonging to S_i in a region containing N cells. (S_i to be considered as one of the cells associated with a gridded photographic mosaic.) The property Y_i for the i^{th} cell is given by:

1. $Y_i = p_i(Y)S_i$

where

2. $0 \leq Y_i \leq S_i$

The total wheat field area Y_t in a region containing N cells (S) is given by:

3. $Y_t = \sum_i^N p_i(Y)S_i = \sum_i Y_i$

It follows that Y_T can be estimated by:

4. $EY_T = N\bar{Y}$

where from the sample subset of n cells selected at random with or without replacement the average acreage $\bar{Y}$ per cell is:

5. $\bar{Y} = \frac{1}{n} \sum_{i=1}^{n} p_i(Y)S_i = \frac{\sum_{i=1}^{n} Y_i}{n}$

therefore:

$$6.\quad EY_T = \frac{N}{n}\sum_{i=1}^{n} p_i(Y)S_i = \frac{N}{n}\sum_{i=1}^{n} Y_i = N\bar{Y}$$

This is a regular estimation procedure in that only the property p_i associated with S_i is used.

For a better estimate, when using random sampling without replacement, the sampling and calculation can be repeated R times to compute the variance of the sample means by[24]:

$$7.\quad \text{Var}\,\bar{Y} = \frac{1}{R(R-1)}\sum_{j=1}^{R}(\bar{Y}_j - \bar{\bar{Y}})^2 = \sigma_{\bar{Y}}^{\,2}$$

Every sample set will contain different cells and thus the estimate $\bar{Y}$ and σ^2 of the mean and variance will differ from set to set. The estimates on the average tend to be equal to the true mean and the variance. Random sampling insures that fluctuations of $\bar{Y}$ about the mean is closer to a minimum than for any other type of estimate. In this sense the estimate of $\bar{Y}$ and σ^2 are unbiased.

Estimates of the mean and variance which vary from sample set to sample set are single value estimates. If a random sample is taken from a normal population, interval estimates of the mean or variance can be made with a chosen degree of confidence. A confidence coefficient γ is the proportion of samples of size (n) for which intervals (confidence intervals) computed by prescribed methods may be expected to bracket the mean[24].

Larger samples tend to give narrower confidence intervals for the same level of confidence. A small variance about the mean as determined from (n) samples implies a "uniformly homogeneous" spacial distribution of the population or constant cell density throughout the region relative to the sample cell size. Poor selection of cell size relative to the areal degree of order (homogensity of clusters, homogeneity of acreage within the cluster) will increase the variance. The variance is important since for a normal distribution it establishes the level of statistical significance and reliability (t) of the estimated mean:

$$\bar{Y}_T = \bar{y}_t + t\,\sigma_{\bar{y}}$$

For $t = 3$, there are 99.7 chances out of 100 that the mean computed from the random sample will not be further away than 3 standard errors of the mean from the true average[15].

Different variances and means may be attributed to non-proportionate sampling, e.g., in the region there are actually n_1 cells with x_1 value, n_2 cells with x_2 value, etc., of which the number of selected cells from the $n_1, n_2 \ldots n_k$ set must be proportional to $n_1, n_2 \ldots n_k$ to yield the same mean density (all other factors being equal). In essence, we assume a random sampling prodecure applied to a population containing (n_1, x_1), (n_2, x_2) where $n_1 = 2n_2$ will sample on the average twice as many of the n_1 sets as the n_2 sets.

A random selection of cells yields a random sampling grid for superimposition over a base mosaic. The spacial distribution of the sample cells is random and hence may show clustering*. Repeating this process would yield a different sample grid with a different spacial distribution of the cells. Therefore, assuming a "random" spacial distribution of selected cells located on the base grid, a "mapping" of two random sample grids on to the base grid would be expected to yield different average cell densities and variances. This, in essence, would be caused by the failure of the selected cells to proportionally sample whatever local degree of "order" the base possessed. In the "limit" as the number of sampled cells (n) approached the number of cells N, the differences in average cell density and variances would tend to zero for repeated sampling (replication) without replacement.

It seems reasonable that as N becomes large for a finite region, a random selection of (n) cells will show a more balanced homogeneous spacial dispersion throughout the region, e.g., a region divided into 10 cells of which 2 or 20% are selected at random would not sample the region as well as 200 cells selected from 1000. Note: Crop acreage is being thought of as a variable connected porous areal matrix irregular in boundary.

Figure 22 is an arbitrary areal distribution of points with an arbitrary map scale and grid size. With no a priori knowledge of the point distribution within the region, the assignment of grid dimensions of the cells for sampling may be arbitrary. Furthermore, a cluster of points can be enlarged at a reduced map scale to give a spacial distribution comparable in complexity to the large scale distribution. Again there is the problem of an arbitrary grid size selection.

If prior knowledge of the spacial distribution of the population in the region (R) exists, then the region may be divided into subregions of approximately constant density and the sampling and estimating procedure repeated for each subregion, e.g., stratification. This could reduce the variance. The S units of the region are divided into L strata where the density of the members (wheat acreage per unit area) of the L^{th} strata is approximately constant, e.g., establishment of uniformity or approximately equi-density subregions. The members of each strata are then sampled at random without replacement.

For the L strata the equations for the parameter being estimated

---

*See page 92A

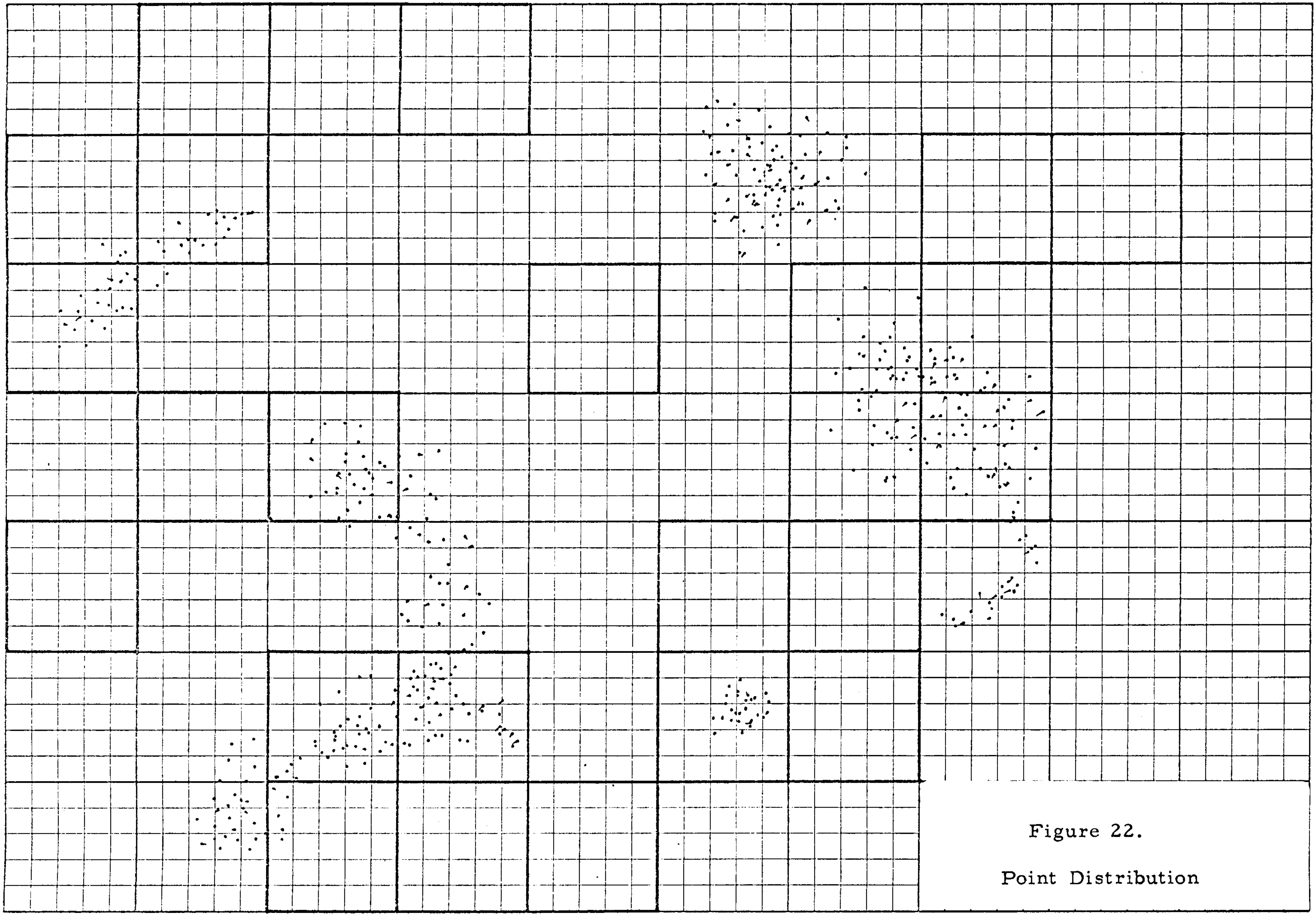


Figure 22.

Point Distribution

from Equation 6 is given by:

$$9. \quad y_1 = N_1 \cdot \frac{1}{n_1} \sum_{i=1}^{n_1} p_{i_1}(y)S_{i_1}$$

$$\vdots$$

$$y_L = N_L \frac{1}{n_L} \sum_{i=1}^{n_L} p_{i_L}(y)S_{i_L}$$

where

$$p_{i_L}(y) \cong \text{constant}, \; N_1 + N_2 + \ldots N_L = S$$

and

$$10. \quad y_T = \sum_{h=1}^{L} y_h$$

3.5 CELL SIZE, VARIANCE AND SAMPLE FRACTION

The question of cell size can be explored from another point of view. In a square region (R) there is one number Y_T which is the sum of the population of interest arbitrarily distributed within (R). If R is divided into 4 equal parts:

$$Y_T(4) = \sum_i^4 y_i$$

Continuing the sub-divisions gives the infinite continium of levels:

$$1. \quad Y_T = Y_T$$

$$2. \quad Y_{T(4)} = \sum_i^4 y_i$$

$$3. \quad Y_{T(16)} = \sum_i^{16} y_i, \; \ldots$$

$$\vdots$$

$$j. \quad Y_{T(k)} = \sum_i^{k} y_i$$

For each level, some fraction of the total number of cells in the region must be selected. Each cell must then be enumerated and a measurement made on the members of the population of interest within the cell. Note that it does not seem reasonable to divide Kansas into 4 cells, assume a sample fraction of .25, select one cell at random, perform all areal measurements within the cell and assume that the total crop acreage in Kansas was 4 times the crop acreage of the selected cell.

If the bounded region of interest in determining crop acreage is considered to be Kansas, one would want some sort of spacial dispersion of the selected cells over the entire state. Therefore, N should be large, but how large is large? Since the advantage of high altitide is large areal coverage it should be used. Planimetric measurements for hundreds of thousands of small areas need be minimized or eliminated. If satellite imagery is fragmented and disseminated on a county level for analysis, then the primary purpose of high altitude photography is not being utilized to advantage except where the facilities exist to do so.

The level of subdivision to be selected would seem to depend upon:

- statistical regularity of the information content
- absence of extreme values
- spacial homogeneity of the sample set relative to the spacial homogeneity of the population.

In the limit as the cells get smaller and smaller with respect to, for example, the size of the smallest fields and the size of field boundary irregularities, the ratio of the number of cells in the fields to those outside will approach the ratio of the total crop acreage to the area of the region. In this case, a dot grid could be superimposed over a photographic mosaic and a simple count of those dots falling within the field could be counted. The basis for this approach (from a non-statistical point of view) is the area within a closed contour can be approximated by gridding the region, locating a point at the center of each cell and counting the number of points which fall within the contour. The smaller the cell, the greater the accuracy of the area estimate. Preferably the number of selected cells and the number of enumerations (or measurements) within the cells should be minimal for the required precision of the prediction.

Some insight regarding cell size or N is provided by examining the formula for the standard error $\sigma_{\bar{Y}}$ of the mean.

The variance ($\sigma_{\bar{Y}}^2$) of the arithmetic mean of a random sample is given by:

$$1.\quad \sigma_{\bar{Y}}^{2} = \frac{1-f}{n} \; \frac{\sum_{i}^{N} (Y_i - \bar{Y})^2}{N-1}$$

when the samples are selected without replacement and:

$$2.\quad \sigma_{\bar{Y}}^{2} = \frac{1}{n} \; \frac{\sum_{i}^{N} (Y_i - Y)^2}{N}$$

when the samples are selected with replacement where f = n/N (sample frequency). It can be shown that the expected value of the sample variance is an unbiased estimate of the population variance when sampling without replacement, e.g.,

$$\sigma_{\bar{Y}}^{2} = \frac{\sum_{i}^{N} (y_i - y)^2}{n} = \frac{\sum_{i}^{N} (Y_i - Y)^2}{N}$$

where $\bar{y}$ is the sample mean and $\bar{Y}$ the population mean.
Equation 1 can be rewritten as:

$$3.\quad \sigma_{\bar{Y}}^{2} = \frac{1}{N}\left[\frac{1}{f} - 1\right] \sigma_{S}^{2}$$

or

$$4.\quad n = (1-f)\left[\frac{\sigma_S}{\sigma_{\bar{Y}}}\right]^2 \;;$$

$$5.\quad N = \left(\frac{1}{f} - 1\right)\left[\frac{\sigma_S}{\sigma_{\bar{Y}}}\right]^2$$

Equation 3 is the standard error of the mean and an unbiased estimate of the population variance as obtained from the sample data.

The computation of the standard error of the mean as a measure of statistical reliability and significance by Equation 3 is applicable whenever the population is finite in size and the size of the sample is appreciable in proportion to the size of the universe[15].

For infinitely large populations or the means of samples which are very small in conunction to the population[15] and when sampling with replacement, the standard error $\sigma_{\bar{y}}$ is computed by:

$$\sigma_{\bar{y}} = \frac{\sigma}{\sqrt{N}}$$

Equations 4 and 5 indicate that other factors being equal, changes in the sample fraction do not effect the number of required samples (n) as much as it does the total number of cells N. For small f, N becomes very large. It seems, therefore, that a more homogeneous spacial dispersion of n in N throughout R is given as N becomes large.

In the limit, if all the N cells are sampled without replacement the average cell density ratio $\bar{y}$ will approach the ratio of the total crop acreage A_c to the area of the region A_r, e.g.,

$$\bar{y} = \frac{A_c}{A_r} = \frac{A_{c1} + A_{c2} + \ldots A_{cn}}{NA_o}$$

We may specify:

1. Standard error of the mean $\sigma_{\bar{Y}}$ such that 99.7 chances out of 100 the mean of the random sample will not be farther away than 3 standard errors from the true average.

2. Sample frequency n/N

and determine the number of cells (N) for the region, e.g.,

$$N = \frac{\sigma_S^2}{\sigma_Y^2}\left[\frac{1}{f} - 1\right]$$

If $f = n/N = .1$ and $\sigma_{\bar{Y}} = .001$ such that $\bar{Y} = \bar{y} \pm .001$, or 99.7 chances out of 100, $\bar{Y} = \bar{y} \pm .003$, corresponding to a permissible error of .3% then,

5. $N = 9 \times 10^6 \sigma_S^2$

We see that N depends upon the spread of σ_S^2 which may be estimated from prior survey information. Furthermore, as the sample fraction becomes smaller, the coefficient of σ_S^2 increases and hence N increases for σ_S^2 = constant.

As σ_S^2 decreases, N decreases, e.g., the number of subdivisions of the region is reduced to achieve the desired reliability in the estimate of the average cell density. More simply, as the homogeneity of the population throughout the region increases, the number of cells required to estimate the <u>average cell density</u> decreases.

N is tabulated below for f = .1 and $\sigma_{\bar{Y}} = .001$ as a function of σ_S^2:

N	σ_S^2	n
1.8×10^6	.2	1.8×10^5
9×10^5	.1	9×10^4
9×10^4	.01	9000
9000	.001	900

Next consider the relative change in N for changes in sampling rate (f) and σ_S^2:

$$N = \left(\frac{1}{f} - 1\right)\frac{\sigma_S^2}{\sigma_Y^2}$$

$$\sigma_{\bar{Y}}^2 \, \Delta N = 2\left(\frac{1}{f} - 1\right)\sigma_S \, \Delta\sigma_S - \sigma_S^2 \frac{\Delta f}{f^2}$$

$$\frac{\Delta N}{N} = \frac{2\Delta\sigma_S}{\sigma_S^2} - \frac{\Delta f}{f-f^2}$$

Since $\Delta f < 1$, $f > \Delta f$ and $f^2 << f$, $\frac{\Delta f}{f-f^2} \lesssim 1$; and since $\Delta\sigma_S < 1$ for $y_i < 1$, $\sigma_S < 1$, $\sigma_S^2 << 1$, and $\frac{\Delta\sigma_S}{\sigma_S^2} \gtrsim 1$.

Therefore the relative change in N is more sensitive to changes in σ_S^2 than in the sampling rate.

σ_S^2 is influenced by the spacial distribution of crops in the region and the spacial distribution of the (n) selected cells mapped on to the N cells of the region.

The spacial distribution of the selected cells would seem to cover more possible spacial distributions of the fields if the selected cells were uniformly, but randomly dispersed throughout the region. The spacial dispersion and homogeneity of (n) in N would increase with N.

3.6 ESTIMATE OF A DISCRETE SUM AND A CONSEQUENCE

Let the equation for a trace be given by

1. $Y = Y(t)$

then the average $\bar{Y}$ over the interval T corresponding to the region is:

2. $\bar{Y} = \frac{1}{T} \int_o^T Y(t)dt$

The area under the trace is:

3. $A = \int_o^T Y(t)dt$

which can be iterated to provide discrete data over some increment of time Δt which might correspond to a cell width or area and the associated measure of crop acreage within the cell, e.g.,

$$A = \int_o^{1\Delta t} Y(t)dt + \int_{1\Delta t}^{2\Delta t} Y(t)dt + \ldots \int_{(N-1)\Delta t}^{N\Delta t} Y(t)dt$$

$$A = Y_1 + Y_2 + \ldots Y_N$$

$$A = (\bar{y}_1 + \bar{y}_2 + \ldots \bar{y}_N)\Delta t = \Delta t \sum_{i=1}^{N} \bar{y}_i$$

$$A = T\bar{Y} = N\Delta t\bar{Y} = \Delta t \sum_{i=1}^{N} y_i$$

$$N\bar{\bar{Y}} = \sum_{i=1}^{N} \bar{y}_i = Y_T$$

4. $\bar{Y} = \bar{\bar{y}}$

If there are N mutually exclusive y_i's or elements then the expected value $\bar{y}_i$ is given by:

5. $E\bar{y}_i = P_1\bar{y}_1 + P_2\bar{y}_2 + \ldots P_N\bar{y}_N$

6. $E\bar{y}_i = \sum_{i=1}^{N} P_i \bar{y}_i$

where P_i is the probability of selecting $\bar{y}_i$ at <u>any</u> drawing.

Suppose the $\bar{y}_i$'s are selected at random without replacement, then P_i can be calculated by determining the probability of drawing $\bar{y}_i$ or the i^{th} element on the j^{th} trial, e.g.,

7. $P_i = \sum_{j}^{N} P_{ij}$

If the probability of occurrence of an event is P_1 and if, after that event has occurred, the occurrence of a second event is P_2, etc., then the probability of occurrence of the events in succession is $P_1 P_2 \ldots P_{(j-1)}$.

The probability of an event not occuring in succession on the $(j-1)^{th}$ trial and occurring on the j^{th} trial is:

8. $P = (P_1, P_2, \ldots P_{j-1}) \cdot P_j$

When sampling without replacement, the probability P_i is given by:

9. $$P_i = \left[\frac{N-1}{N} \cdot \frac{N-2}{N-1} \cdot \frac{N-3}{N-2} \cdots \frac{N-(j-1)}{N-(j-1)+1}\right] \cdot \left[\frac{1}{N-j+1}\right]$$

which reduced to:

$$P_i = \left[\frac{N-1}{N} \cdot \frac{N-2}{N-1} \cdot \frac{N-3}{N-2} \cdots \frac{N-j+1}{N-j+2}\right] \cdot \left[\frac{1}{N-j+1}\right] = \frac{1}{N}$$

Therefore:

$$E\bar{y}_i = \sum_{i}^{N} P_i \bar{y}_i = \frac{\sum_{i}^{N} \bar{y}_i}{N} = \bar{\bar{y}} = \bar{Y}$$

e.g., <u>the expected value of each observation is the arithmetic mean of the population if simple random sampling is used.</u>

If we assume:

$$E\bar{\bar{y}} = \bar{Y}$$

where:

$$E\bar{\bar{y}} = \frac{E\sum_{i}^{n} \bar{y}_i}{n} = \frac{\sum_{i}^{n} E\bar{y}_i}{n}$$

then we have proven:

$$\bar{\bar{y}} = \frac{\sum_{i}^{n} \bar{y}_i}{n} = \frac{\sum_{i}^{n} \bar{Y}}{n} = \frac{n\bar{Y}}{n} = \bar{Y}$$

is an unbiased estimate of $\bar{Y}$ if simple random sampling is used to select (n) y_i's for estimating a discrete sum Y_T over the interval $T = N\Delta t$, e.g.,

$$Y_T = N\bar{Y} = N\bar{\bar{y}}$$

where:

$$\bar{\bar{y}} = \frac{\sum_{i}^{n} \bar{y}_i}{n}$$

We note that a single y_n is also unbiased. Whether or not any given statistic is good depends upon how close the sample value is to the value of the statistical property in question.

For a continuous trace, y_i averaged over some increment Δt acts as a smoothing function for y(t). As the increment is increased the homogeneity of the discrete data increases. If the data is more homogeneous in magnitude the reliability of the estimated sum Y_T is increased. If the increment is considered the cell size for a 2-dimensional spacial distribution of fields and the trace is generated by gridding a region and tying consecutive rows or columns of cells together as abscissa values with their respective crop acreages as ordinates, smoothing would require either more planimetric measurements for each sample cell or an estimate of each cell acreage by subsampling, i.e., any estimating techniques applicable to a region containing N cells is applicable to the cell containing K subcells, etc.

If a region R is divided into N cells, each selected cell is divided into N subcells for sampling ad infinitum, the "cutoff" level or final subcell size specification should be that level for which the subcell is smaller than the smallest target area of interest. The cell would be filled or empty and therefore, counting rather than planimetric measurements are required.

For this limiting case, the ratio of the number filled to the number empty is expected to approach the ratio of crop area (A_c) to the area of the region (A_r). Therefore, it is applicable to all the cells in the region (R), e.g., a random distribution of "dots" can be located on a transparent overlay to reduce any photomosaic for target area. If the crop acreage is assumed to be random in size, boundary and location on the mosaic, a square dot grid can be generated. What are the required number of dots for a specified per cent error (E) in estimating A_c with a level of statistical significance (t) in a region (A_r)?

3.7 DEVELOPMENT OF DOT SAMPLING TECHNIQUE

If a random variable is sampled systematically or any variable at random with replacement, the variance of the sample mean is given by:

$$1.\quad \sigma_{\bar{Y}}^2 = \frac{1}{n^2} \sum_{n=1}^{n} \sum_{m=1}^{n} \left[E(y_n y_m) - \bar{y}^2\right]$$

where E is the expected value of the product of the n^{th} and m^{th} sample and $\bar{y}$ is the sample mean.

If the samples are highly correlated:

$$2.\quad E(y_n y_m) = E(y^2) \quad \text{and} \quad \sigma_{\bar{Y}}^2 = \sigma_y^2$$

which for areal sampling of crop acreage implied a constant density. Assuming the samples are uncorrelated (statistically independent or selected at random with replacement):

$$E(y_n y_m) = E(y_n)E(y_m) = m_y^2, \quad n \neq m$$

and Equation 1 **reduces** to:

$$3.\quad \sigma_{\bar{Y}}^2 = \frac{\sigma_y^2}{n}$$

For any region of N cells where $N \rightarrow \infty$ the expected error in the mean for finite sample set (n) is given by the Chebyschev inequality:

$$P(/\bar{Y} - \bar{y}/ \geq e) \leq \frac{\sigma_{\bar{Y}}^2}{e^2}$$

or

$$4.\quad P(/\bar{Y} - \bar{y}/ \geq e) \leq \frac{\sigma_y^2}{ne^2}$$

where: $\bar{Y} = \frac{A_c}{A_r} = \frac{\text{crop area}}{\text{area of region}}$ = true population mean density or proportion

σ^2 = variance as determined from the sample data
e = specified per cent error in estimating Y
$\bar{y}$ = sample mean

If the cell sizes are made sufficiently small with respect to the area of smallest field and the regularity of the boundaries such that each cell will be completely filled or completely empty, then the value associated with the cell will be 1 or 0 with a probability p and (1-p) respectively.

For a region of N cells let

$$p = \frac{\text{total crop area in the region}}{\text{total area of the region}} = \frac{A_c}{A_r}$$

The expected value of any selected cell should be:

5. $E(y_n) = p$ (the probability of occurrence)

since the expected value of each observation is the arithmetic mean of the population if simple random sampling is used:

$$E(\bar{Y}) = \frac{1}{n} \sum_{n=1}^{n} E(y_n) = \bar{y}$$

$$E(\bar{y}) = p.$$

e.g., the statistical average of the relative frequency of occurrence of an event is equal to the probability of occurrence of the event.

Since for uncorrelated samples:[38]

$$\sigma^2(y_n) = E(y_n{}^2) - E^2(y_n) = p-p^2$$

and

$$\sigma_{\bar{Y}}{}^2 = \frac{\sigma_y{}^2}{N} = E\ \sigma_{\bar{Y}}{}^2 = \frac{\sigma_y{}^2}{n}$$

6. $\sigma_{\bar{Y}}{}^2 = \frac{p(1-p)}{N} = E\ \sigma_{\bar{Y}}{}^2 = \frac{p(1-p)}{n}$

The maximum variance of the mean occurs when $p = \frac{1}{2}$.

Then: $$\sigma_{\bar{Y}}^2{}_{max} = \frac{1}{4N} = E\sigma_y^2 = \frac{1}{4n}$$

Using the Chebyschev inequality:

$$P\left[\left|\frac{A_c}{A_r} - p\right| \geq e\right] \leq \frac{p(1-p)}{ne^2} \leq \frac{1}{4ne^2}$$

e.g., the probability that the difference between the relative frequency $E(Y) = y = n(A/n)$ where $(A = 1)$ as determined from the data and the estimated p is greater than or equal to a specified error (e) in estimating Ac/Ar will be less than or equal to $1/4\ ne^2$ where n is the number of selected cells in the region R.

Since the variance of the relative frequency tends to zero as $n \to \infty$ it can be shown that the relative occurrence of an event converges in probability to the probability of occurrence of that event as the number of uncorrelated samples increases without limit.

We note from the equations for uncorrelated samples that:

$$\sigma_p^2 = \frac{p(1-p)}{n}$$

or

$$7.\quad n = p(1-p)\left(\frac{1}{\sigma_p}\right)^2$$

If the true ratio p_T of crop acreage to regional area is:

$$8.\quad p_T = p_t \pm E$$

and E is the error in the proportion, then based upon the sample data

$$p_T = p_t \pm t\,\sigma_p$$

where

$$9.\quad E = t_\gamma\,\sigma_p$$

and t_γ is the reliability of the estimate or level of statistical significance. Substituting σ_p into Equation 7 gives:

$$10.\quad n = p(1-p)\left[\frac{t}{E}\right]^2$$

e.g., a sample of size n guarantees a probability not greater than γ ; that an estimate of p is in error by more than E. This equation gives the number of required samples knowing approximately p and specifying E and t; note that:

$$p(1-p)_{max} = .25 \text{ when } p = .5; \quad n_{max} = .25 \left(\frac{t}{E}\right)^2$$

Since E is the specified error in the proportion, Equation 8 may be rewritten:

$$\frac{A_{cT}}{A_r} = \frac{A_{ct}}{A_r} \pm E$$

11. $A_{cT} = A_{ct} \pm EA_r$

where E is the specified error in the total area. If:

12. $U_c A_c = EA_r$

where U_c is the specified error in A_c (crop area), then:

13. $E = \frac{U_{ct} A_c}{A_r} = U_{ct} p$

Substituting $U_{ct}p$ for E in Equation 10 gives:

14. $n = \frac{1-p}{p} \left[\frac{t}{U_c}\right]^2$

Note: That as $p \to 0$; $n \to \infty$ (no maxima); e.g., as A_c becomes very small with respect to A_r, the number of sample points in A_r must increase to insure the specified reliability in the estimate of A_c.

Crop acreage is calculated from the sample using the identity:

15. $\frac{A_c}{A_r} = \frac{\text{number of dots within fields of interest}}{\text{Total number of dots in the region}}$

One point remains regarding Equation 14. If a region with a proportion p_T is divided into 4 equal subregions with known unequal p_i's:

16. $n(p_T) \neq n(p_1) + \ldots n(p_4)$

e.g., the number of sample points for the total region is not equal to the sum of the number of samples for the subregions. Since an areal proportion is infinitely variable between zero and unity, the use of Equation 14 and subsequent specifications of the size of the region seems completely arbitrary unless empirical judgements tempered with sufficient experience varified by empirical proof can provide the answer.

3.8 APPLICATION OF DOT SAMPLING TO PHOTOGRAPHIC MOSAIC OF KANSAS

It is customary to determine the number of sample dots based upon the assumption that the number counted for a given accuracy depends upon the estimated proportion. In otherwords, prior knowledge of the per cent area in "crops" are required to estimate the number of dots for the region. If the proportion of crop area to regional area is less than .5, p is taken to be the largest reasonable guess. If the proportion is greater than .5, p is taken to be the smallest reasonable guess[29].

Grids with 64 dots/square inch are commonly used with 1:20, 000 photographs. Each dot represents .996 or approximately 1 acre[33].

As shown in Table 10, 92.8% of wheat planted acreages for the United States was located in 17 states where:

$A_r = 953.84 \times 10^6$ acres
$A_c = 53.02 \times 10^6$ acres
$p = .0556$

If the per cent error (U_c) in determining the crop acreage is 1 per cent with a statistical reliability (t) of 1.96, then for the above region the number of dots is:

652, 000 dots or 1463 acres/dot.

The state of Kansas represented 20% of the United States wheat acreage (1965). If:

$U_c = 1\%$
$t = 1.96$
$A_c = 11.39 \times 10^6$ acres
$A_r = 52.66 \times 10^6$ acres
$p = .216$

the number of sample dots is 139, 400 or 378 acres/dot.

The primary advantages of a dot grid for large scale area estimations are:

- dot grids are easily made
- no planimetric measurements are required

- questions regarding definition of a "field" and any involved associative classification procedures (whether or not a field belongs to a given farm, etc.) are avoided.

The advantage of high altitude imagery is the scale of observation. Satisfactory ground resolution (less than 50 ft.) permit a variable scope of observation ranging from thousands of square miles to less than one acre from one primary data base.

The scale of observation capability of satellite imagery versus the scale of interest is important. We are faced on one hand with an enormous areal coverage and on the other, areal targets of interest which may be smaller than one acre. The Continental United States contains 3×10^6 sq mi or approximately 2×10^9 acres.

The ground resolution of one frame may contain 3600 sq mi or 4767.9 sq mi of which the unaided eye can resolve 1/254 inch. A 9"x9" photographic frame would have a ground scale of 1" = 7.67 mi or 40,508 ft. The unaided eye can resolve an area $(1/254)^2$ or $(159.4 \text{ ft})^2$ - something less than an acre.

The entire Continental United States can be imaged on 629 9"x9" frames each with a ground coverage of 3600 sq n. mi. The ground scale on the aerial photo in Chapter 1 is about 1" = .91 miles. An enlargement of about 8.42X would give the same scale (1" = .91 miles) to the satellite imagery. Each enlarged master frame would be 75.6 x 75.6 inches. For a map scale of 1" = .91 mi = 4805 ft, the eye can resolve an area about 19 x 19 sq ft. comparable to the obtainable photographic ground resolution limit at 200 nautical miles altitude.

Complete coverage of Kansas subject to the above photographic requirements would result in (representative) 17-1/4 mosaics each 75.6 x 75.6 inches. To estimate crop acreage (A_c) within 1% with the specified statistical reliability, a dot grid would be superimposed over the mosaic. The grid size would be .841" x .841" with one dot located in the center of each square for a total of 8081 dots.

Note: Kansas = 82,276 sq mi

$$\frac{82,276 \text{ mi}^2}{4767.9 \text{ mi}^2/\text{frame}} = 17.25 \text{ frames}$$

$$\frac{5715 \text{ in}^2}{\text{mosaic}} \times 17 + 5715 \times .25 = 98,584 \text{ in}^2$$

$$\frac{98,584 \text{ in}^2}{139,400 \text{ dots}} = .7072 \text{ in}^2/\text{dot or } .841'' \times .841'' \text{ grid}$$

$$\frac{5715\ \text{in}^2/\text{mosaic}}{.7072} = 8081\ \text{dots/mosaic}$$

Each mosaic would consist of:

Coverage: 69.05 x 69.05 $(\text{mi})^2$
Size: 75.6 x 75.6 $(\text{in})^2$
Scale: 1" = .91 mi.

comparable to the aerial photograph in Chapter 1.

Assuming appropriate color differentiation, a great number of land usage targets could be estimated very accurately and very rapidly by overlaying the mosaic with a systematic grid of dots sized to determine the percentage of interest.

The preceding statement needs to be analyzed. To use a dot grid satisfactorily on a mosaic of Kansas, ideally the wheat fields should "stand out" in a unique characteristic color. Then a rapid count of the dots falling within a field can be made. <u>But, if such physical discrimination was possible, then the whole mosaic could be enumerated 100% automatically by a scanning device and hence "sampling" would not be needed</u>. Nevertheless, for a wide range of land usage identifible by rapid observation of the mosaic, the dot sampling would be a quick way to estimate percentage of areal land usage. Adequate discrimination of some areal targets not amenable to machine analysis on a gross scale by appropriate mapping may permit the nature of the spacial distribution and population density to be established over thousands of square miles allowing stratification and bounding of relative homogeneous subregions for enumeration.

3.9 CLOUD COVER AND AREAL SAMPLING

The dot sampling technique applied to a photographic mosaic obtained from orbiting satellites need be altered to accommodate the cloud cover masking of terrain areal targets.

If the probability of occurrence of 2 independent events are p_1, p_2, then the probability that both events will occur is:

$$p = p_1 p_2$$

If the probability of a dot falling upon a cloud is:

1. $p_1 = \frac{Acc}{Ar} = \frac{\text{cloud area}}{\text{region area}} = \%$ cloud cover

and the probability of a dot falling upon a wheat field is:

$$2.\quad p_2 = \frac{Ac}{Ar} = \frac{\text{crop area}}{\text{region area}}$$

then the probability of a dot falling on both a cloud and a field is:

$$3.\quad p^* = p_1 p_2$$

The number of dots required to sample this combination is given by:

$$4.\quad n^* = p^*(1 - p^*) \left[\frac{t}{E^*}\right]^2$$

where (t) denotes the level of statistical significance and E* is the specified error in the true proportion $p_T{}^*$, e.g.,

$$5.\quad p_T{}^* = p_t{}^* \pm E^*$$

$$6.\quad E^* = t\,\sigma_y{}^*$$

Since Equation 5 can be rewritten:

$$7.\quad \frac{A_{cc_T} A_{c_t}}{A_r{}^2} = \frac{A_{cc_t} A_{c_t}}{A_r{}^2} \pm E^*,$$

E* also is the specified or maximum permissible error expressed as a per cent of the square of the regional area.

The number of dots required to sample the crop area A_c is given by:

$$8.\quad n_c = p_2(1 - p_2) \left[\frac{t}{E}\right]^2 \qquad p_2 = \frac{A_c}{A_r}$$

where E is the maximum permissible error expressed as a per cent of the regional area, e.g.,

$$9.\quad \frac{A_{c_T}}{A_r} = \frac{A_{c_t}}{A_r} \pm E$$

E* may be related to E in the preceding section by:

$$10.\quad E^* A_r{}^2 = E A_r$$

An estimate of crop area ψ is then obtained by:

11. $\psi = \psi^* + \psi_c$

where from Equation 4 and 8:

$$\psi^* = \frac{n(\text{number of dots falling on a cloud assumed to obscure a field})}{n^* (\text{total number of sample dots})} \times A_r$$

and

$$\psi_c = \frac{n(\text{number of dots falling on a field})}{n_c (\text{total number of sample dots})} \times A_r$$

CHAPTER 4

SYSTEMS REQUIREMENTS

4.1 INTRODUCTION

It is the purpose of this chapter to:

- establish those systems ground resolutions compatible with the target requirements discussed in Chapter 2 at orbital altitudes

- bracket the system (photographic) requirements which will provide maximum coverage compatible with the orbit requirements in Chapter 5 (1° longitude swath width) and a ground resolution compatible with the majority of targets of interest (10 to 20 ft.)

Since this will result in only a small segment for integration into a total system concept, a descriptive map is given in Figure 23 to allow the reader a more clearly defined choice pattern for realistic solution to the complicated problem of obtaining intelligence from orbital surveys.

An orbital survey is a total remote sensing problem; therefore, a complete program analysis must be conducted covering all interrelated functions within the framework of:

- mission definition
- orbital data gathering system definition
- ground support control system definition

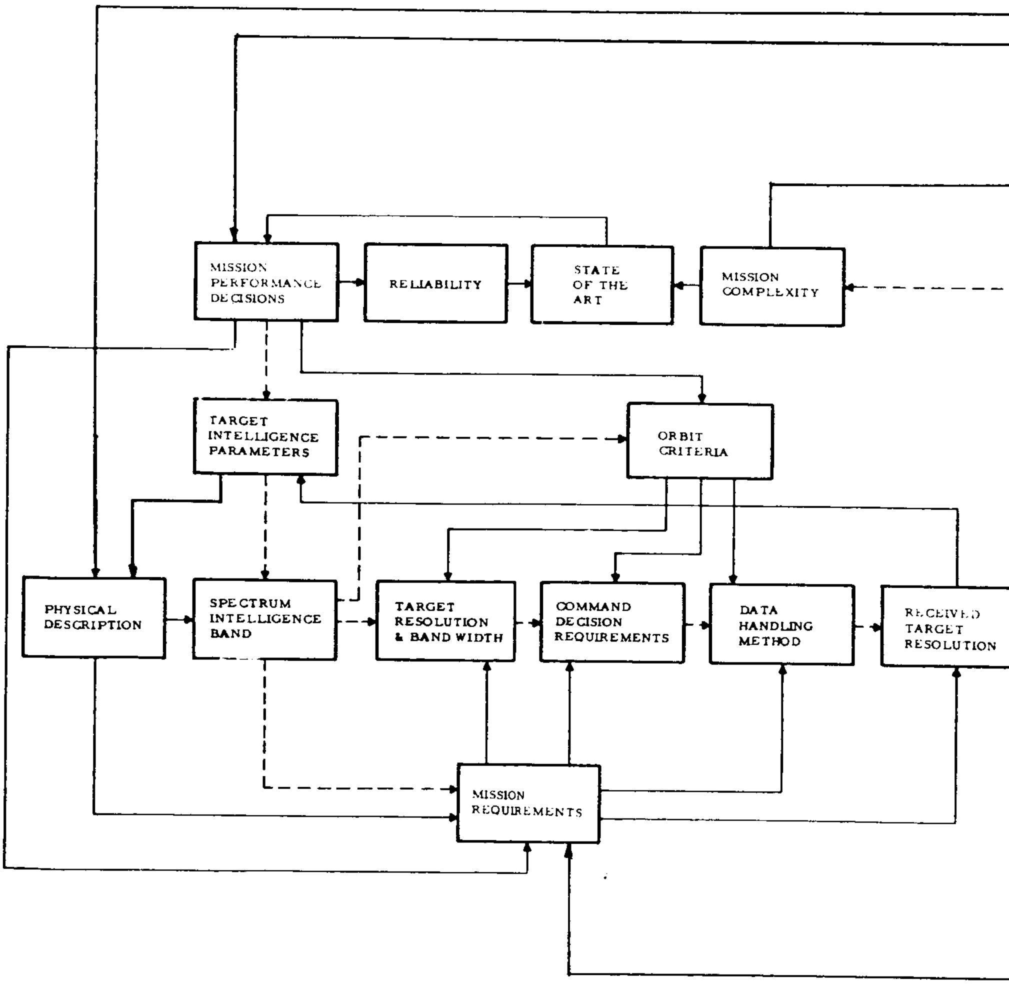
The accompanying chart (Figure 23) has been prepared to present the functional interrelationships or decision criteria subject to a basic analytical requirement:

All specifications and parameters must be integrated within a total program analysis. Should any parameter be exceeded, a proposed alternate component solution must be cycled completely through the program analysis to undercover any discrepancies. The basis for this requirement is simple. For any discrete interacting intelligence system it does not necessarily follow that:

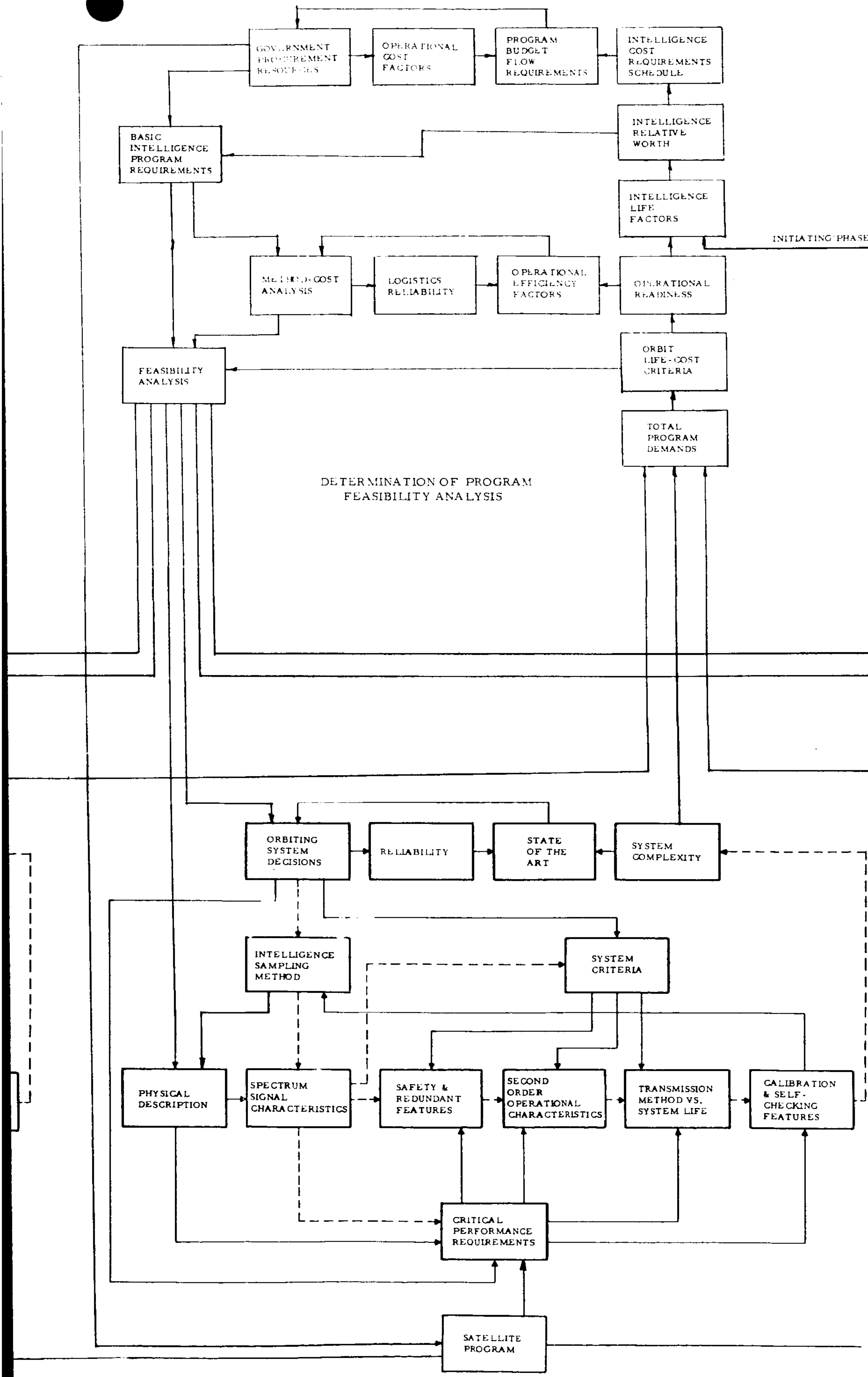
$$A+B = B+A$$

e.g., a specification of A is not automatically compatible with B or vice versa or their interacting sum C obtained by adjusting A to B or B to A is not

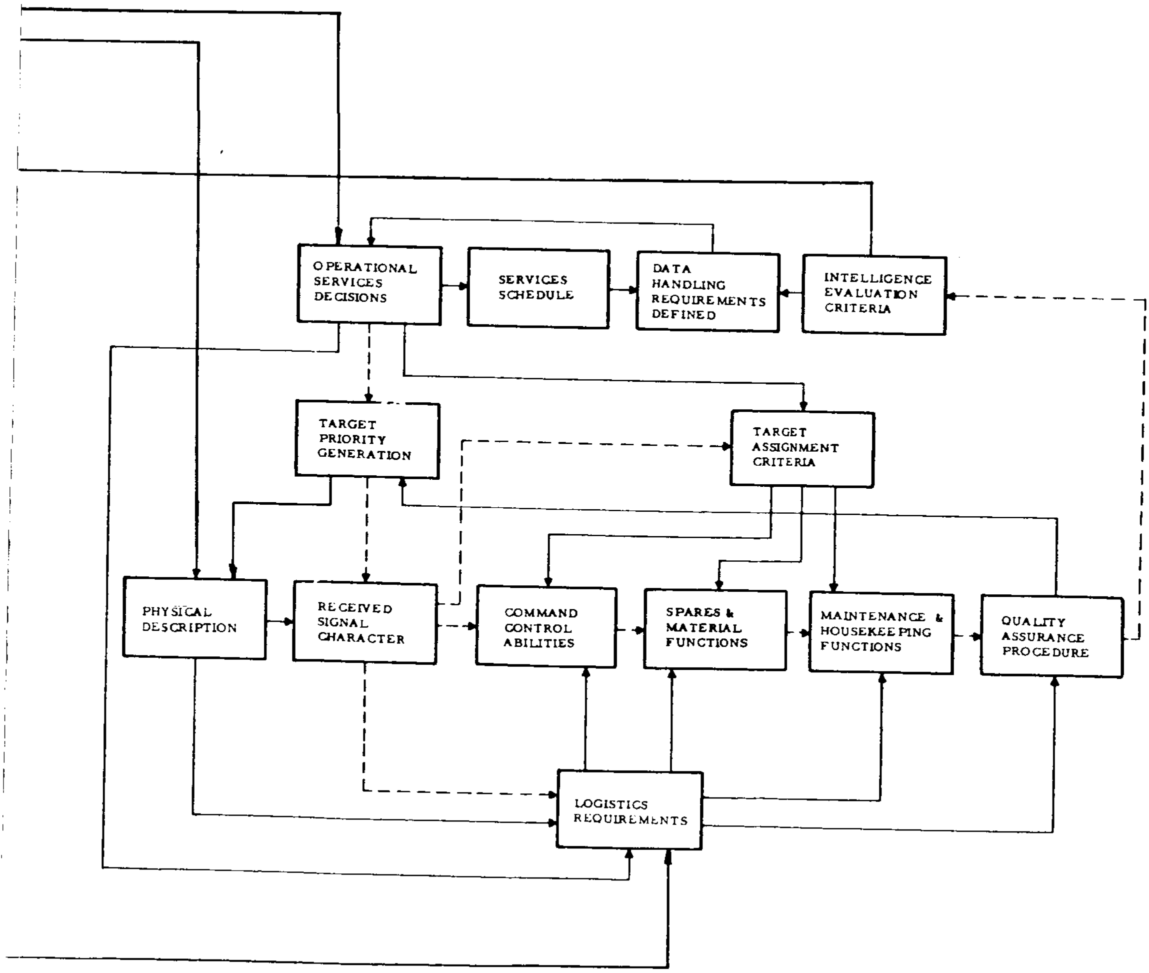
Figure 23.


MISSION PERFORMANCE DECISIONS
RELIABILITY
STATE OF THE ART
MISSION COMPLEXITY
TARGET INTELLIGENCE PARAMETERS
ORBIT CRITERIA
PHYSICAL DESCRIPTION
SPECTRUM INTELLIGENCE BAND
TARGET RESOLUTION & BAND WIDTH
COMMAND DECISION REQUIREMENTS
DATA HANDLING METHOD
RECEIVED TARGET RESOLUTION
MISSION REQUIREMENTS

DETERMINATION OF MISSION DEFINITION


GOVERNMENT PROCUREMENT RESOURCES
OPERATIONAL COST FACTORS
PROGRAM BUDGET FLOW REQUIREMENTS
INTELLIGENCE COST REQUIREMENTS SCHEDULE
BASIC INTELLIGENCE PROGRAM REQUIREMENTS
INTELLIGENCE RELATIVE WORTH
INTELLIGENCE LIFE FACTORS
INITIATING PHASE
METHOD-COST ANALYSIS
LOGISTICS RELIABILITY
OPERATIONAL EFFICIENCY FACTORS
OPERATIONAL READINESS
FEASIBILITY ANALYSIS
ORBIT LIFE-COST CRITERIA
TOTAL PROGRAM DEMANDS
DETERMINATION OF PROGRAM FEASIBILITY ANALYSIS
ORBITING SYSTEM DECISIONS
RELIABILITY
STATE OF THE ART
SYSTEM COMPLEXITY
INTELLIGENCE SAMPLING METHOD
SYSTEM CRITERIA
PHYSICAL DESCRIPTION
SPECTRUM SIGNAL CHARACTERISTICS
SAFETY & REDUNDANT FEATURES
SECOND ORDER OPERATIONAL CHARACTERISTICS
TRANSMISSION METHOD VS. SYSTEM LIFE
CALIBRATION & SELF-CHECKING FEATURES
CRITICAL PERFORMANCE REQUIREMENTS
SATELLITE PROGRAM

DETERMINATION OF ORBITING DATA GATHERING SYSTEM DEFINITION


OPERATIONAL SERVICES DECISIONS
SERVICES SCHEDULE
DATA HANDLING REQUIREMENTS DEFINED
INTELLIGENCE EVALUATION CRITERIA
TARGET PRIORITY GENERATION
TARGET ASSIGNMENT CRITERIA
PHYSICAL DESCRIPTION
RECEIVED SIGNAL CHARACTER
COMMAND CONTROL ABILITIES
SPARES & MATERIAL FUNCTIONS
MAINTENANCE & HOUSEKEEPING FUNCTIONS
QUALITY ASSURANCE PROCEDURE
LOGISTICS REQUIREMENTS

DETERMINATION OF GROUND SUPPORT CONTROL SYSTEM DEFINITION necessarily the optimum solution to C within the framework of a total program.

The initiating phase of a system decision tree to program feasibility is chosen to be a description of the characteristics of the desired intelligence. From this is derived the relative worth of the useful data. First order costs are set to a schedule for budget evaluation. Proposed program budget flow must be viewed in the light of procurement resources for compatibility. If the program budget is acceptable, operational cost factors are described in usual procurement terms and checked for compliance with the original schedule. When a balance is gained, a basic intelligence program requirement relating relative worth, cost and schedule parameters is written. From this document a second order cost analysis is conducted, scrutinized for obvious logistics and reliability extremes, compared with acceptable operational efficiency factors and then combined to provide a feasibility analysis that can justify procurement planning. No procurement is done obviously, but if the feasibility analysis is sufficiently comprehensive it will hold up under criticism.

The output of the feasibility analysis is used to better describe the mission performance and physical description of the target intelligence parameters. The performance thus described is stated in terms of reliability and compared with known state-of-the-art system parameters. The target intelligence parameters can now be applied to acceptable specific frequency bands, i.e., infrared, visual, etc. The basic orbit criteria and a mission requirement definition yields target resolution and data bandwidth limits. Some flexibility can be exercised here by changing the spectrum and orbit criteria if the resultant resolution is not what was desired. Command requirements of the system and vehicle will allow determination of a data handling method. This is the most extensive and comprehensive study, for the decision of how to store, retrieve and transform the data into intelligence will affect more of the total program than any other single decision. When the method is selected, system requirements compatible to target acquisition and vehicle constraints are generated to describe the mission complexity and this is rechecked with the state-of-the-art, performance and reliability of present and future systems.

The mission characteristics should then be sufficiently defined to warrant primary consideration of the orbiting system and the effect upon mission and system performance.

The first task in the definition of the orbital data gathering system is to formulate some basic decisions about the orbiting system and based upon what we know, determing the intelligence sampling method and physical description. The resulting specific spectrum signal characteristics and other inputs yield the critical performance requirements. Safety and redundant features and second order operational characteristics as modified by the (orbit) system criteria complete the necessary inputs for an analysis of the selected data transmission method versus the system operational life. This analysis can be very encompassing if desired, including cost effectiveness trade-offs, worth depreciation, etc. In order to assure operational effectiveness, calibration and checking features are added to complete the system complexity picture. Here many details are re-evaluated - power, weight, cost, life, etc., and recycled through state-of-the-art, system descriptions and reliability.

Ground support control system definition service decisions are compared with the affected operational services schedule. The function of data handling requirements definition must describe the quantity as well as the quality and method of intelligence discrimination in real time as it will apply when the system is in operation. The actual act of data reduction and analysis offtimes becomes an unplanned for tidal wave that renders the complete program useless. Targets described as to priority and their descriptive parameters should yield a realistic received signal character. The command control, spares and maintenance functions can be defined by target assignment criteria. Logistics requirements modified by the general satellite program and housekeeping functions will determine procedures for active quality assurance. The output now is the criteria regulating the intelligence evaluation. Again, this is recycled through data handling, operational and services characteristics for compatibility.

Having completed the three subsections, the complexities of each are assembled. The mission, systemand the resulting intelligence evaluation grade the fulfillment of the total program demands. Applicable information is fed to life-cost assumptions and operational readiness factors. Operational efficiency factors are recycled for acceptance with method-cost, logistics and reliability parameters. When the cycle is completed, the critical and last test is the final comparison of what is obtained versus what was expected. The stopping point is a rewritten and more comprehensive feasibility analysis which now contains all relevant factors necessary for program initiation.

4.2 BASICS

Remote sensing is a target/system/enviromment dependent problem. Specification of the target and associated frequency dependent signature within a given environment defines the type of system and outlines the requirements for data acquisition. Signature as used in this context refers to the nature of an electromagnetic energy exchange process of a target as a reflector or emitter of energy.

Generally the nature of the energy exchange which is to be detected in an active (radar) or passive (IR, visual) mode is a geometric and substance dependent function of frequency. Hence, the use of different sensing frequencies by a system may disclose more information associated with the physical properties of the object other than shape which may be used for identification.

In the case of terrain analysis, the common useful method of display has been imagery, e.g., a two dimensional recording of a complex energy exchange process. Cameras, infrared and radar systems operating in different frequency ranges and with an image display or recording unit are useful for terrain analysis. Any terrain image is useful regardless of the spectral band being sensed. Usefulness depends upon the value of the required intelligence. Resolution and contrast are of primary importance in the extraction of intelligence from imagery. Cameras, infrared and radar systems have a decreasing resolution capability; however, environmental influences may warrant sensor selection on a basis other than resolution. Table 13 is a ranking of sensors for earth observation subject to both general environmental and resolution needs.

TABLE 13[18]

SENSOR MATRIX FOR EARTH OBSERVATIONS

Function	Photo-Optical (camera)	Image Tube (TV)	Point Detector (Infrared)	Radar
High Resolution				
Broad coverage	1	3	4	3
Narrow coverage	1	2	4	2
Low Resolution				
Broad coverage	2	1	2	4
Clear Weather				
Day	1	3	4	3
Night	4	3	1	2
Cloudy Weather	4	4	4	1
Rapid Data Return	2	1	1	1

Photo-optical systems are more capable of higher resolution for broad or narrow coverage than image tube or TV systems. Where low resolution broad coverage is a requirement, image tube systems are more useful, especially where data transfer from satellite to earth is a consideration. The resolution needs for mapping the greatest number of targets, regardless of size at high altitudes and the developing target discrimination capability of multispectral techniques in the visual portion of the spectrum suggests a limitation of the study to primarily photographic systems.

4.3 GENERAL SYSTEMS CAPABILITY

Photographic, image tube, and radar systems for earth observation from satellites are subject to three interrelated specifications:

- resolution
- swath width
- altitude

which may be limited by vehicle size, power, system sensitivity and telemetry requirements.

Figure 24 is a nomogram of maximum resolution versus maximum slant range parameters in systems capability present and future. Since slant range altitude and swath width are functionally related, a second nomogram is provided to associate maximum ground resolution with altitude and maximum swath width subject to specification of the slant range.

Slant range is related to the beam width or field of view of the system and may define the system size subject to limitations by the vehicle and/or the attenuation properties of the atmosphere. The field of view is a function of the aperture size and focal length.

The maximum ground resolutions achievable with existing (1965) systems at 200 nautical miles altitude, if subject to no vehicle constraints (size, weight, power, control, etc.), are:

Infrared & Radar	174.0 ft.
Image Tube	11.6 ft.
Film (1965)	5.8 ft.
Film (1970)	2.3 ft.

Mapping missions are concerned with area coverage. Television and radar systems are capable of large swath widths perpendicular to the ground track, but limited in strip width parallel to the ground track. Figures 25 & 26 give the practical limiting strip widths as a function of altitude for ground resolution of 20 & 1000 ft. Photo-optical sensors are optics limited in altitude and horizon-atmosphere limited in strip width. Image tube limitations are due to optics size in maximum altitude and the number of resolution elements on the image tube cathode in strip width.

Characteristic television camera tubes and their equivalent optical resolution in lines/mm are given in Table 14. Approximately 47 lines/mm is the maximum equivalent resolution for these tubes which may be compared with film resolutions ranging from 100 lines/mm to a possible 1000 lines/mm[16]. Appendix E is a tabulation of satellite TV systems and their significant characteristics.

Infrared scanning systems in the 2.0 - 14.0 micron region are limited in ground resolution to a few hundred feet at 200 nautical mile altitude for estimated apparent temperature differences of less than a .1° K.

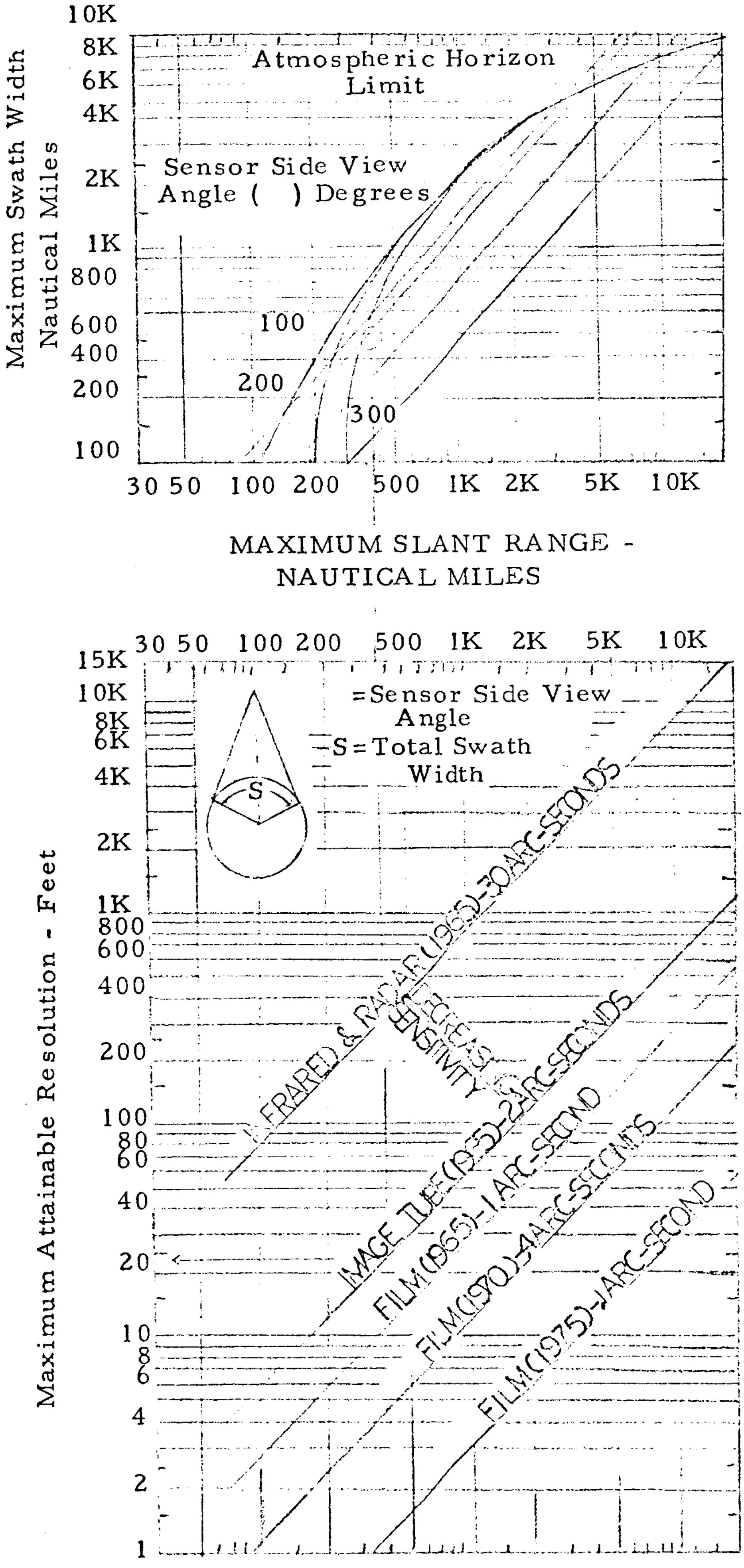


Figure 24 Observation Sensor Capabilities

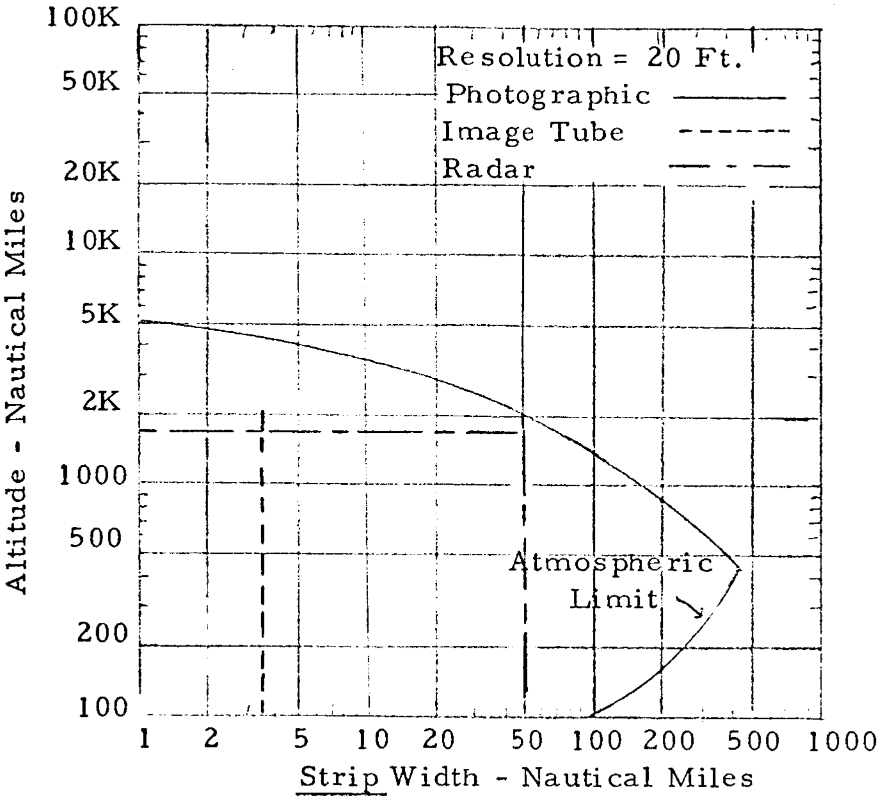


Figure 25 Limits of Area Coverage for 20-foot Resolution.

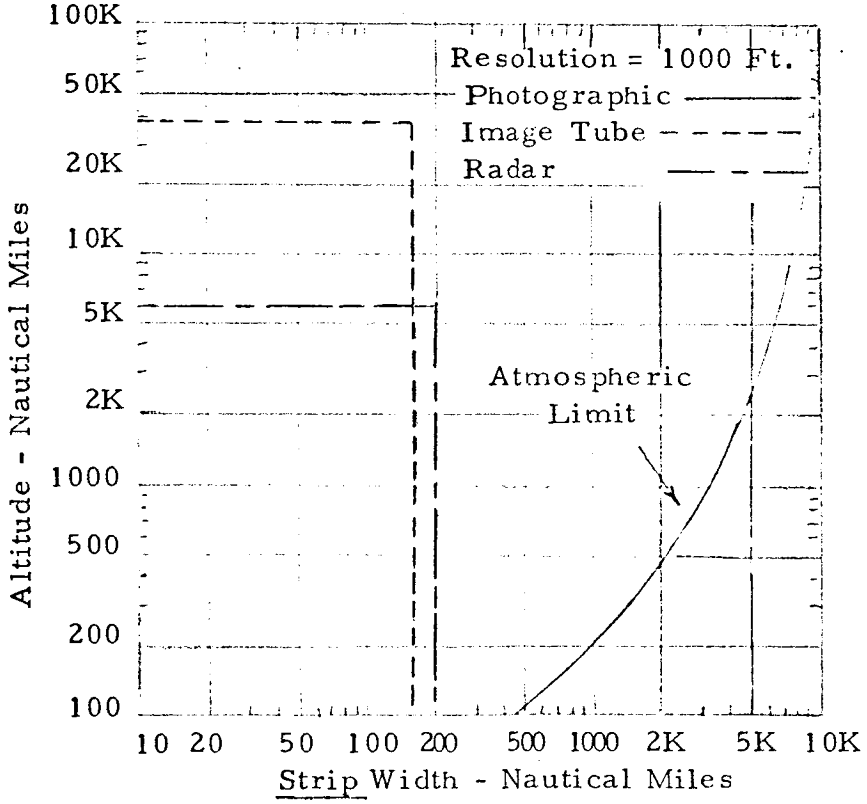


Figure 26 Limits of Area Coverage for 1000-foot Resolution.

TABLE 14[35]

CHARACTERISTICS OF REPRESENTATIVE TELEVISION CAMERA TUBES

Source: Manufacturers' Data

Camera Tube Type	Nominal Diameter (inches)	Designation	Development Status	Photosensitive Surface		Vertical Resolution TV Lines Per Raster	Equivalent Optical Lines/MM	Remarks
				Raster Format (inches)	Maximum Dimension (inches)			
VIDICON	0.5		Special	0.25 x 0.25	0.35	500	40	
	1.0	6198	Production	0.5 x 0.375	0.62	600	32	Industrial; Blue-Green Sensitive
	"	6326	"	"	"	"	"	Broadcast
	"	6326-A	"	"	"	"	"	Broadcast; Visible Illumination
	"	7038-A	"	"	"	"	"	Broadcast
	"	7262-A	"	"	"	900	47	Industrial
	"	7290	"	0.95 x 0.375	0.92	600	32	Slow Scan
	"	7325	"	0.5 x 0.375	0.62	600 +	32 +	Industrial
	"	7697	"	"	"	?	?	Auto-Sensitivity Control
	"	7735-A	"	"	"	900	47	Industrial;Broadcast
IMAGE ORTHICON	3.0	WX-4323	Development	1.3 x 1.0	1.6	600	12	High Horizontal Resolution; 10 Sec. Storage
	"	Z-5294	"	1.4 x 1.1	1.8	500	9	Low Light Level
	"	Z-5358	"	"	"	500 +	9 +	Ruggedized
	"	Z-5395	"	"	"	?	?	Red-Infrared
	"	5820	Production	"	"	350	6	Broadcast
	"	6474	"	1.3 x 1.0	1.6	525	10	Broadcast
	"	7198	"	"	"	625	12	Ruggedized
	"	7293	"	1.4 x 1.1	1.8	?	?	Broadcast
	"	7629	"	"	"	?	?	Ruggedized
	"	7611	"	"	"	?	?	Broadcast

TABLE 14[35] (Cont.)

Camera Tube Type	Nominal Diameter (inches)	Designation	Development Status	Photosensitive Surface		Vertical Resolution TV Lines Per Raster	Equivalent Optical Lines/MM	Remarks
				Raster Format (inches)	Maximum Dimension (inches)			
	4.5	7295-A	Production	1.3 x 1.0	1.6	800	16	Broadcast
	"	7389-A	"	"	"	"	"	Broadcast
IMAGE DIS-SECTOR	4.5		"	2.20 x 1.65	2.75	1000	12	Variety of Aperture Square Aperture

Systems resolution exclusive of infrared scanners and radar systems overlap the ground resolution for a majority of targets as discussed in Chapter 2. Therefore, in conclusion, the majority of targets can be imaged at orbital altitudes subject to sufficient contrast with the background. Figure 27 is a chart of earth observation vehicle costs as a function of altitude for 20 & 100 ft. ground resolution. At altitudes less than 500 nautical miles, cost for photography are less than other types of sensing systems. The costs include R&D, production and operations cost estimates for one vehicle. Table 15 is a list of successful space photography flights for reference and further target discrimination studies.

Telemetry requirement for transmission of data is important. For example, the transmission of a 9"x9" photograph at 100 lines/mm resolution with a transmission bandwidth of 4.25 mc/sec requires approximately 30 minutes. One thousand non-overlapping photographs of the United States would require 20.8 days of continuous transmission[16]. Reception of transmission is limited to approximately 10 minutes per station pass[16].

4.4 PHOTOGRAPHIC SYSTEM PERFORMANCE PARAMETERS

Photographic systems have the primary advantage of high resolution, broad coverage, and a possible crop discrimination/identification when used with appropriate film/filter combinations.

Relatively common aerial photographs in use today have a photographic scale of 1:20,000. The photograph in Figure 1 has a scale of 1:58,000. Theoretical possible scale factors of 1:75,000, 250,000 & 750,000 at orbital altitudes along with the ground and system resolution are shown in Table 16. (The basis for these calculations and the meaning of spacial resolution as applied to visual photographic systems is given in Appendix B.)

TABLE 16[16]

THEORETICAL RESOLVING POWER OBTAINABLE FROM A RECONNAISSANCE SATELLITE AT AN ALTITUDE OF 142 STATUTE MILES

Focal Length	Scale	Ground Resolution	
	Film Resolution:	40 lines/mm	100 lines/mm
12"	1/750,000	60 ft.	24 ft.
36"	1/250,000	20 ft.	8 ft.
120"	1/75,000	6 ft.	24 ft.

Note: 240" focal length camera developed by USAF, film of 1000 lines/mm possible, 100 lines/mm common, Scale = 1/37,500

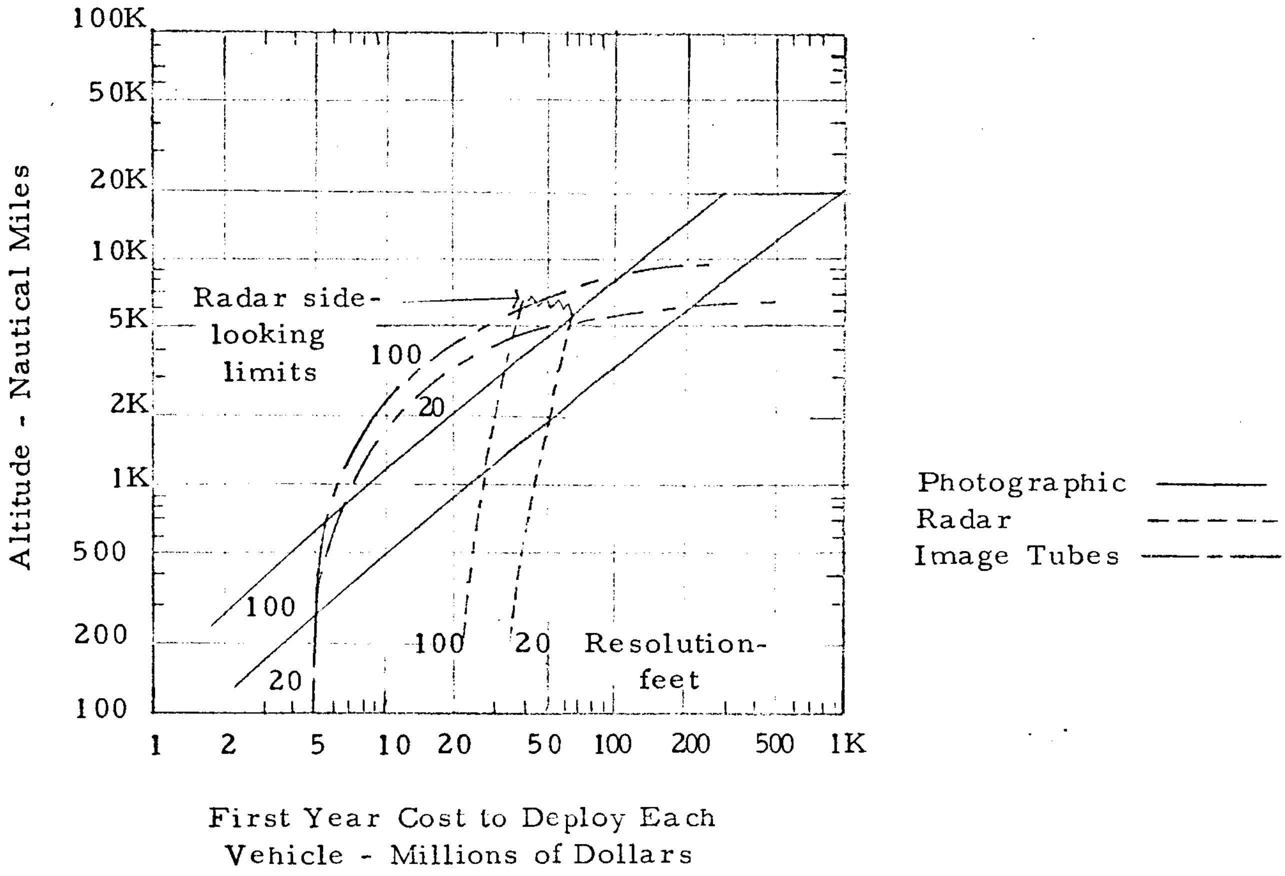


Figure 27 Earth Observation Vehicle Costs[18]

Includes:

1. DT&E Cost divided among initial deployment. Deployment assumes 40 to 6 vehicles from 100 to 20,000 nautical mile altitudes respectively.
2. Launch cost with existing launching vehicles.
3. First year operations cost.
4. Average production cost.

TABLE 15

SUMMARY OF SUCCESSFUL SPACE PHOTOGRAPHY FLIGHTS[17]

Vehicle	Date	Cameras	Film (Filter)*	Area	Altitude (mi.)
V-2	1946	35 mm. Motion	Super XX (25A)	SW U.S.A.	76
V-2	1947	K-25 Aircraft	Infrared Reconnaissance Base (25A)	SW U.S.A.	100
Aerobee and V-2	1946-50	K-25 Aircraft	Aerographic Super XX (25A)	SW U.S.A.	60-80
		35 mm. Motion Picture	Eastman IN Spectroscopic (29A)	SW U.S.A.	
		16 mm. Gunsight	Kodachrome	SW U.S.A.	
Vikings 11 and 12	1954-55	K-25 Aircraft	Eastman Hi-Speed Infrared	SW U.S.A.	Up to 158
Atlas	1959	16 mm. Time-lapse	Recordak Fine-gr. Panchromatic	Atlantic Ocean SE of Atlantic Missile Range	Up to 230
Aerobee	1960	Maurer 220 70 mm. Aerial	Kodak IR Aerographic (88A) Kodak Experimental Ektachrome (8778) Kodak High-Definition Negative (3)	North Central Canada, Hudson Bay	47-140
Mercury Flight MR-1	1960	Maurer 220G 70 mm.	Super Anscochrome	Florida, Bahama Islands	Maximum over 130

TABLE 15 (Cont.)

Vehicle	Date	Cameras	Film(Filter)*	Area	Altitude (mi.)
Mercury Flight MA-2	1961	Maurer 220G 70 mm.	Super Anscochrome	Not Known	Low Altitude Abort Flight
Mercury Flight MR-3	1961	Maurer 220G 70 mm.	Super Anscochrome	Florida, Bahama Islands, Mainly Cloud Covered	
Mercury Flight MA-4	1961	Maurer 220G 70 mm.	Super Anscochrome	First Orbit Flight Path: Atlantic Ocean, North and Central Africa	86-123
Mercury Flight MA-5	1961	Maurer 220G 70 mm. Milliken DBM7, 16 mm. (periscope observer camera)	Super Anscochrome Kodachrome EK Type II	SE U.S.A., West Coast of Mexico North Africa	86-128
Mercury Flight MA-6	1962	Ansco Autoset 35 mm.	Eastman Color Negative	Florida, North Africa	87-141
Mercury Flight MA-7	1962	Robot Recorder 35 mm.	Eastman Color Negative	West Africa, Atlantic Ocean, and other areas	87-145
Mercury Flight MA-8	1962	Hasselblad 500C, Modified 70 mm.	Anscochrome 200	Western U.S.A., Mexican Gulf Coast, South Atlantic Ocean	87-145

TABLE 15 (Cont.)

Vehicle	Date	Cameras	Film (Filter)*	Area	Altitude (mi.)
Mercury Flight MA-9	1963	Hasselblad 500C, Modified 70 mm.	Anscochrome 200	South-Central Asia, Philippine Islands, Pacific Ocean, Middle East, North Africa	87-144

---

*Wratten filter numbers

System resolution requirements are important. The larger the permissible photographic scale, the lesser the requirements for long focal length and large aperture systems and the greater the areal coverage for a single orbital swath. The systems can be made smaller and the quantity of data reduced for transmittal or recovery.

The two basic cameras used for terrestrial observations are the frame and slit type. In a frame camera, the film is exposed to the instantaneous field of view each time the aperture is opened. It is best used for photographing a series of discrete scenes.

The slit camera views a scene through a narrow slit. The film is moved continuously past the slit synchronized with the image speed.

Photographic performance requirements are based upon:

1. Ground resolution
2. Altitude
3. Nadir angle (angle from vertical to object being photographed)
4. Angular resolution
5. Focal length
6. Area photographed
7. Entrance pupil diameter
8. Aperture control factor
9. Exposure time
10. Slit width (for slit camera)
11. Film resolution (typical values 100-200 lines/mm)

which can be used to determine the film and sensor weight. Tables 17, 18 & 20 connect these factors functionally for a total photographic systems analysis[18]. The tables have system flow line to indicate their use.

To use Table 17 for the frame camera select the desired ground resolution (2 ft.) and move horizontally to the selected altitude (200 mi.). Move down the chart to the appropriate nadir angle which can be considered 1/2 the field of view (35°). The angular resolution .001 milliradians or approximately 3.6 minutes can be determined from the horizontal line. Proceed along the horizontal line to the selected film resolution (200 lines/mm) and then vertically to read a focal length of 120 inches. The line is then extended to the selected area to be photographed (10 million square nautical miles). From this point proceed horizontally to the selected altitude (200 mi.) and then read the required film weight (500 lbs.) to image the area. The exposure time can be determined from Table 18. First the aperture control factor must be selected. This is the amount the aperture need be increased to satisfy insufficient target illumination over that of a diffraction limited system. A value of 1 corresponds to the diffraction limited case and should be kept small (less than 2). An increase in 20% increments is permissible with small increases in film resolution.

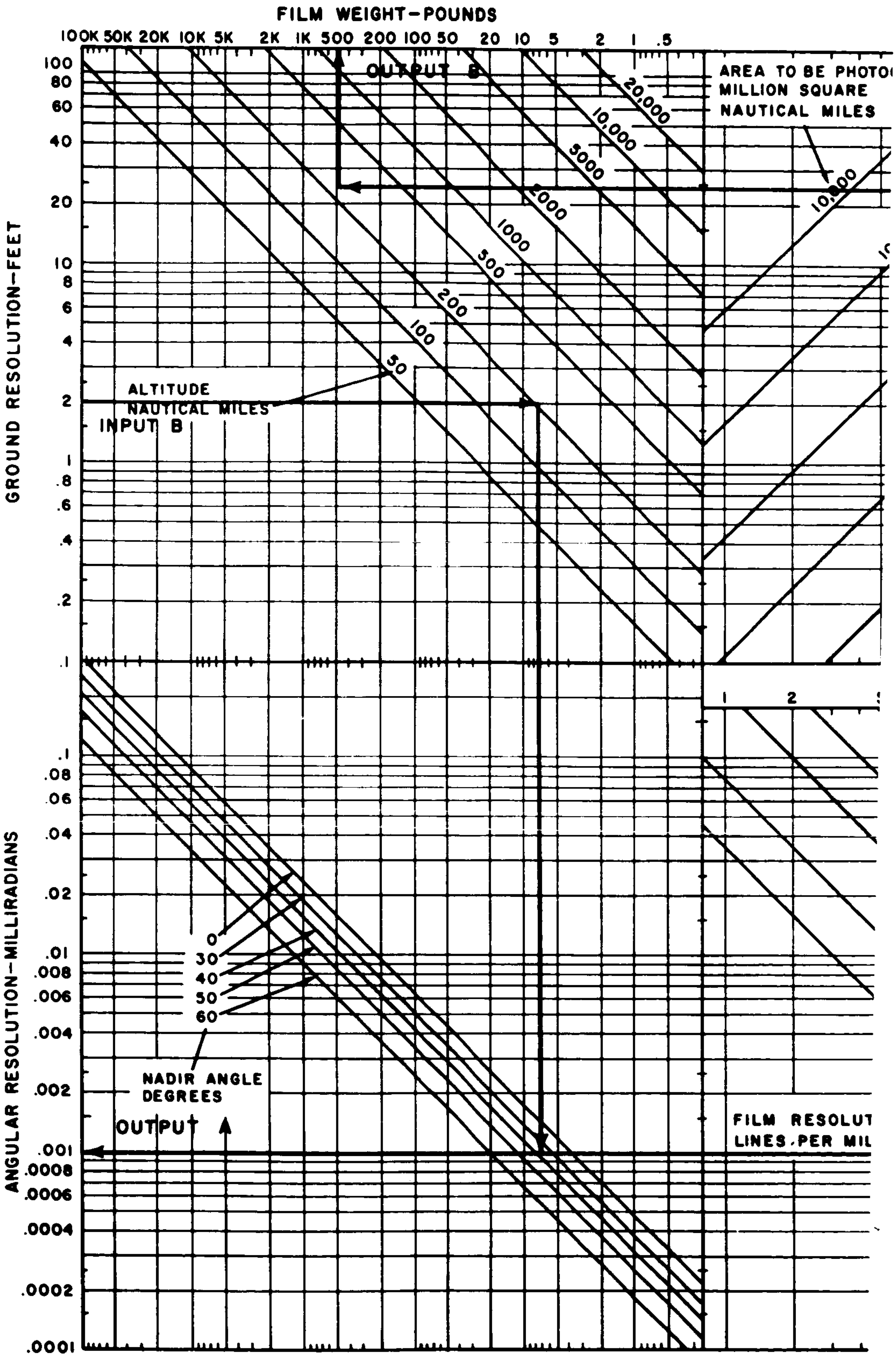
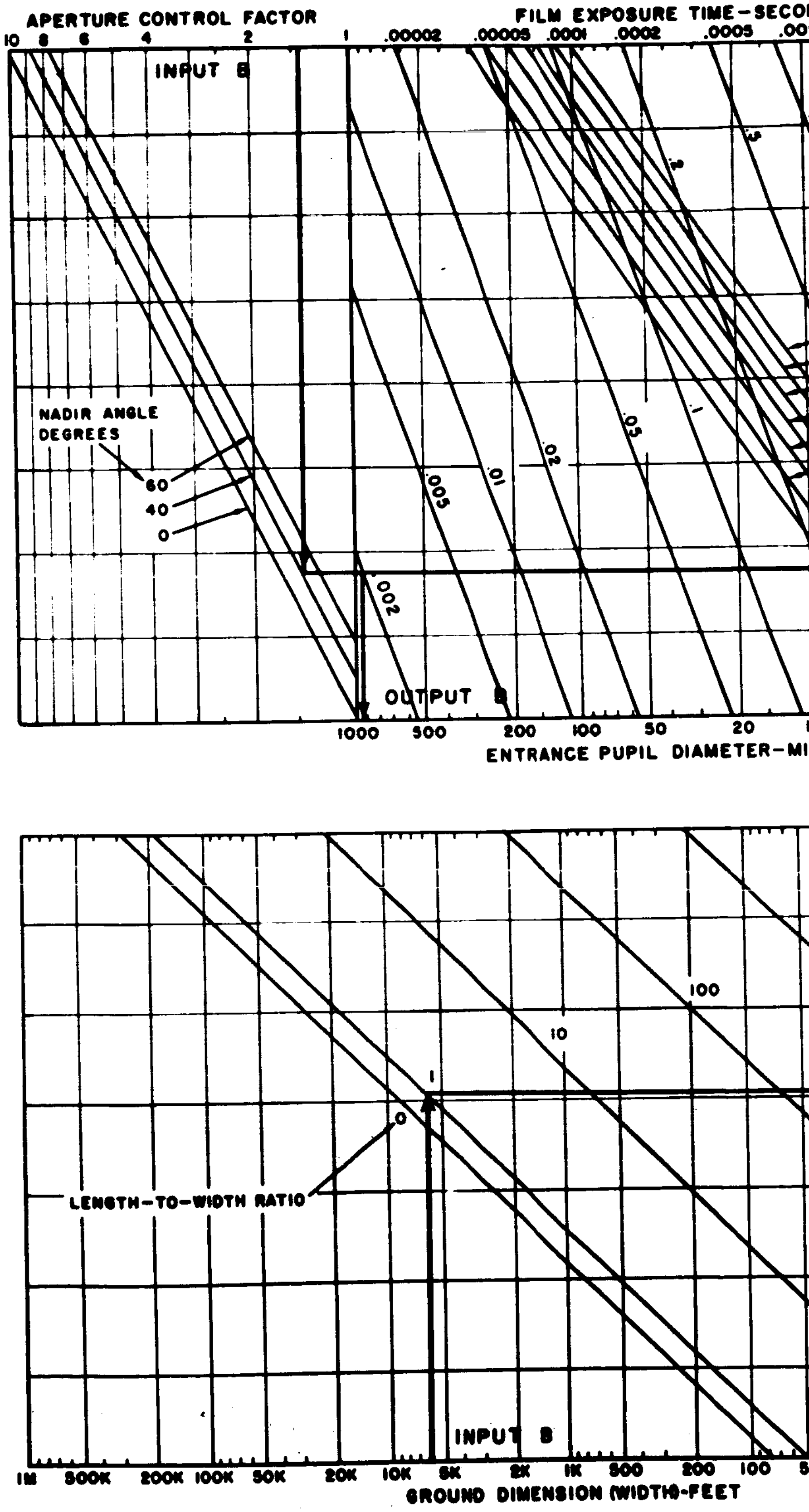


Table 17[18]

Angular Resolution, Focal Length an
for Photographic Earth Observati

Table 18[18]

Slit Half Width and Entrance Pupil Diameter for Earth Observation Sensors



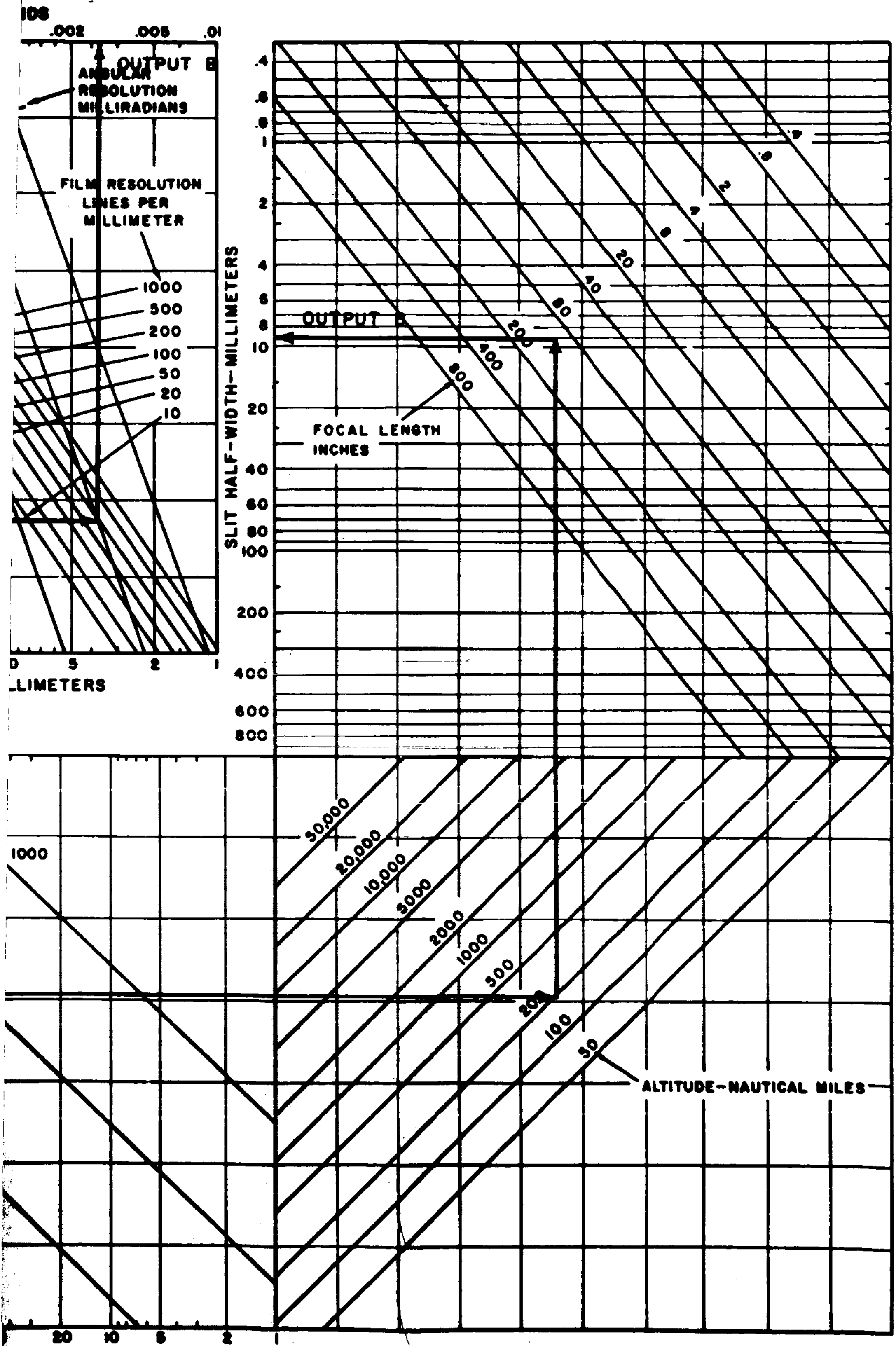

IDS
.002
.005
.01
OUTPUT B
ANGULAR RESOLUTION MILLIRADIANS
FILM RESOLUTION LINES PER MILLIMETER
1000
500
200
100
50
20
10
0
5
2
1
LLIMETERS
SLIT HALF-WIDTH—MILLIMETERS
.4
.6
.8
1
2
4
6
8
10
20
40
60
80
100
200
400
600
800
OUTPUT B
.4
.8
2
4
8
20
40
80
200
400
800
FOCAL LENGTH INCHES
1000
50,000
20,000
10,000
5000
2000
1000
500
200
100
50
ALTITUDE—NAUTICAL MILES
20
10
5
2
1

Table 20[18]

Photographic Observation Sensor Weight and Volume

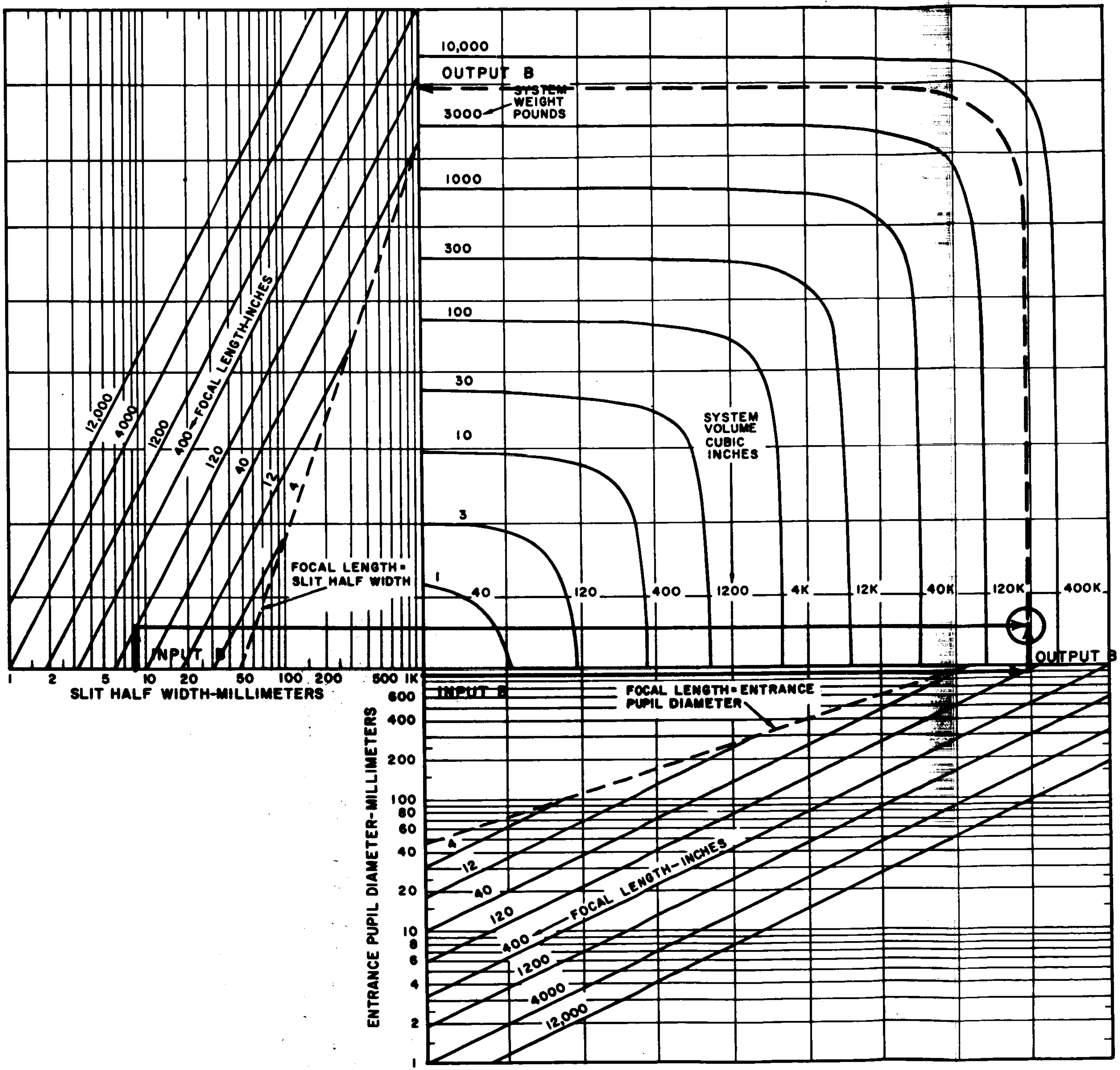


Table 19 shows the aperture control value as a function of illumination and film resolution.

TABLE 19

APERTURE CONTROL FACTOR[18]

Illumination	Film Resolution		
	40	100	200
High 45° - 90° Solar Angle	1.0	1.0	1.1
Average 15° - 45° Solar Angle	1.2	1.3	1.4
Low 5° - 15° Solar Angle	2.2	2.4	2.6

Selecting the aperture control factor (1.5), move down to the nadir angle 35°, over to the film resolution (200 lines/mm), and up to the film exposure time .0034 seconds.

For slit type cameras, the slit half width in millimeters must be specified. The slit width is determined from Table 18 by selecting the swath width moving vertically to a length/slit width ratio of zero then horizontally to the specified altitude, vertically to the specified focal length and horizontally to the slit width value. For frame cameras, a length/width ratio of 1 is used.

Table 20 is used to determine system weight and volume. The flow diagram is self-explanatory using either the slit width for slit cameras or the entrance pupil and focal length for the frame type camera.

Generally, the entrance pupil diameter and slit width are restrained to smaller values than the focal length. The usual common photographic techniques are applicable, e.g., film resolution can compensate for excessive focal lengths, and short exposure time by increasing the aperture control.

4.5 PRELIMINARY PHOTOGRAPHIC SYSTEM ANALYSIS

In Chapter 5, swath widths for coverage of the United States are 1 degree longitude at 200 n mi altitude or 54.5 n mi, 25° latitude and 38.7 n mi, 50° latitude. The field of view for 60 n mi coverage at 200 n mi altitude is 17°. Allowing ± 1/2° for satellite roll will give coverage .8 n mi outside and 1 n mi inside the swath boundaries. Hence, adequate overlap is provided for coverage of the United States by a 17° field of view, but not comparable to standard aerial survey practices. A field of view or 1/2 the nadir angle for 60 n mi coverage will be used in the following development to establish minimal requirements; however, as discussed in Chapter 6, Cloud Cover, it may be necessary to increase the field of view to 25° producing a coverage of two swath widths on one pass. The effect of cloud cover can be reduced by providing complete coverage of a target area at two different times.

Referencing Table 17, the selection of 10 ft ground resolution, 8.5° nadir angle and 100 lines/mm film gives a focal length of approximately 40 inches. Assuming the mapping of the United States (3 x 10^6 sq mi) at an altitude of 200 n mi, approximately 17 lbs. of film is required. The photographic scale factor is 1:364,000. Increasing the nadir angle to 17.5° or 120 n mi coverage requires a small increase in focal length (to 45 inches) and doubles the film weight.

Assuming an aperture control factor of unity corresponding to high solar angles (45° - 90°) for 100 lines/mm film resolution, a .008 milliradian angular resolution, the exposure time and entrance pupil diameter as determined from Table 18 is .005 seconds and 200 millimeters or approximately 8 inches. The f/number is about 5.

Orbital velocity for a 200 n mi polar satellite (non-rotating earth) is 14,169 knots or 23,917 ft/sec. The ground velocity is .9449 of the orbital velocity or 22,599 ft/sec. Therefore, during a .005 sec exposure, the uncompensated camera has moved approximately 120 feet in orbit or 113 ft along the ground track. Image motion compensation is important for large scale imagery. If a larger aperture control factor is selected, say 2.4 for low solar angles (5° - 15°) the entrance pupil diameter is 400 mm or 16 inches and the film exposure time .001 seconds. The time corresponds to approximately 23 ft of ground motion during exposure.

To reduce image blur to 11.3 ft comparable to the desired 10 ft ground resolution for an uncompensated camera requires an exposure time of .0005 sec, aperture control factor of 3.5, and an entrance pupil diameter of nearly 600 mm or 24 inches for 100 lines/mm film. The f/number is about 1.7. These are somewhat impractical requirements which must be eliminated by image motion compensation. From Table 20, system weights for a focal length of 40 inches and entrance pupil diameters 400-600 mm range from 2000 to 5000 lbs.

Table 21 is a summary of camera system specifications. The above calculations bracket those of the C_3 & C_4 systems. In conclusion, it seems reasonable that broad areal coverage (60 to 120 n mi) with a 10-20 ft ground resolution can be obtained from a 200 n mi altitude orbiting satellite subject to image motion compensation.

TABLE 21

SUMMARY OF CAMERA SYSTEM SPECIFICATIONS[8]

	C_1	C_2	C_3	C_4	C_5	C_6
Ground Resolution Requirements (feet)						
200 n. mi.	1	5	10.	20	50.	100
150 n. mi.	.75	3.75	7.5	15	37.5	75
100 n. mi.	.50	2.50	5.0	10	25.	50
Aperture Requirement (inches)						
	130	26	13	6.5	2.6	1.3
Aperture Recommended (inches)						
	38	16	16	6	3	1.2
Focal Length (inches)						
	960	240	120	24	12	6
f/Number						
	25.3	15	7.5	4	4	5
Photo Scale Factor (200 n. mi. altitude)						
200 n. mi.	15K	60K	120K	600K	1200K	2400K
150 n. mi.	11.2K	45K	90K	450K	900K	1800K
100 n. mi.	7.5K	30K	60K	300K	600K	1200K
Film Equivalent to Ground Resolution (mm)						
200 n. mi.	.020	.025	.025	.013	.013	.013
150 n. mi.	.030	.037	.037	.020	.020	.020
100 n. mi.	.040	.050	.050	.026	.026	.026

TABLE 21 (Cont.)

	C_1	C_2	C_3	C_4	C_5	C_6
Film Size	16mm	35mm	70mm	9"x9"	9"x9"	9"x9"
Field Angle (degrees)	0.3	0.5	1.0	21.3	41.1	73.8
Ground Coverage (n. mi.)						
200 n. mi.	1.0x1.0	1.7x1.7	3.5x3.5	75x75	150x150	300x300
300 n. mi.	1.5x1.5	2.6x2.6	5.3x5.3	113x113	225x225	450x450
400 n. mi.	2.0x2.0	3.4x3.4	7.0x7.0	150x150	300x300	600x600
200 n. mi. (acres)	847.5	2449	10, 381	$47x10^5$	$19x10^6$	$76x10^6$
Present Development Status	Res.	Dev.*	Oper.	Oper.	Oper.	Oper.

*Single telescope with variable focal length

CHAPTER 5

ORBITAL REQUIREMENTS

5.1 INTRODUCTION

Orbital parameters of importance in this chapter are:

- Altitude
- Ground Coverage

Orbital altitudes are limited by the effects of atmospheric drag, radiation levels, and resolution requirements of the sensing systems. The position of the orbital plane relative to the earth's equatorial plane and specified by the inclination is a function of the mission spacial and temporal ground coverage. The inclination or angle between the equatorial and orbital planes specify the maximum and minimum latitude of coverage. Polar orbits with inclination of 90° give space flight ground track lines converging at the poles. Retrograde or prograde orbits with inclinations less than 90° give a sinusoidal criss-crossed ground track (Figure 28).

For coverage of the United States, an orbital inclination of 45° will provide coverage to approximately the Canadian border. The swaths will criss-cross diagonally over the country and converge along the 45 parallel as the number of orbits increases. A polar orbit resulting in approximately parallel ground tracks may be more convenient from a data processing viewpoint. Relative to the tangential velocity vector of the earth's orbit about the sun, the plane of a satellite orbit is fixed. Hence as the earth revolves about the sun, a polar orbital plane will parallel the dusk/dawn or twilight zone twice a year. This may be an important consideration for a long survey flight in excess of 3 months. It does permit survey coverage to progress steadily into smaller sun angles providing shadows which may be of importance to topographic and other targets.

Certain launch constraints exist when firing from Cape Kennedy on the east coast or Vandenberg on the west coast. The problem is launching over populated regions. East coast firing limitations subject to this constraint are limited between 28° NE and 121° SW. West coast limitations are 309° NW and 144° SE[18]. Flight time limitations due to drag assuming no propulsion are 50 hours - 100 mile altitude to approximately 208 days at 200 miles altitude. Figure 29 is a plot of this drag limitation in flight time versus altitude.

Additional considerations must be given to command and control sites relative to timing of the imaging systems, position, altitude determinations, vehicle orientation, and data retrieval. Figure 30 reviews these sites on a worldwide basis. It is worth noting that altitudes of meteorological satellites and the time of exposure (position equivalent) are known to within 1 kilometer[19].

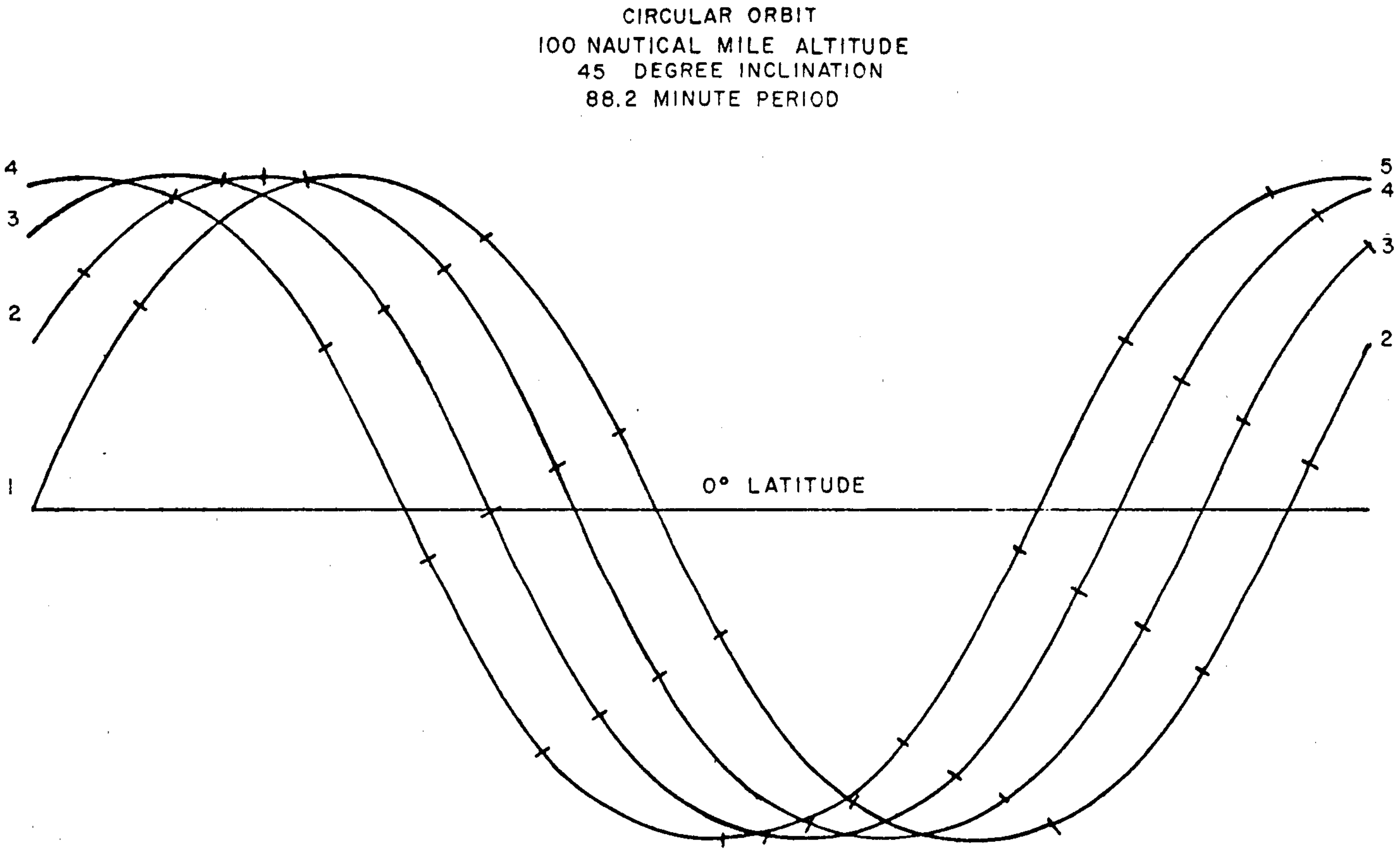


Figure 28. Satellite Ground Track

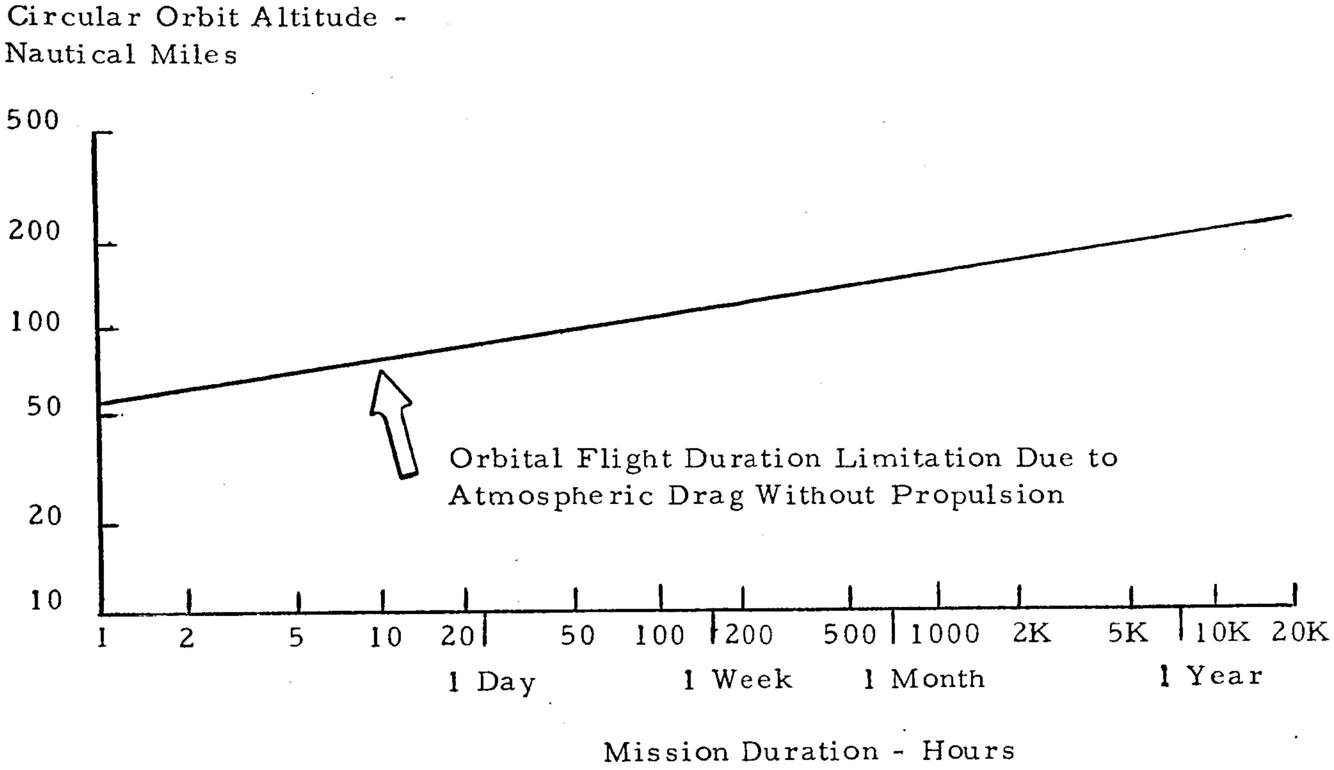


Figure 29. Drag Influence on Flight Time as a Function of Altitude

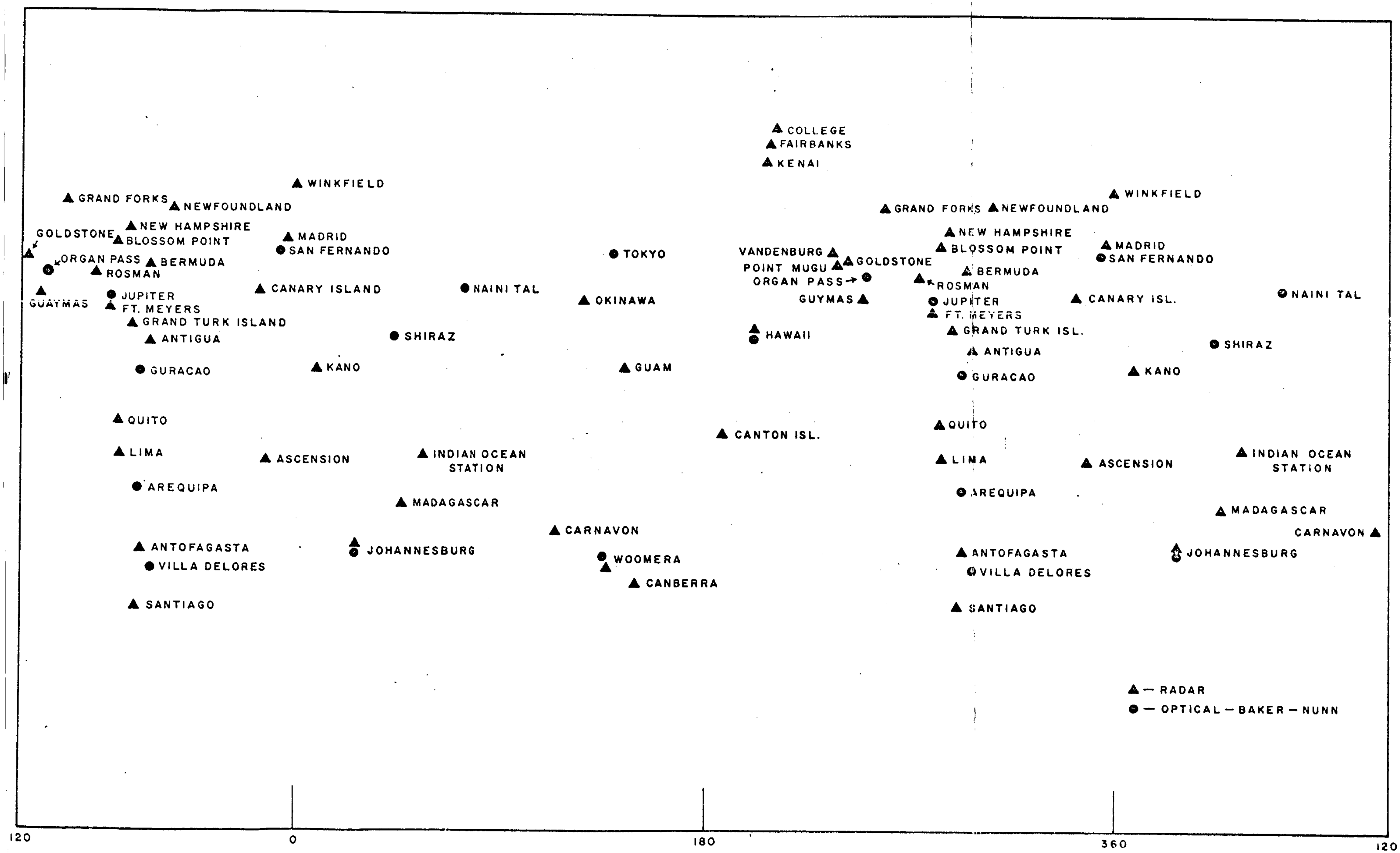


Figure 30. Command & Control Sites

The roll, yaw and pitch motion of the vehicle varies the line of sight of the sensing system about the ground track. Generally, this angle can be limited to from 1/2 to 1 minute of arc[20].

5.2 ORBITAL PARAMETERS

The orbital parameters of importance for the development of ground track coverage requirements are altitude, ground velocity, orbital period and westward displacement. Table 22 is a summary of these variables as a function of the altitude range expected to be of use by terrain imaging systems[21].

The westward displacement of the ground track due to the earth's rotation is of primary importance in determining the spacing across the United States as a function of orbit number. Because of the earth's rotation the sub-point or ground track of the satellite does not retrace from one orbit to the next.

The displacement (d) is calculated by[21]:

$$d = \frac{360^\circ}{1440 \text{ arc minutes}} \times \text{Period (minutes)}$$

$$= .25 \text{ P (minutes) of arc}$$

Because the earth is oblate, the orbital plane is not fixed in space, but rotates slowly around the axis of the earth for inclinations less than 90°. The rate of precession of the orbital plane in degrees/day is given by[22]:

$$r = 9.97 \left(\frac{R}{a}\right)^{3.5} \cos i \text{ (degrees/day)}$$

where: R = radius of earth, 6370 kilometers
a = mean distance of satellite from center of earth
i = orbit inclination

The orbital precession for TIROS, 400 mile altitude, 48° inclination is about 5 degrees/day westward. For polar orbits, cos 90° is zero and precession of the orbital plane need not be considered. Another effect of the earth's shape is to rotate the orbital ellipse in its own plane. The effect can be eliminated or reduced by polar and/or circular orbits.

5.3 ORBITAL GROUND TRACK CALCULATIONS FOR THE UNITED STATES

Orbital altitudes of interest will be limited to 200 & 300 nautical miles because ground resolutions on the order of 20 feet cover the widest range

TABLE 22

Orbital Parameters as a Function of Altitude[21]

Orbit Altitude (KM)	Orbit Altitude N. Miles	Orbital Velocity		Ground Velocity (Non-Rotating Earth)		Orbital Period		Westward Displace. Per Orbit	Sun-Synchronous Inclination	*Approx. Max. Latitude
		km/hr	knots	km/hr	knots	hours	min.	Deg. Long.	Degrees	(Degrees)
185	100	28080	15203	27285	24773	1.468	88.08	22.02	96.27	83.73
200	108	28004	15188	27150	14725	1.476	88.56	22.14	96.33	83.67
250	135	27901	15130	26846	14558	1.492	89.52	22.38	96.49	83.51
278	150	27839	15099	26675	14468	1.502	90.12	22.53	96.59	83.41
300	162	27795	15074	26544	14396	1.509	90.54	22.64	96.67	83.33
350	189	27690	15017	26245	14233	1.526	91.56	22.89	96.85	83.15
371	200	27649	14994	26128	14169	1.533	91.98	23.00	96.92	83.08
400	216	27589	14962	25956	14076	1.543	92.58	23.15	97.03	82.97
450	243	27488	14905	25671	13920	1.560	93.60	23.40	97.22	82.78
463	250	27462	14893	25600	13883	1.565	93.90	23.48	97.26	82.74
500	270	27386	14851	25390	13768	1.578	94.68	23.67	97.41	82.59
550	297	27287	14798	25115	13620	1.595	95.70	23.93	97.60	82.40
556	300	27277	14793	25087	13605	1.597	95.82	23.96 (24°)	97.67	82.33

*(For Sun-synchronous inclination)

of targets and represent state-of-the-art capability at 200 n. mi. If the altitude is doubled, the ground resolution is decreased by a factor of two. Primary interest in this section will be given to approximate calculation of swath widths and passage times over the United States.

The westward displacement for a 200 n. mi. altitude circular polar orbit (inclination 90°) is 23.00°W per orbit. The orbital period is 1.533 hours. Assuming an initial firing at 0° Lat. 80°W Long., 00:00 hours CST due north for the first orbit, the second orbit will begin as the vehicle passes over the equator at 103.00°W Long., 1.533 hours later or 1.533 hours CST, the third at 126.00°W Long., 3.066 hours CST, etc. (Note: The initial firing location is such that the orbit passes approximately over Cape Kennedy.)

As the number of orbits increases, the beginning of each orbit progresses around the equator at 23.00° intervals in longitude. At some point in this progression, the beginning of an orbit will be on the equator in the eastern hemisphere and pass from north to south over the United States. These orbits are referenced by the W_s longitudes.

The longitude of the passage over the equator in the western hemisphere (W_s) for the eastern hemisphere orbit longitude (E) is given by:

$$W_s^{\circ} = 180^{\circ} - E^{\circ} + \frac{23.00^{\circ}}{2}$$

The "W_s" orbits pass over the United States in a north to south direction. For example, the 39th orbit starts at 126° E Long. on the 2nd day - 10.254 hours and passes over the equator in the western hemisphere at 65.5° W_s Long. .767 hour later than the tabulated times in the accompanying tables.

The "W" orbits pass over the United States in a south to north direction. For example, the 63rd orbit starts at 66.0° W Long. on the 3rd day - 23.046 hours CST. This time is equivalent to the total flight time with the first orbit starting at 00:00 hours CST at 80° W Long. 0° Lat.

A tabulation of orbits (position of equatorial intersect, orbit number and flight time) is given in Table 23 for longitudes of 65° W to 125° W encompassing the United States. The positions given in Table 23 are the equatorial ground track intersects in the western hemisphere. The times of orbital intersects are all given in Central Standard Time. The "W_s" times are <u>not</u> corrected by the addition of .767 hours to accommodate the half period required for passage to the equator from the eastern to the western hemisphere. Table 23 shows that only the "W_s" orbits pass over the United States during daylight hence the initial launch time could be .767 hours earlier to give the tabulated time of passage over the equator in the western hemisphere.

Table 24 is a tabulation of the "W_s" orbits over the United States

TABLE 23

Altitude: 200 n.mi.
Displacement/Orbit: 23.00°W Long.
Period: 1.533 hours

Position	Orbit	Central Standard Time		Orbit	Central Standard Time		Approx. Time Zone
		Day	Hour		Day	Hour	
65.0 W	16	-	22.99	376	23	22.87	EST
65.5 Ws	39	2	10.25	399	25	10.13	EST
66.0 W	63	3	23.04	423	26	22.92	EST
66.5 Ws	86	5	10.30	446	28	10.18	EST
67.0 W	110	6	23.09	470	29	22.98	EST
67.5 Ws	133	8	10.35	493	31	10.24	EST
68.0 W	157	9	23.14	517	32	23.03	EST
68.5 Ws	180	11	10.40	540	34	10.29	EST
69.0 W	204	12	23.19	564	35	23.08	EST
69.5 Ws	227	14	10.45	587	37	10.34	EST
70.0 W	251	15	23.25	611	38	23.13	EST
70.5 Ws	274	17	10.50	634	40	10.39	EST
71.0 W	298	18	23.30	658	41	23.18	EST
71.5 Ws	321	20	10.56	681	43	10.44	EST
72.0 W	345	21	23.35	705	44	23.23	EST
72.5 Ws	8	-	10.73	368	23	10.61	EST
73.0 W	32	1	23.52	392	24	23.42	EST
73.5 Ws	55	3	10.78	415	26	10.66	EST
74.0 W	79	4	23.57	439	27	23.45	EST
74.5 Ws	102	6	10.83	463	29	10.71	EST
75.0 W	126	7	23.62	486	30	23.71	EST
75.5 Ws	149	9	10.88	509	32	10.76	EST
76.0 W	173	10	23.67	533	33	23.56	EST
76.5 Ws	196	12	10.93	556	35	10.82	EST
77.0 W	220	13	23.72	580	36	23.63	EST
77.5 Ws	243	15	10.98	603	38	10.89	EST
78.0 W	267	16	23.77	627	39	23.66	EST
78.5 Ws	290	18	11.03	650	41	10.92	EST
79.0 W	314	19	23.82	674	42	23.73	EST
79.5 Ws	337	21	11.08	697	44	10.97	EST
80.0 W	1	00:00		361	22	23.88	EST
80.5 Ws	24	1	11.25	384	24	11.14	EST
81.0 W	48	3	.05	408	25	23.93	EST
81.5 Ws	71	4	11.31	431	27	11.19	EST
82.0 W	95	6	.10	455	28	23.98	EST

TABLE 23 (Cont.)

Position	Orbit	Central Standard Time		Orbit	Central Standard Time		Approx. Time Zone
		Day	Hour		Day	Hour	
82.5 Ws	118	7	11.36	478	30	11.24	EST
83.0 W	142	9	.15	502	32	.03	EST
83.5 Ws	165	10	11.41	525	33	11.29	EST
84.0 W	189	12	.20	549	35	.08	EST
84.5 Ws	212	13	11.46	572	36	11.34	EST
85.0 W	236	15	.25	596	38	.14	CST
85.5 Ws	259	16	11.51	619	39	11.39	CST
86.0 W	283	18	.30	643	41	.19	CST
86.5 Ws	306	19	11.56	666	42	11.44	CST
87.0 W	330	21	.35	690	44	.24	CST
87.5 Ws	353	22	11.61	713	45	11.50	CST
88.0 W	17	1	.52	377	24	.41	CST
88.5 Ws	40	2	11.78	400	25	11.67	CST
89.0 W	64	4	.57	424	27	.46	CST
89.5 Ws	87	5	11.83	447	28	11.72	CST
90.0 W	111	7	.63	471	30	.53	CST
90.5 Ws	134	8	11.88	494	31	11.77	CST
91.0 W	158	10	.68	518	33	.56	CST
91.5 Ws	181	11	11.94	541	34	11.82	CST
92.0 W	205	13	.73	565	36	.61	CST
92.5 Ws	228	14	11.99	588	37	11.89	CST
93.0 W	252	17	.78	612	39	.66	CST
93.5 Ws	275	17	12.04	635	40	11.92	CST
94.0 W	299	19	.83	659	42	.71	CST
94.5 Ws	322	20	12.09	682	43	11.99	CST
95.0 W	346	22	.88	706	45	.76	CST
95.5 Ws	9	-	12.26	369	23	12.14	CST
96.0 W	33	2	1.05	393	25	.93	CST
96.5 Ws	56	3	12.31	416	26	12.20	CST
97.0 W	80	5	1.10	440	28	.99	CST
97.5 Ws	103	6	12.36	463	29	12.25	CST
98.0 W	127	8	1.15	487	31	1.04	CST
98.5 Ws	150	9	12.41	510	32	12.30	CST
99.0 W	174	11	1.20	534	34	1.09	CST
99.5 Ws	197	12	12.46	557	35	12.35	CST
100.0 W	221	14	1.26	581	37	1.14	CST
100.5 Ws	244	15	12.51	604	38	12.40	CST
101.0 W	268	17	13.10	628	40	1.19	CST
101.5 Ws	291	18	12.57	651	41	12.45	CST

TABLE 23 (Cont.)

Position	Orbit	Central Standard Time		Orbit	Central Standard Time		Approx. Time Zone
		Day	Hour		Day	Hour	
102.0 W	315	20	13.62	675	43	1.24	CST
102.5 Ws	338	21	12.62	698	44	12.50	CST
103.0 W	2	-	1.53	362	23	1.41	CST
103.5 Ws	25	1	12.79	385	24	12.69	CST
104.0 W	49	3	1.58	409	26	1.46	CST
104.5 Ws	72	4	12.84	432	27	12.72	CST
105.0 W	96	6	1.63	456	29	1.51	MST
105.5 Ws	119	7	12.89	479	30	12.79	MST
106.0 W	143	9	1.68	503	32	1.56	MST
106.5 Ws	166	10	12.94	526	33	12.82	MST
107.0 W	190	12	1.73	550	35	1.61	MST
107.5 Ws	213	13	12.99	573	36	12.89	MST
108.0 W	237	15	1.78	597	38	1.66	MST
108.5 Ws	260	16	13.04	620	39	12.92	MST
109.0 W	284	18	1.83	644	41	1.71	MST
109.5 Ws	307	19	13.09	667	42	12.99	MST
110.0 W	331	21	1.89	691	44	1.77	MST
110.5 Ws	354	22	13.14	714	45	13.02	MST
111.0 W	18	1	2.06	378	24	1.94	MST
111.5 Ws	41	2	13.32	401	25	13.20	MST
112.0 W	65	4	2.11	425	27	1.99	MST
112.5 Ws	88	5	13.37	448	28	13.25	MST
113.0 W	112	7	2.16	472	30	2.04	MST
113.5 Ws	135	8	13.42	495	31	13.30	MST
114.0 W	159	10	2.214	519	33	2.09	MST
114.5 Ws	182	11	13.47	542	34	13.35	MST
115.0 W	206	13	22.64	566	36	2.14	PST
115.5 Ws	229	14	13.52	589	37	13.40	PST
116.0 W	253	16	23.16	613	39	2.19	PST
116.5 Ws	276	17	13.57	636	40	13.45	PST
117.0 W	300	19	2.36	660	42	2.24	PST
117.5 Ws	323	24	13.62	683	43	13.50	PST
118.0 W	347	22	2.41	707	45	2.29	PST
118.5 Ws	10	-	13.79	370	23	13.67	PST
119.0 W	34	2	2.58	394	25	2.46	PST
119.5 Ws	57	3	13.84	417	26	13.72	PST
120.0 W	81	5	2.64	441	28	2.52	PST
120.5 Ws	104	6	13.89	464	29	13.77	PST

TABLE 23 (Cont.)

Position	Orbit	Central Standard Time Day	Central Standard Time Hour	Orbit	Central Standard Time Day	Central Standard Time Hour	Approx. Time Zone
121.0 W	128	8	2.69	488	31	2.62	PST
121.5 Ws	151	9	13.95	511	32	13.83	PST
122.0 W	175	11	2.74	535	34	2.62	PST
122.5 Ws	198	12	14.00	558	35	13.88	PST
123.0 W	222	14	2.79	582	37	2.67	PST
123.5 Ws	245	15	14.05	605	38	13.93	PST
124.0 W	269	17	2.84	629	40	2.72	PST
124.5 Ws	292	18	14.10	652	41	13.98	PST
125.0 W	316	20	2.89	676	43	2.77	PST
125.5 Ws	339	21	14.15	699	44	14.03	PST

TABLE 24

Altitude: 200 n.mi.
Start Time: 00:00 CST
Start Position: 80°W Long. - 0° Lat.
Inclination: 90° (Polar Orbit), Circular Orbit

Position	Orbit	Standard Time		Orbit	Standard Time		Approx. Time Zone
		Day	-Hour		Day-	Hour	
65.5 Ws	39	2	11.25	399	25	11.13	EST
66.5 Ws	86	5	11.31	446	28	11.19	EST
67.5 Ws	133	8	11.36	493	31	11.24	EST
68.5 Ws	180	11	11.41	540	34	11.29	EST
69.5 Ws	227	14	11.46	587	37	11.34	EST
70.5 Ws	274	17	11.51	634	40	11.39	EST
71.5 Ws	321	20	11.56	681	43	11.44	EST
72.5 Ws	8	-	11.73	368	23	11.61	EST
73.5 Ws	55	3	11.78	415	26	11.66	EST
74.5 Ws	102	6	11.83	462	29	11.71	EST
75.5 Ws	149	9	11.88	509	32	11.76	EST
76.5 Ws	196	12	11.94	556	35	11.82	EST
77.5 Ws	243	15	11.99	603	38	11.89	EST
78.5 Ws	290	18	12.04	650	41	11.92	EST
79.5 Ws	337	21	12.09	697	44	11.97	EST
80.5 Ws	24	1	12.26	384	24	12.14	EST
81.5 Ws	71	4	12.31	431	27	12.19	EST
82.5 Ws	118	7	12.36	478	30	12.24	EST
83.5 Ws	165	10	12.41	525	33	12.29	EST
84.5 Ws	212	13	12.46	572	36	12.34	EST
85.5 Ws	259	16	11.51	619	39	11.39	CST
86.5 Ws	306	19	11.57	666	42	11.44	CST
87.5 Ws	353	22	11.62	713	45	11.50	CST
88.5 Ws	40	2	11.79	400	25	11.67	CST
89.5 Ws	87	5	11.84	447	28	11.72	CST
90.5 Ws	134	8	11.89	494	31	11.77	CST
91.5 Ws	181	11	11.94	541	34	11.82	CST
92.5 Ws	228	14	12.00	588	37	11.89	CST
93.5 Ws	275	17	12.04	635	40	11.92	CST
94.5 Ws	322	20	12.09	682	43	11.99	CST
95.5 Ws	9	-	12.26	369	23	12.14	CST
96.5 Ws	56	3	12.32	416	26	12.20	CST
97.5 Ws	103	6	12.37	463	29	12.25	CST

TABLE 24(Cont.)

Position	Orbit	Standard Time		Orbit	Standard Time		Approx. Time Zone
		Day	Hour		Day	Hour	
98.5 Ws	150	9	12.42	510	32	12.30	CST
99.5 Ws	197	12	12.47	557	35	12.35	CST
100.5 Ws	244	15	12.52	604	38	12.40	CST
101.5 Ws	291	18	12.57	651	41	12.45	CST
102.5 Ws	338	21	12.62	698	44	12.50	CST
103.5 Ws	25	1	12.79	385	24	12.69	CST
104.5 Ws	72	4	12.84	432	27	12.72	CST
105.5 Ws	119	7	11.89	479	30	11.79	MST
106.5 Ws	166	10	11.94	526	33	11.82	MST
107.5 Ws	213	13	12.00	573	36	11.90	MST
108.5 Ws	260	16	12.05	620	39	11.93	MST
109.5 Ws	307	19	12.10	667	42	12.00	MST
110.5 Ws	354	22	12.15	714	45	12.03	MST
111.5 Ws	41	2	12.32	401	25	12.20	MST
112.5 Ws	88	5	12.37	448	28	12.25	MST
113.5 Ws	135	8	12.42	495	31	12.30	MST
114.5 Ws	182	11	12.47	542	34	12.35	MST
115.5 Ws	229	14	11.52	589	37	11.40	PST
116.5 Ws	276	17	11.58	636	40	11.46	PST
117.5 Ws	323	20	11.63	683	43	11.51	PST
118.5 Ws	10	-	11.80	370	23	11.68	PST
119.5 Ws	57	3	11.85	417	26	11.73	PST
120.5 Ws	104	6	11.90	464	29	11.78	PST
121.5 Ws	151	9	11.95	511	32	11.83	PST
122.5 Ws	198	12	12.00	558	35	11.88	PST
123.5 Ws	245	15	12.05	605	38	11.93	PST
124.5 Ws	292	18	12.10	652	41	11.98	PST
125.5 Ws	339	21	12.15	699	44	12.03	PST

Note: Ws orbit time at "orbital equator" Eastern hemisphere, to reach (South to North) latitude 40°N requires .77 hour or 46 minutes.

with the times adjusted for their approximate relative time zones. Coverage of the United States is possible in 22 days with 1 degree longitude swath width at any specified hour ± 2 hours, standard time zones.

An important aspect of polar orbits is the fixation of the orbital plane. The calculations in this section consider only the rotation of the earth inside the orbital plane. As the earth revolves around the sun, the time of passage over the United States will reach the dawn/dusk interface in approximately 91.3 days or 1/4 year for a midnight launch from Cape Kennedy. Assuming a dawn/dusk twilight time of 0600 and 1800 hours, the first time shift is about 6 hours per 91.3 days or 4 minutes per flight day. Therefore, the times listed in the table should be adjusted by about 1 hour 28 minutes for the 22nd day of flight. At this time the orbital plane is perpendicular to the radius vector of the earth and sun. Past this period the time of flight over the United States shifts again toward noon with the W orbits moving into daylight and the W_s orbits into nighttime.

A tabulation of the 300 nautical mile altitude orbits is given in Table 25 . Swath widths are .6° longitude. Complete coverage of the United States is obtained in 39 days.

5.4 CLOUD COVER INFLUENCE OF UNITED STATES COVERAGE TIME

At 200 nautical mile altitude, 1° longitude swath width coverage of the United States can be completed in about 22 days subject to no cloud cover. The tables given in Chapter 6 show the mean monthly per cent cloud cover distribution over the United States.

Assuming an average cloud cover or probability of occurrence is .5, an estimate of the total number of day required for unobscured coverage of the United States can be calculated. If the probability of the occurrence of an event on a single trial is p, then the probability that the event will occur at least r times in n independent trials is[34]:

$$1. \quad p \geq r = p^n + nC_1 p^{n-1} q + nC_2 p^{n-2} q^2 + \ldots + nC_{n-r} p^r q^{n-r}$$

where:

$$nCr = \frac{n!}{r!\,(n-r)!} \qquad q = 1-p$$

If p is the per cent cloud cover (.5), or probability of occurrence in a single complete coverage of the United States and n = 8 complete coverages, then the probability of r = 1 complete unobscured combined coverage is from Equation 1 about 99%.

In conclusion, approximately 8 x 22 days or 176 days in flight will be required for a 99% reliability in obtaining complete unobscured coverage

TABLE 25

Altitude: 300 n.mi.
Displacement/Orbit: 23.96°W Long.
Period: 1.597 hours

Position	Orbit	Central Standard Time		Time Zone
		Day	Hour	
65.00 W	376	24	21.86	EST
65.30 Ws	368	24	9.10	EST
65.50 W	361	23	21.92	EST
65.90 Ws	353	23	9.14	EST
66.20 W	346	22	21.97	EST
66.50 Ws	338	22	9.19	EST
66.80 W	331	21	22.01	EST
67.10 Ws	323	21	9.23	EST
67.40 W	316	20	22.06	EST
67.70 Ws	308	20	9.28	EST
68.00 W	301	19	22.10	EST
68.30 Ws	293	19	9.32	EST
68.60 W	286	18	22.15	EST
68.90 Ws	278	18	9.37	EST
69.20 W	271	17	22.19	EST
69.50 Ws	263	17	9.41	EST
69.80 W	256	16	22.24	EST
70.10 Ws	248	16	9.46	EST
70.40 W	241	15	22.28	EST
70.70 Ws	233	15	9.50	EST
71.00 W	226	14	22.33	EST
71.30 Ws	218	14	9.55	EST
71.60 W	211	13	22.37	EST
71.90 Ws	203	13	9.59	EST
72.20 W	196	12	22.42	EST
72.50 Ws	188	12	9.64	EST
72.80 W	181	11	22.46	EST
73.10 Ws	173	11	9.68	EST
73.40 W	166	10	22.51	EST
73.70 Ws	158	10	9.73	EST
74.00 W	151	9	22.55	EST
74.30 Ws	143	9	9.77	EST
74.60 W	136	8	22.60	EST
74.90 Ws	128	8	9.82	EST
75.20 W	121	7	22.65	EST

TABLE 25 (Cont.)

Position	Orbit	Central Standard Time Day	Hour	Time Zone
75.50 Ws	113	7	9.86	EST
75.80 W	106	6	22.69	EST
76.10 Ws	98	6	9.91	EST
76.40 W	91	5	22.73	EST
76.70 Ws	83	5	9.95	EST
77.00 W	76	4	22.78	EST
77.30 Ws	68	4	10.00	EST
77.60 W	61	3	22.82	EST
77.90 Ws	53	3	10.04	EST
78.20 W	46	2	22.87	EST
78.50 Ws	38	2	10.09	EST
78.80 W	31	1	22.91	EST
79.10 Ws	23	1	10.13	EST
79.40 W	16	-	22.96	EST
79.70 Ws	8	-	10.18	EST
80.00 W	1	00:00		EST
80.26 Ws	594	39	10.02	EST
80.56 W	587	38	22.84	EST
80.86 Ws	579	38	10.07	EST
81.16 W	572	37	22.89	EST
81.46 Ws	564	37	10.11	EST
81.76 W	557	36	22.93	EST
82.06 Ws	549	36	10.16	EST
82.36 W	542	35	22.98	EST
82.66 Ws	534	35	10.20	EST
83.96 W	527	34	23.02	EST
83.26 Ws	520	34	11.84	EST
83.56 W	512	33	23.07	EST
83.86 Ws	505	33	11.89	EST
84.16 W	497	32	23.11	EST
84.46 Ws	490	32	11.93	EST
84.76 W	482	31	23.16	EST
85.06 Ws	474	31	11.38	CST
85.36 W	467	31	.20	CST
85.66 Ws	459	30	11.42	CST
85.96 W	452	30	.25	CST
86.26 Ws	444	29	11.47	CST
86.56 W	437	29	.29	CST
86.84 Ws	429	28	11.52	CST

TABLE 25 (Cont.)

Position	Orbit	Central Standard Time		Time Zone
		Day	Hour	
87.16 W	422	28	.34	CST
87.46 Ws	414	27	11.56	CST
87.76 W	407	27	.38	CST
88.06 Ws	399	26	11.61	CST
88.36 W	392	26	.43	CST
88.66 Ws	384	25	11.65	CST
88.96 W	377	25	.47	CST
89.26 Ws	369	24	11.70	CST
89.56 W	362	24	.52	CST
89.86 Ws	354	23	11.74	CST
90.16 W	347	23	.56	CST
90.46 Ws	339	22	11.79	CST
90.76 W	332	22	.61	CST
91.06 Ws	324	21	11.83	CST
91.36 W	317	21	.65	CST
91.66 Ws	309	20	11.88	CST
91.96 W	302	20	.70	CST
92.26 Ws	294	19	11.92	CST
92.56 W	287	19	.74	CST
92.86 Ws	279	18	11.97	CST
93.16 W	272	18	.79	CST
93.46 Ws	264	17	12.01	CST
93.76 W	257	17	.83	CST
94.06 Ws	249	16	12.06	CST
94.36 W	242	16	.88	CST
94.66 Ws	234	15	12.10	CST
94.96 W	227	15	.92	CST
95.26 Ws	219	14	12.15	CST
95.56 W	212	14	.97	CST
95.86 Ws	204	13	12.19	CST
96.16 W	197	13	1.01	CST
96.46 Ws	189	12	12.24	CST
96.76 W	182	12	1.06	CST
97.06 Ws	174	11	12.28	CST
97.36 W	167	11	1.10	CST
97.66 Ws	159	10	12.33	CST
97.96 W	152	10	1.15	CST
98.26 Ws	144	9	12.37	CST
98.50 W	137	9	1.19	CST

TABLE 25(Cont.)

Position	Orbit	Central Standard Time		Time Zone
		Day	- Hour	
98.86 Ws	129	8	12.42	CST
99.16 W	122	8	1.24	CST
99.46 Ws	114	7	12.46	CST
99.76 W	107	7	1.28	CST
100.06 Ws	99	6	12.51	CST
100.36 W	92	6	1.33	CST
100.66 Ws	84	5	12.55	CST
100.96 W	77	5	1.37	CST
101.26 Ws	69	4	12.60	CST
101.56 W	62	4	1.42	CST
101.86 Ws	54	3	12.64	CST
102.16 W	47	3	1.46	CST
102.46 Ws	39	2	12.69	CST
102.76 W	32	2	1.51	CST
103.06 Ws	24	1	12.73	CST
103.36 W	17	1	1.55	CST
103.66 Ws	9	-	12.78	CST
103.96 W	2	-	1.58	CST
104.22 Ws	595	39	12.62	CST
104.52 W	588	39	1.43	CST
104.82 Ws	580	38	12.66	CST
105.12 W	573	38	2.48	MST
105.42 Ws	565	37	13.71	MST
105.72 W	558	37	2.53	MST
106.02 Ws	550	36	13.75	MST
106.32 W	543	36	2.57	MST
106.62 Ws	535	35	13.80	MST
106.92 W	528	35	2.62	MST
107.22 Ws	520	34	13.84	MST
107.52 W	513	34	2.66	MST
107.82 Ws	505	33	13.89	MST
108.12 W	498	33	2.71	MST
108.42 Ws	490	32	13.93	MST
108.72 W	473	32	2.75	MST
109.02 Ws	475	31	13.98	MST
109.32 W	468	31	2.80	MST
109.62 Ws	460	30	14.02	MST
109.92 W	453	30	2.84	MST
110.22 Ws	445	29	14.07	MST

TABLE 25 (Cont.)

Position	Orbit	Central Standard Time		Time Zone
		Day-	Hour	
110.52 W	438	29	2.89	MST
110.82 Ws	430	28	14.11	MST
111.12 W	423	28	2.93	MST
111.42 Ws	415	27	14.16	MST
111.72 W	408	27	2.98	MST
112.02 Ws	400	26	14.20	MST
112.32 W	393	26	3.02	MST
112.62 Ws	385	25	14.25	MST
112.92 W	378	25	3.07	MST
113.22 Ws	370	24	14.29	MST
113.52 W	363	24	3.11	MST
113.82 Ws	355	23	14.34	MST
114.12 W	348	23	3.16	MST
114.42 Ws	340	22	14.38	MST
114.72 W	333	22	3.20	MST
115.02 Ws	325	21	15.43	PST
115.32 W	318	21	4.25	PST
115.62 Ws	310	20	15.47	PST
115.92 W	303	20	4.29	PST
116.22 Ws	295	19	15.52	PST
116.52 W	288	19	4.34	PST
116.82 Ws	280	18	15.56	PST
117.12 W	273	18	4.38	PST
117.42 Ws	265	17	15.61	PST
117.72 W	258	17	4.43	PST
118.02 Ws	250	16	15.65	PST
118.32 W	243	16	4.47	PST
118.62 Ws	235	15	15.70	PST
118.92 W	228	15	4.52	PST
119.22 Ws	220	14	15.74	PST
119.52 W	213	14	4.56	PST
119.82 Ws	205	13	15.79	PST
120.12 W	198	13	4.61	PST
120.42 Ws	190	12	15.83	PST
120.72 W	183	12	4.65	PST
121.02 Ws	175	11	15.88	PST
121.32	168	11	4.70	PST
121.62 Ws	160	10	15.92	PST

TABLE 25 (Cont.)

Position	Orbit	Central Standard Time Day	Hour	Time Zone
121.92 W	153	10	4.74	PST
122.22 Ws	145	9	15.97	PST
122.52 W	138	9	4.79	PST
122.82 Ws	130	8	16.01	PST
123.12 W	123	8	4.83	PST
123.42 Ws	115	7	16.06	PST
123.72 W	108	7	4.88	PST
124.02 Ws	100	6	16.10	PST
124.32 W	93	6	4.92	PST
124.62 Ws	85	5	16.15	PST
124.92 W	78	5	4.97	PST

of the United States for a 200 n mi altitude orbit.

Reviewing the spacial and temporal variability of cloud cover distribution over the United States as given in Chapters 2 & 6 serve to point out a possible need for and perhaps the impossible solution to determining how many passes over the United States or for that matter any region, will be needed for complete coverage. In fact, cloud cover is difficult to predict on a local basis with any accuracy and seems to be something which must be accepted. Rather than deal with aggregate cloud cover averages over some time period, the types of cloud forms should be investigated as a function of geographic region and time.

Of interest would be closely packed clouds represented by cirrocumulus, altocumulus, stratocumulus, altostratus and stratus. Typical cumulus clouds are characteristic of fine weather and tend to be scattered resulting in a terrain mask made up of small opaque enclosures. Since all clouds (enclosures) are in motion, two complete overflights of a region might be sufficient for maximum exposure of terrain targets. At 200 n mi altitude, a 120 n mi field of view would permit complete overlapping or twice the coverage of the United States at two different times during one 22 days period. A 35° field of view for a photographic system with a ground resolution of 10 - 20 feet is feasible.

CHAPTER 6

CLOUD COVER OVER THE UNITED STATES

6.1 INTRODUCTION

The transformation of data from orbital sensors into intelligence must contend with cloud cover. The term data references the coverage of aggregate areal targets of different area and "connectiveness" dispersed among thousands of square miles. This data base, is in turn, masked by an opaque areal aggregate variable in location, area, time and connectiveness.

The time variance of the spacial distribution of clouds may be the key in obtaining complete coverage of a given area by the simple expedient of mapping two swath widths on each pass. This will provide twice the coverage of the area at different times reducing the likelihood of a cloud obscuring a specific area. The cloud type representative of size and seasonal variations relative to target area would be an important consideration in determining a regional likelihood of complete coverage. Of specific interest would be the regional/time variability of closely packed clouds, e.g., cirrocumulus, stratocumulus, altocumulus and stratus.

Typical scattered fine weather clouds, cumulus, with up to 40% cloud cover may not represent a barrier to nearly complete coverage if the survey can be repeated at two different times and the target area is large relative to the average cloud area.

6.2 CLOUD COVER ESTIMATES FOR THE UNITED STATES

The amount of cloud cover over the United States varies from month to month. Various factors influence this phenomena; among these are mountain ranges, upper air movements and aggregate thermal differences. Variability of weather occurrences is always a problem and makes forecasting difficult. There is, on the whole, however, a tendency for the same kind of weather to continue for a few days and often, in a larger sense, for several months. When the general distribution of pressure remains essentially the same, and barometric disturbances follow one another along the same path, or when air becomes quescent over a large area, the same type of weather is likely to presist. A sudden change to another type is an indication of some change in the general movement of the air, marked by a change in the course of traveling highs and lows.

Basic differences in cloud cover between coastal and central regions especially northern central regions, are occasioned by differences in type of air mass effecting them. Along with terrain changes, seasonal differences are much more marked throughout the northern inland and central United States than along the coast.

The per cent cloud cover given in the accompanying figures and tables was obtained with the assistance of the U. S. Weather Bureau and in part from the "Annual Summary with Comparative Data", prepared by the U. S. Department of Commerce.

Figure 31 shows the average sky cover for the year throughout the United States. Figures 32 through 43 are monthly averages. Table 26 lists the mean sky cover for the 17 states which planted 92.8% of the wheat acreage in the United States and is coded for Winter Wheat Harvest and Planting periods.

All cloud cover data are time averages for the weather stations ranging from 3 to 89 years.

YEAR AVERAGE SKY COVER, 1966

(In Per Cent)

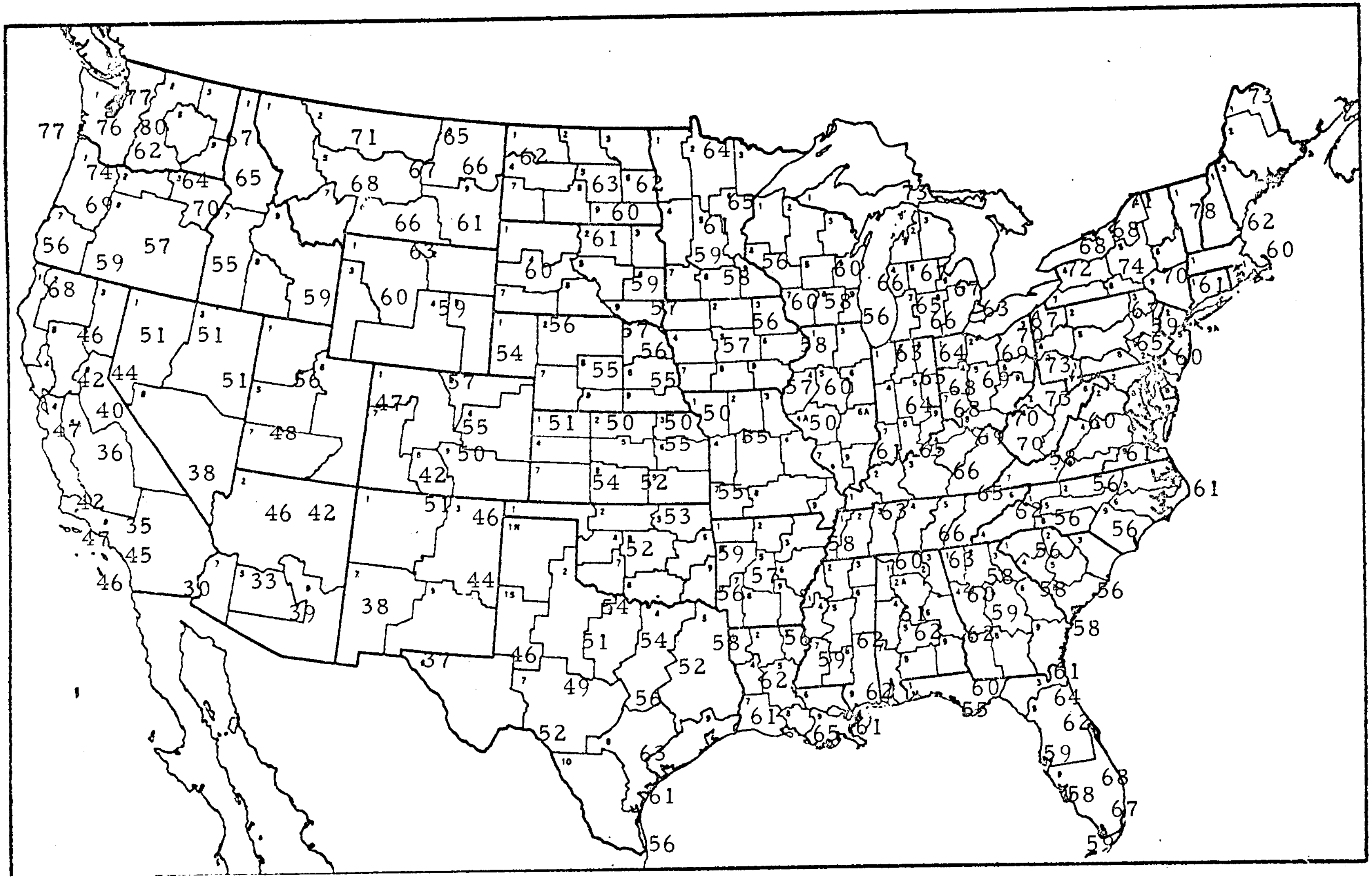


Figure 31

MEAN CLOUD COVER - JANUARY
(In Per Cent)

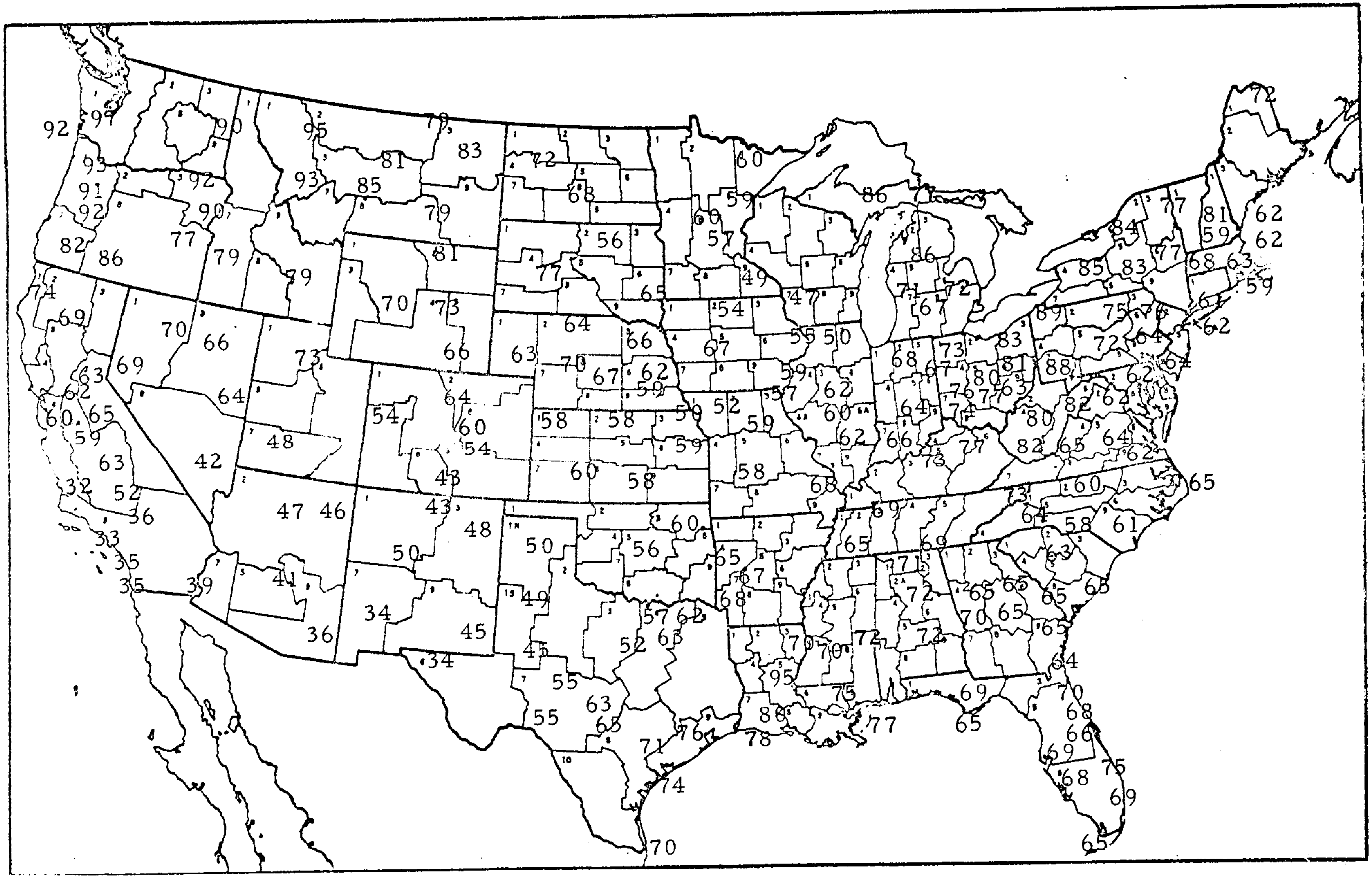


Figure 32

MEAN CLOUD COVER - FEBRUARY
(In Per Cent)

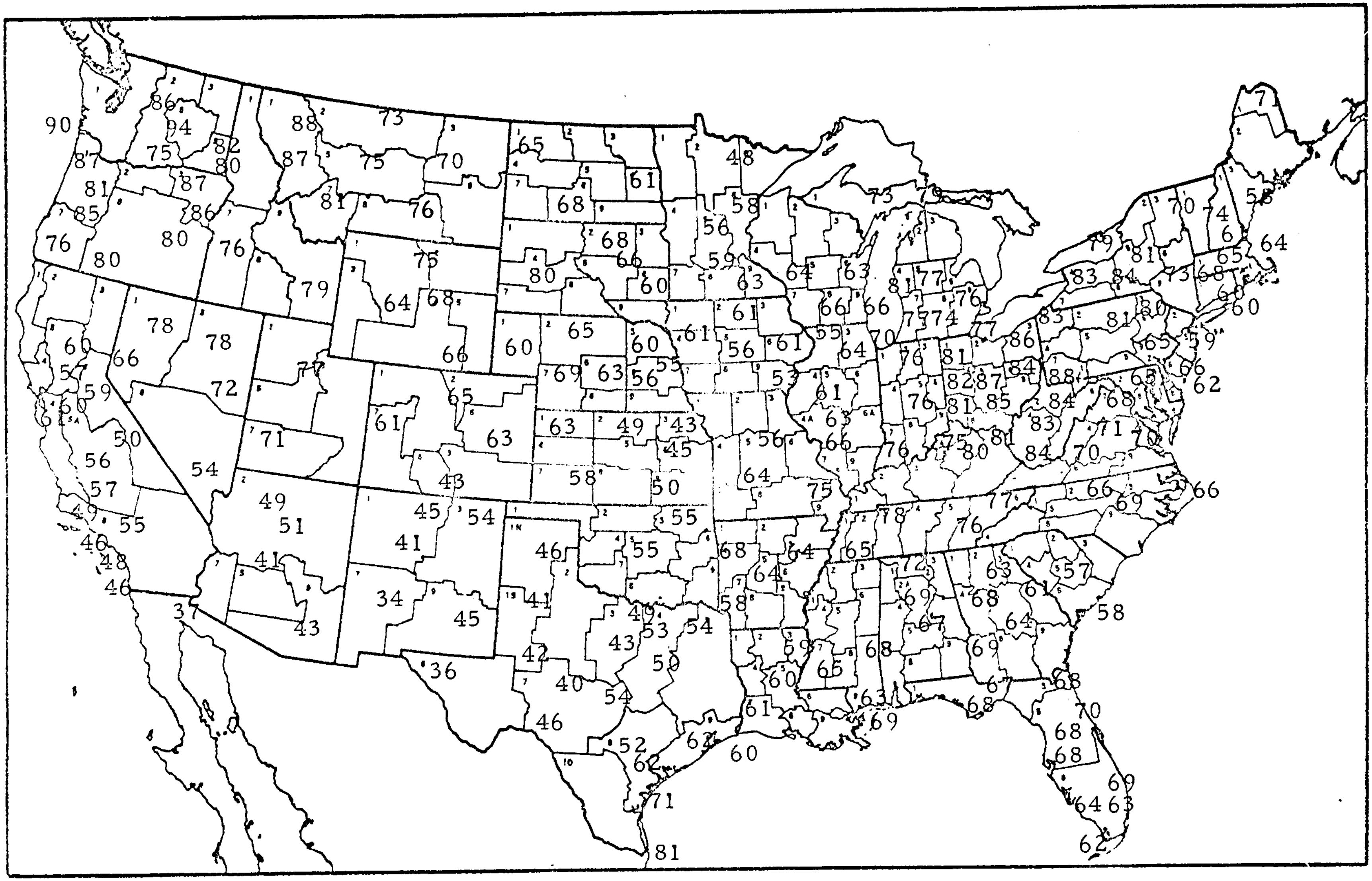


Figure 33

MEAN CLOUD COVER - MARCH
(In Per Cent)

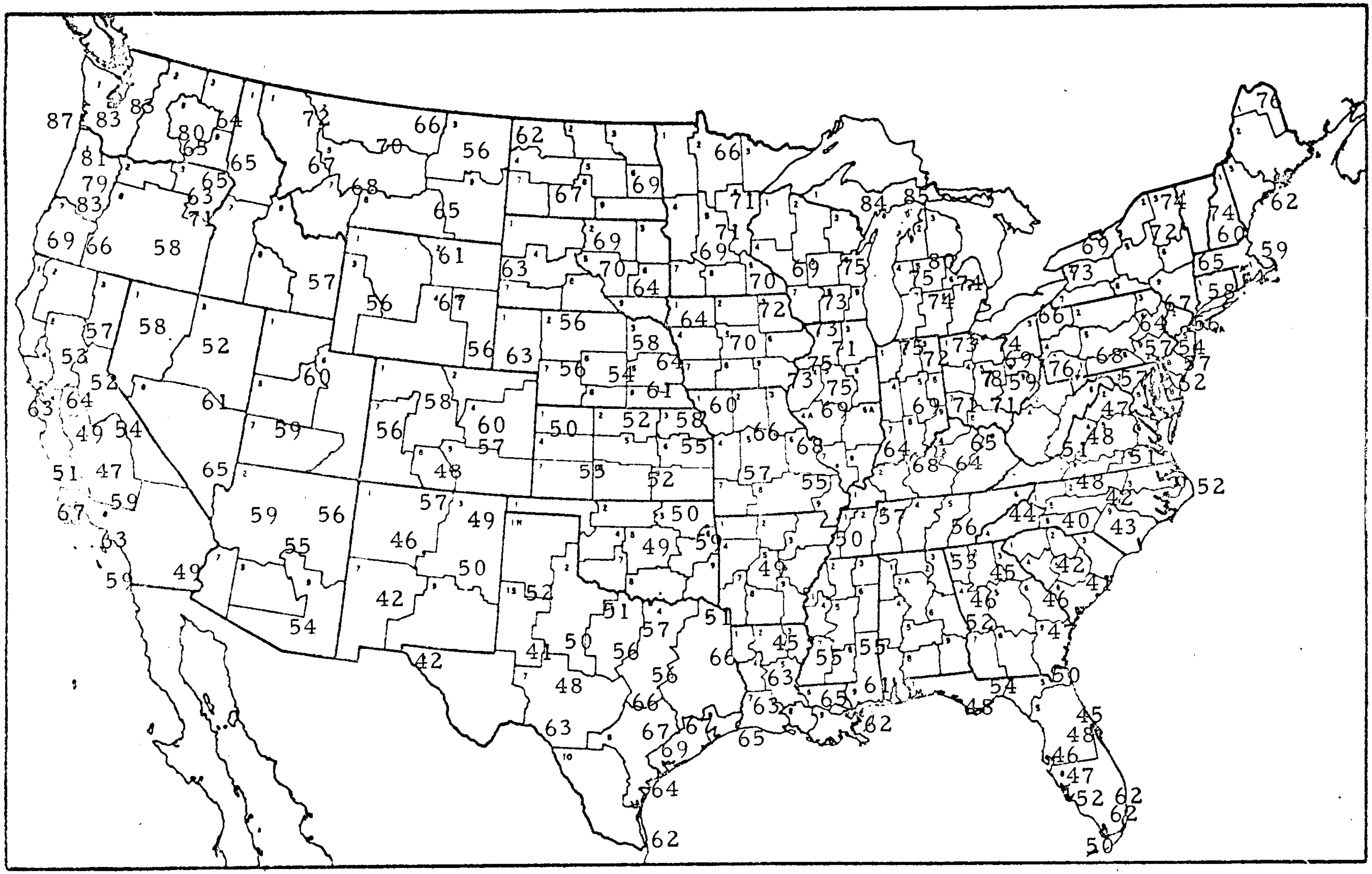


Figure 34

MEAN CLOUD COVER - APRIL
(In Per Cent)

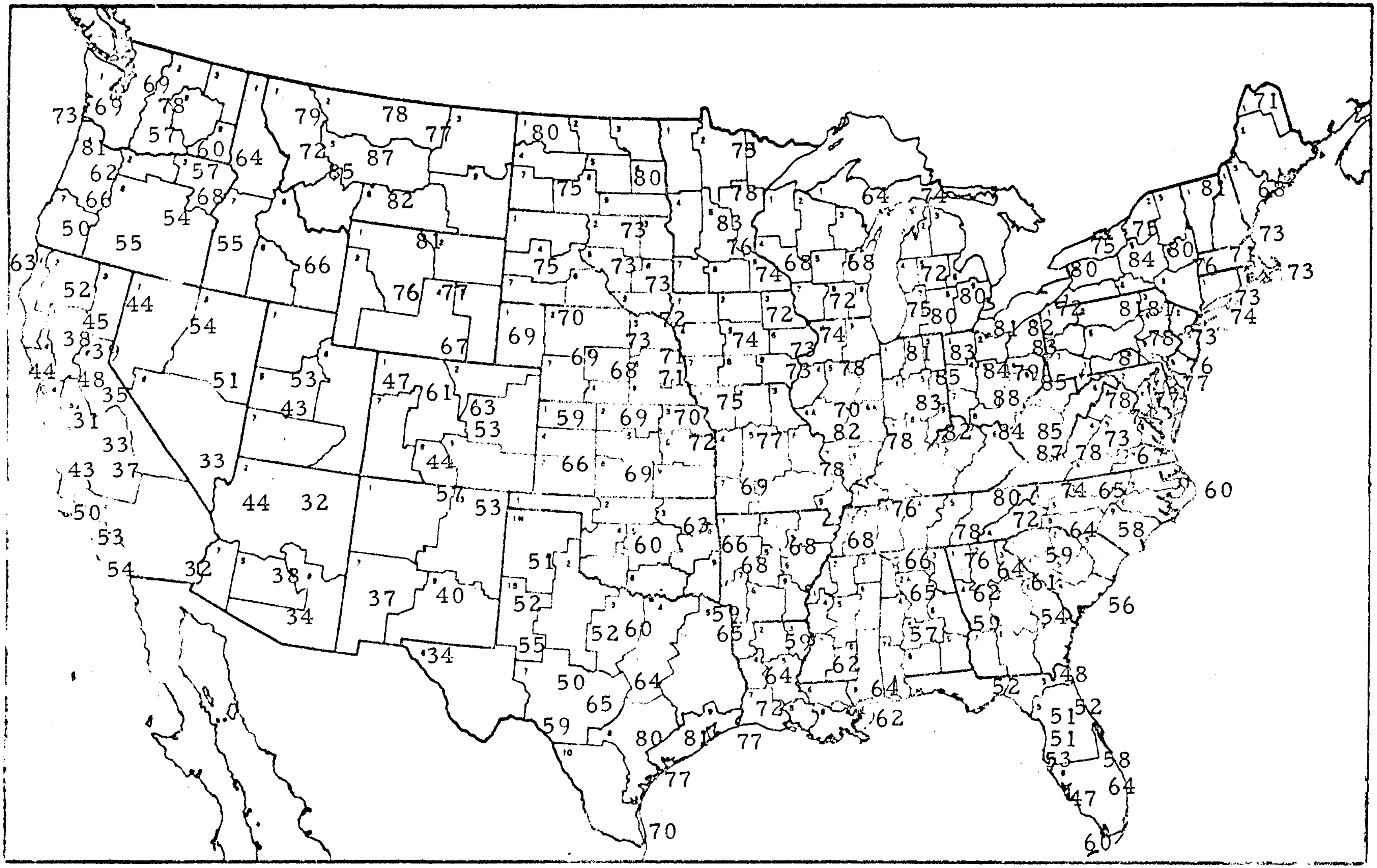


Figure 35

MEAN CLOUD COVER - MAY

(In Per Cent)

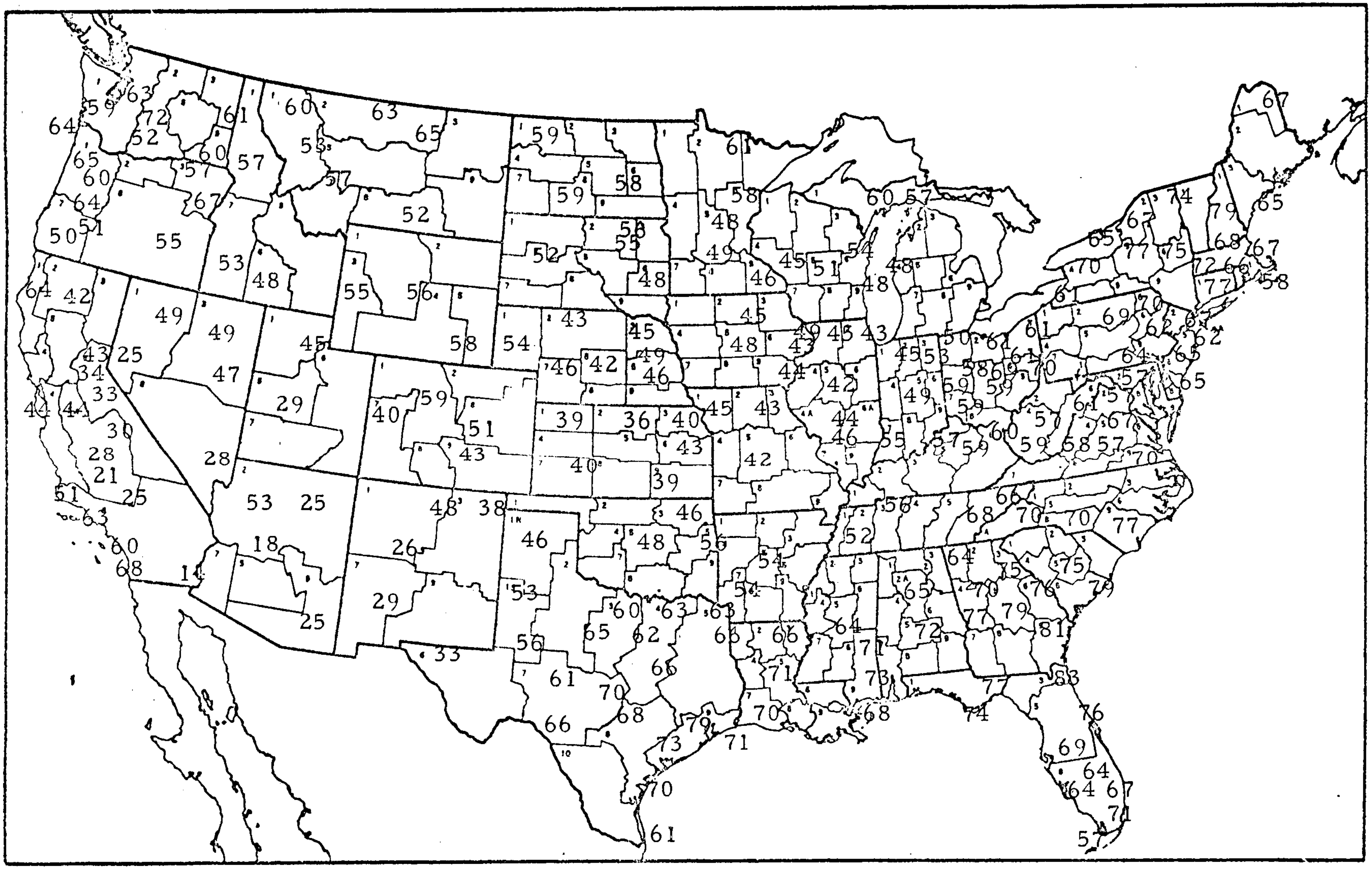


Figure 36

MEAN CLOUD COVER - JUNE
(In Per Cent)

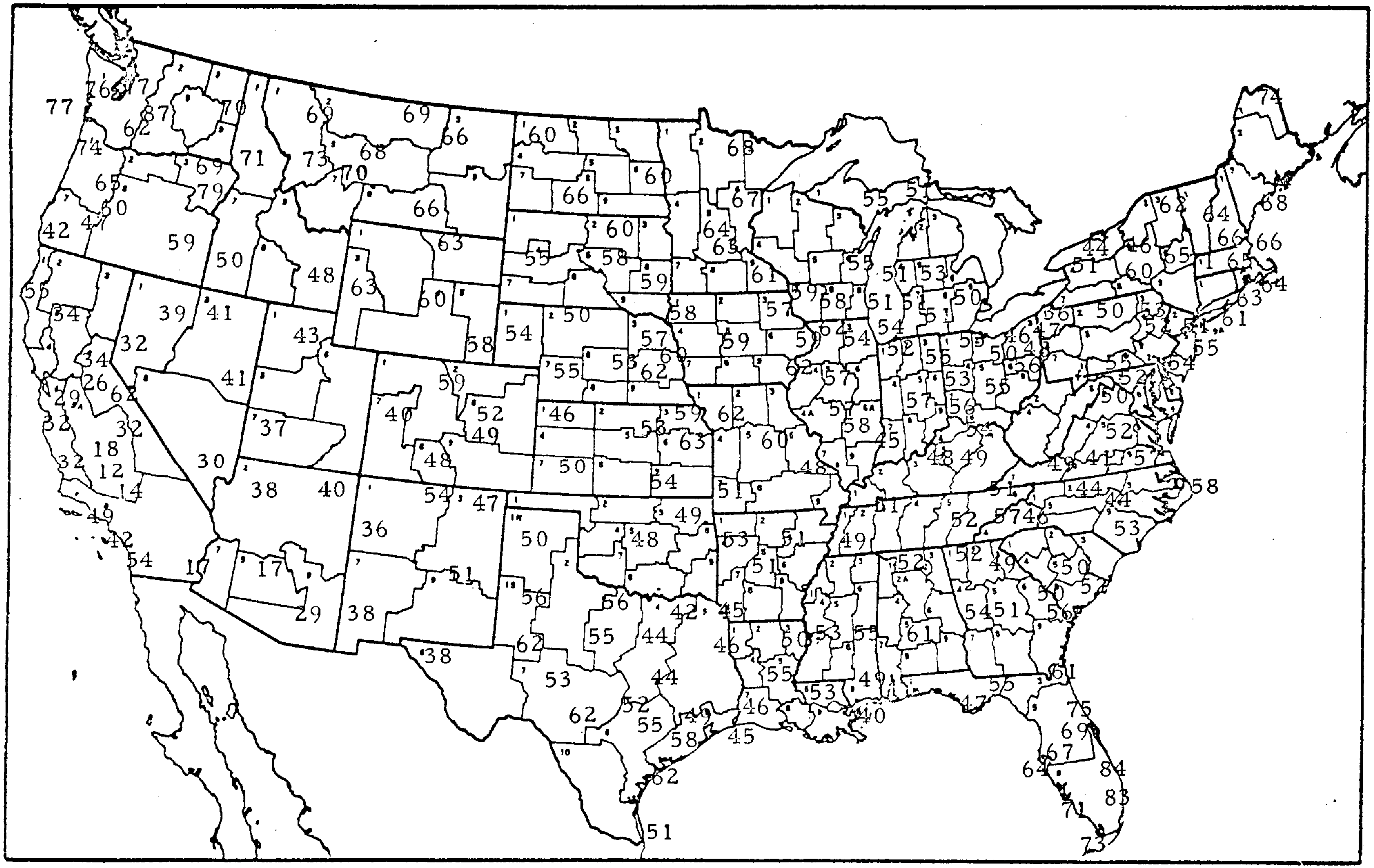


Figure 37

MEAN CLOUD COVER - JULY
(In Per Cent)

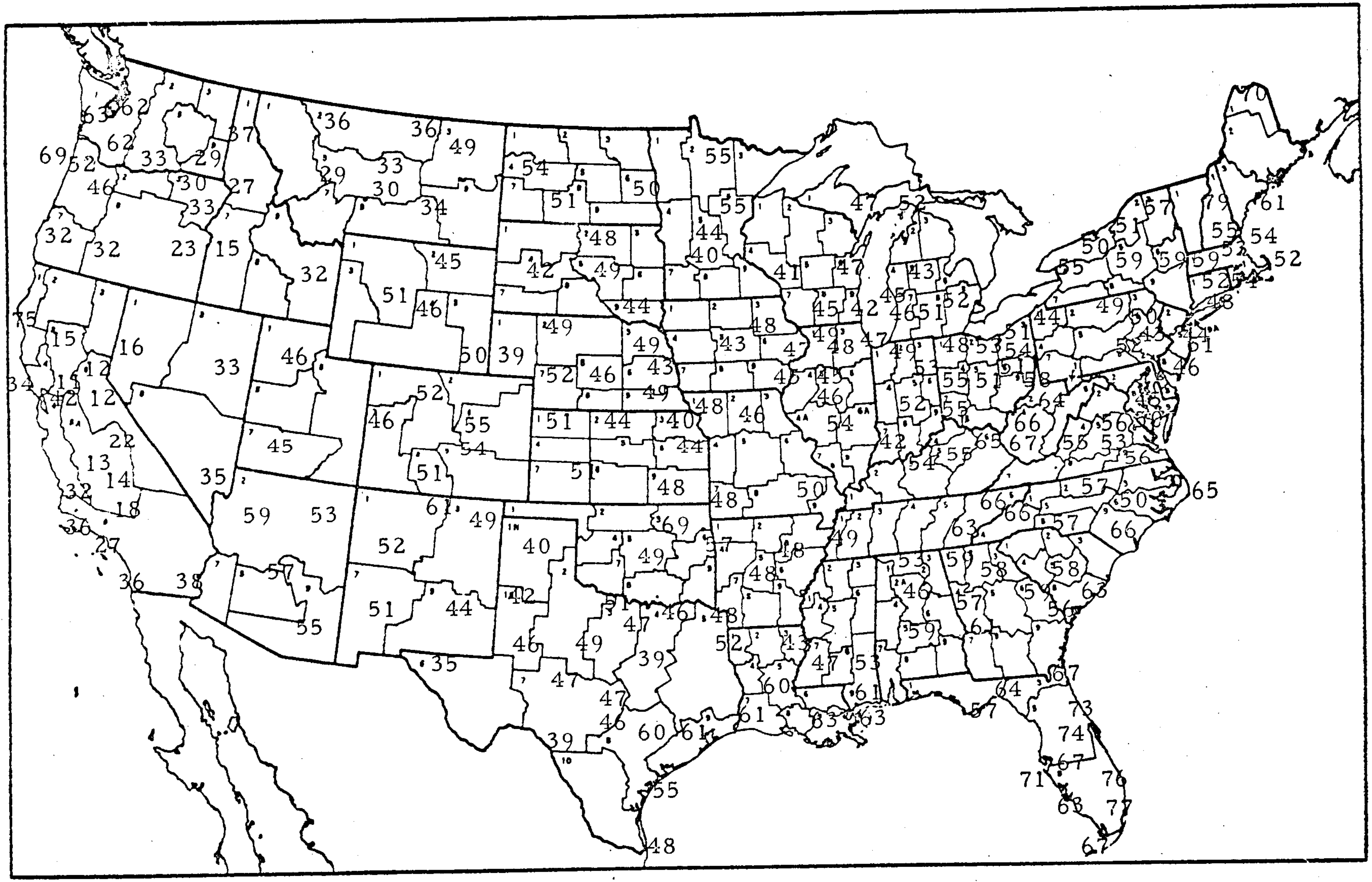


Figure 38

MEAN CLOUD COVER - AUGUST

(In Per Cent)

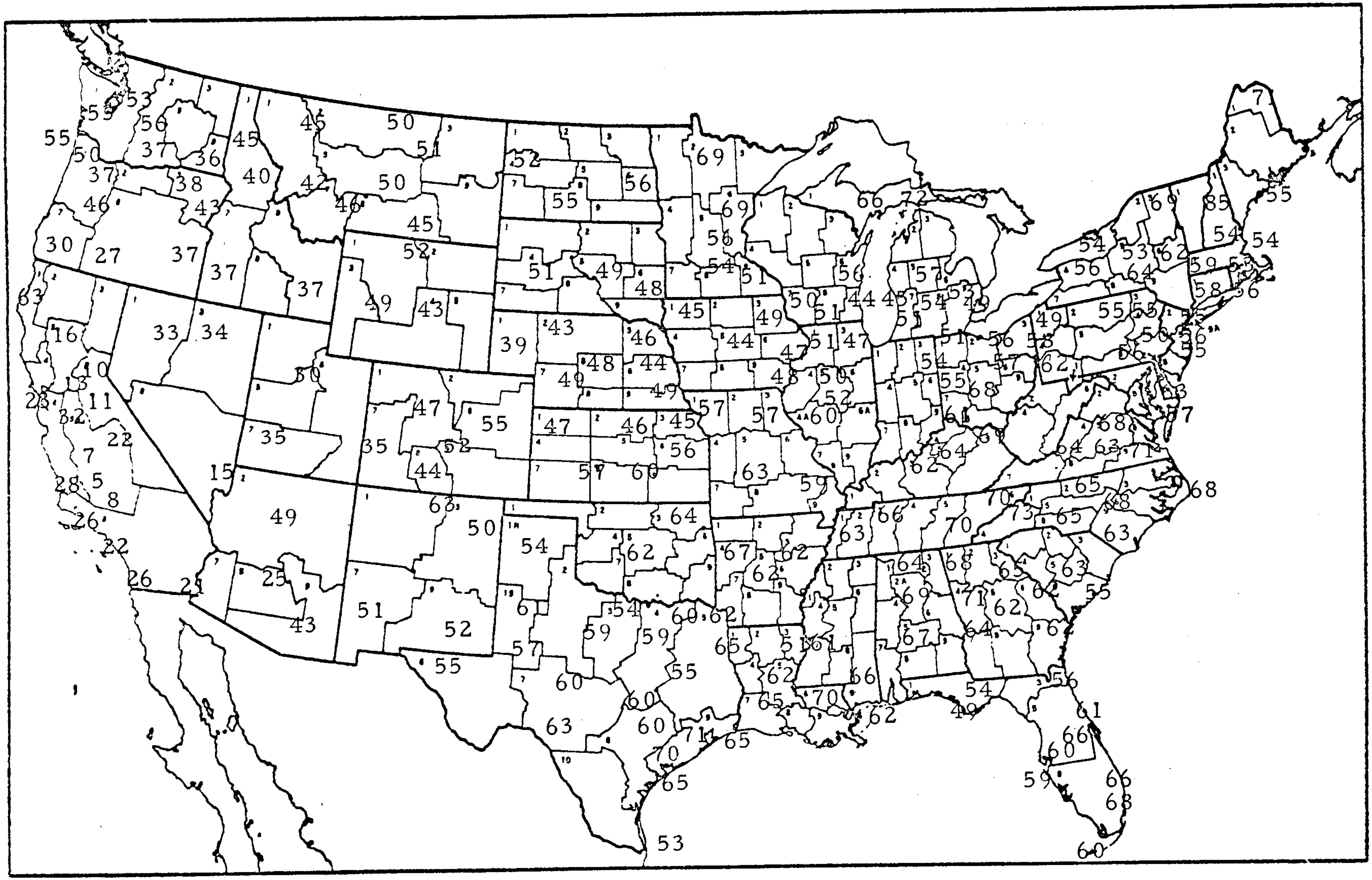


Figure 39

MEAN CLOUD COVER - SEPTEMBER

(In Per Cent)

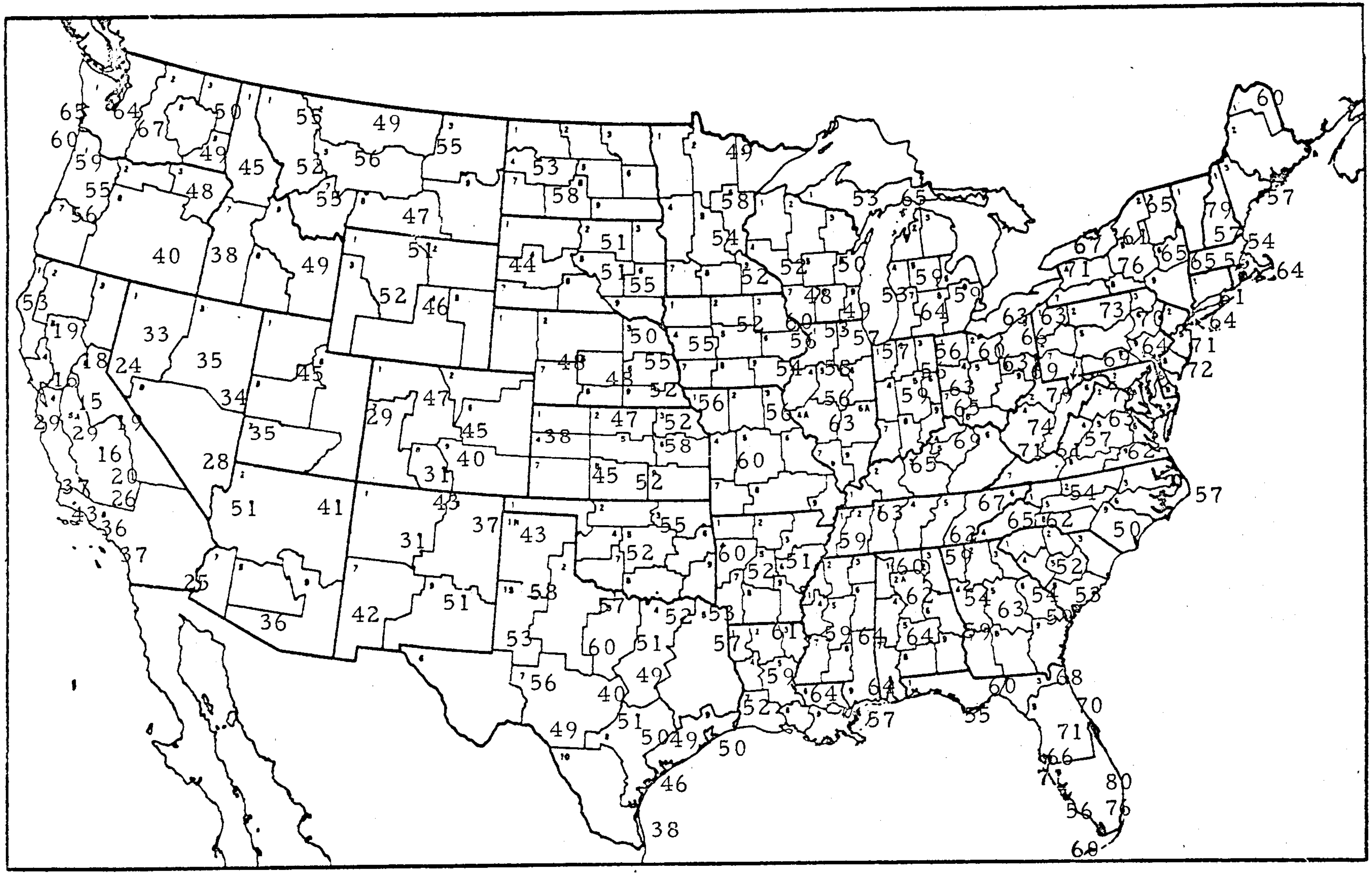


Figure 40

MEAN CLOUD COVER - OCTOBER
(In Per Cent)

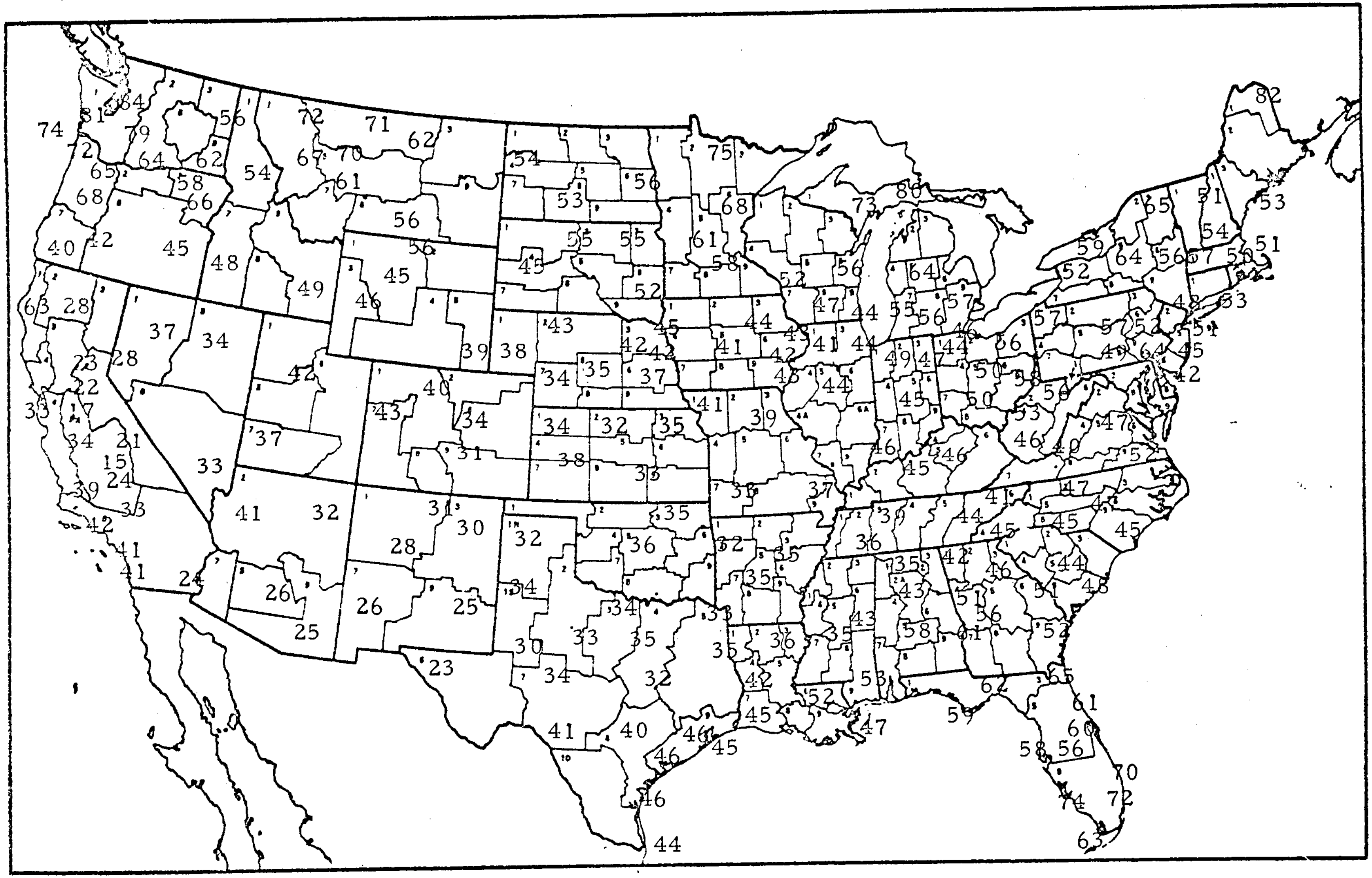


Figure 41.

MEAN CLOUD COVER - NOVEMBER

(In Per Cent)

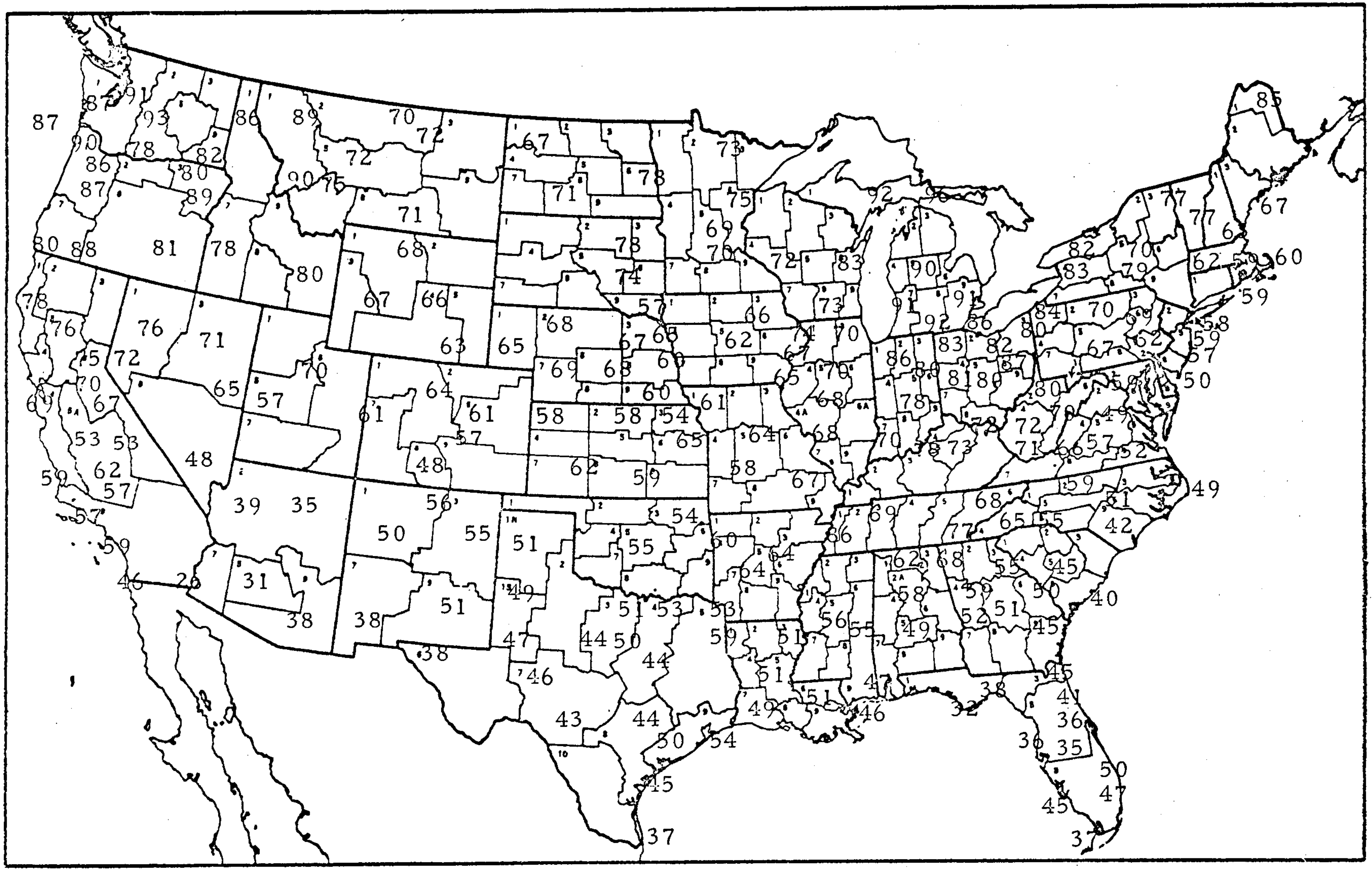


Figure 42

MEAN CLOUD COVER - DECEMBER

(In Per Cent)

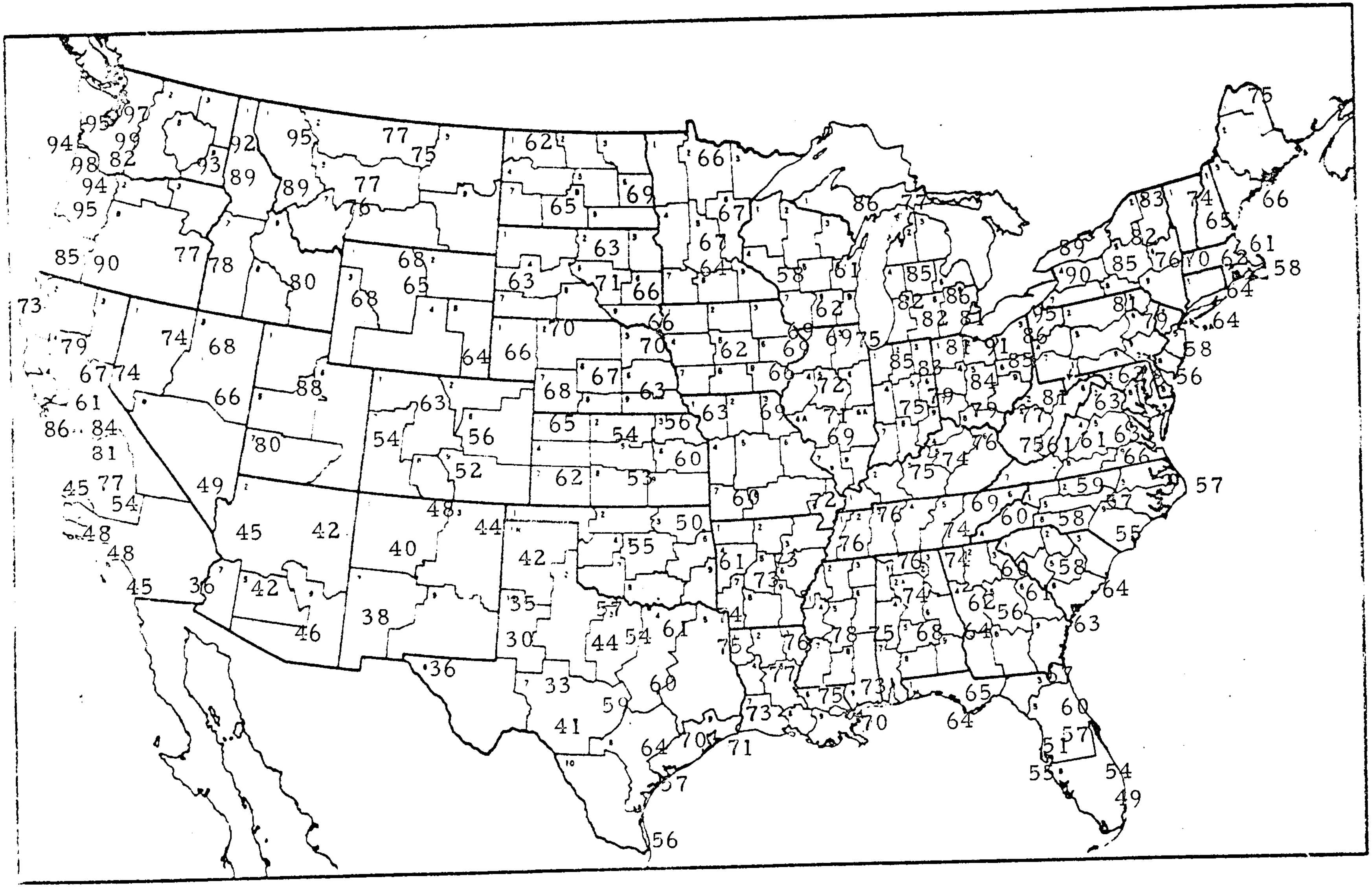


Figure 43

TABLE 26

MEAN SKY COVER

KANSAS

	Concordia	Dodge City	Goodland	Topeka	Wichita
Jan.	5.5	5.3	5.4	6.2	5.9
Feb.	5.1	5.8	5.9	6.4	6.0
Mar.	5.7	5.7	5.8	6.6	6.0
Apr.	6.2	5.8	5.8	6.5	6.3
May	5.3	5.7	5.8	6.3	6.0
June	5.3	4.8	4.5	6.1	5.5
July	4.3	4.6	4.3	5.4	4.9
Aug.	4.9	4.4	4.2	4.8	4.5
Sept.	5.4	4.2	4.0	4.7	4.6
Oct.	3.4	4.0	3.7	4.5	4.3
Nov.	5.3	4.9	4.9	5.5	5.2
Dec.	6.0	5.4	5.3	6.1	6.0
Year Avg. =	5.2	5.1	5.0	5.1	5.4

State Avg. = 5.2

NORTH DAKOTA

	Bismark	Fargo	Williston
Jan.	6.6	6.3	7.2
Feb.	6.8	6.1	6.5
Mar.	7.0	6.9	6.2
Apr.	6.7	8.0	8.0
May	6.5	5.2	5.9
June	6.1	6.0	6.0
July	4.7	5.0	5.4
Aug.	4.8	5.6	5.2
Sept.	5.5	5.0	5.3
Oct.	5.5	5.8	5.4
Nov.	6.9	7.8	6.7
Dec.	6.8	6.9	6.2
Year Avg. =	6.2	6.2	6.2

State Avg. = 6.2

—— Winter Wheat Planting Time
---- Winter Wheat Harvesting Time

TABLE 26(Cont.)

OKLAHOMA

	Oklahoma City	Tulsa
Jan.	5.6	6.0
Feb.	5.5	5.5
Mar.	4.9	5.0
Apr.	6.0	6.3
May	4.8	4.6
June	4.8	4.9
July	4.9	4.9
Aug.	6.2	6.4
Sept.	5.2	5.5
Oct.	3.6	3.5
Nov.	5.5	5.4
Dec.	5.5	5.0
Year Avg. =	5.2	5.3

State Avg. = 5.25

MONTANA

	Billings	Glasgow	Great Falls	Havre
Jan.	6.9	7.1	7.1	7.0
Feb.	7.1	7.2	7.3	7.3
Mar.	7.1	7.0	7.2	7.0
Apr.	7.1	7.4	7.3	7.4
May	6.5	6.6	6.8	6.6
June	5.9	6.0	6.5	6.0
July	4.0	4.6	3.9	3.9
Aug.	4.2	4.9	4.6	4.7
Sept.	5.3	5.7	5.6	5.7
Oct.	5.5	5.9	6.1	5.9
Nov.	6.8	7.1	7.2	7.2
Dec.	6.7	7.3	7.1	7.4
Year Avg. =	6.1	6.4	6.4	6.3

TABLE 26 (Cont.)

MONTANA (Cont.)

	Helena	Kalispell	Miles City	Miscoula
Jan.	7.4	9.5	6.8	8.4
Feb.	7.4	8.8	7.0	8.2
Mar.	7.2	7.2	6.9	7.8
Apr.	7.3	7.9	6.8	7.6
May	6.9	6.0	6.5	7.0
June	6.4	6.9	5.5	6.5
July	3.9	3.6	4.0	3.6
Aug.	4.5	4.5	4.0	4.5
Sept.	5.5	5.5	5.1	5.5
Oct.	5.9	7.2	5.4	6.8
Nov.	7.2	8.9	6.6	8.3
Dec.	7.4	9.5	6.5	8.6
Year Avg. =	6.4	7.1	5.9	6.9
State Avg. =	6.5			

TEXAS

	Abilene	Amarillo	Austin	Brownsville
Jan.	5.6	5.0	6.3	6.6
Feb.	5.6	5.2	6.1	6.5
Mar.	5.4	5.1	6.1	6.7
Apr.	5.2	5.1	6.2	6.6
May	5.5	5.1	6.1	5.9
June	4.3	4.4	5.1	5.2
July	4.5	4.4	4.6	4.7
Aug.	4.3	4.1	4.6	4.8
Sept.	4.2	3.7	4.8	5.2
Oct.	4.2	3.7	4.5	5.7
Nov.	4.5	4.1	5.3	5.8
Dec.	5.1	4.7	5.9	6.6
Year Avg. =	4.9	4.6	5.5	5.8

TABLE 26 (Cont.)

TEXAS (Cont.)

	Corpus Cristi	Dallas	Del Rio	El Paso
Jan.	6.6	6.1	4.8	4.6
Feb.	6.5	5.9	5.1	4.0
Mar.	6.7	5.8	5.9	4.4
Apr.	6.7	6.0	6.2	3.7
May	6.3	5.9	7.2	3.2
June	5.1	4.7	5.9	2.8
July	4.7	4.3	3.4	4.5
Aug.	4.6	4.1	5.0	4.1
Sept.	5.0	4.2	5.5	3.2
Oct.	4.4	4.3	3.3	3.1
Nov.	5.8	4.8	5.3	3.4
Dec.	6.4	5.6	5.5	4.2
Year Avg. =	5.7	5.1	5.2	3.8

	Fort Worth	Houston	Lubbock	Midland
Jan.	6.1	6.9	5.0	5.1
Feb.	5.6	6.8	4.8	5.0
Mar.	5.7	6.7	4.9	5.0
Apr.	6.1	7.0	4.8	4.8
May	5.9	6.4	5.0	4.8
June	4.5	5.6	4.0	3.9
July	4.0	5.9	4.2	4.6
Aug.	3.9	5.7	3.9	4.1
Sept.	4.2	5.7	3.9	3.9
Oct.	4.1	5.4	3.5	3.5
Nov.	5.0	4.7	4.0	4.1
Dec.	5.5	5.9	4.6	4.6
Year Avg. =	5.0	6.1	4.4	4.5

TABLE 26(Cont.)

TEXAS (Cont.)

	Port Arthur	San Angelo	San Antonio
Jan.	6.9	5.5	6.2
Feb.	6.4	4.0	6.2
Mar.	6.4	4.8	6.2
Apr.	6.8	5.0	6.3
May	6.1	6.1	6.3
June	5.5	5.3	5.3
July	5.9	4.7	4.8
Aug.	5.9	6.0	4.6
Sept.	5.5	5.6	4.9
Oct.	4.7	3.4	4.6
Nov.	5.8	4.6	5.8
Dec.	6.4	3.3	5.6
Year Avg. =	6.0	4.9	5.6

	Victoria	Waco	Wichita Falls
Jan.	6.5	6.3	5.5
Feb.	6.2	6.0	5.4
Mar.	6.7	5.8	5.3
Apr.	7.4	6.1	5.3
May	6.9	6.1	5.2
June	6.0	4.7	4.1
July	5.1	4.2	4.1
Aug.	5.3	4.1	3.8
Sept.	5.6	4.4	3.7
Oct.	4.2	4.3	3.8
Nov.	5.8	5.1	4.4
Dec.	7.0	5.7	5.1
Year Avg. =	6.1	5.2	4.7

State Avg. = 5.1

TABLE 26(Cont.)

NEBRASKA

	Grand Island	Lincoln	Norfolk
Jan.	6.0	6.0	6.1
Feb.	6.4	6.0	6.3
Mar.	6.4	6.6	6.7
Apr.	6.2	6.3	6.3
May	6.0	6.2	6.2
June	5.1	5.7	5.4
July	4.3	5.0	4.7
Aug.	4.4	4.7	4.6
Sept.	4.6	5.1	4.8
Oct.	4.0	4.4	4.4
Nov.	5.7	5.7	6.0
Dec.	5.9	6.2	6.1
Year Avg. =	5.4	5.7	5.6

	North Platte	Omaha	Scottsbluff	Valentine
Jan.	6.1	6.1	6.0	6.2
Feb.	6.6	6.3	6.4	6.4
Mar.	6.5	6.6	6.3	6.6
Apr.	6.4	6.4	6.5	6.5
May	6.4	6.3	6.3	6.2
June	5.1	5.6	5.2	5.3
July	4.5	4.7	4.1	4.3
Aug.	4.6	4.7	4.5	4.2
Sept.	4.6	4.7	4.2	4.6
Oct.	4.2	4.4	4.3	4.2
Nov.	5.6	5.8	5.9	5.8
Dec.	5.8	5.8	5.9	6.0
Year Avg. =	5.5	5.6	5.5	5.5

State Avg. = 5.5

TABLE 26 (Cont.)

COLORADO

	Alamosa	Colorado Springs	Denver	Grand Junction	Pueblo
Jan.	4.5	4.9	5.2	5.9	4.9
Feb.	4.7	5.5	5.9	6.2	5.4
Mar.	5.0	5.7	5.9	6.0	5.3
Apr.	5.3	5.9	6.2	5.9	5.8
May	5.4	6.0	6.2	5.5	5.7
June	3.9	4.7	5.0	3.9	4.5
July	5.1	5.0	4.9	4.2	4.7
Aug.	4.8	4.9	4.9	4.3	4.7
Sept.	3.7	4.1	4.3	3.5	3.9
Oct.	3.4	3.8	4.2	3.8	3.8
Nov.	4.1	4.9	5.2	5.2	4.7
Dec.	4.2	4.8	5.1	5.7	4.8
Year Avg. =	4.5	5.0	5.3	5.0	4.9

State Avg. = 4.9

WASHINGTON

	Olympia	Seattle	Spokane
Jan.	8.6	8.4	8.2
Feb.	8.4	8.3	8.0
Mar.	8.1	8.0	7.3
Apr.	7.7	7.7	7.0
May	7.1	7.1	6.6
June	7.0	7.1	6.0
July	5.3	5.3	3.4
Aug.	6.0	5.9	4.3
Sept.	6.1	6.2	4.8
Oct.	7.8	7.6	6.5
Nov.	8.5	8.4	8.0
Dec.	8.9	8.8	8.7
Year Avg. =	7.4	7.4	6.6

TABLE 26(Cont.)

WASHINGTON (Cont.)

	Stampede Pass	Walla Walla	Yakima
Jan.	8.7	8.5	7.7
Feb.	8.6	7.9	7.5
Mar.	8.3	7.0	6.9
Apr.	8.0	6.3	6.4
May	7.4	5.9	5.9
June	7.3	5.0	5.3
July	4.9	2.4	2.9
Aug.	5.5	3.2	3.5
Sept.	5.7	4.2	4.2
Oct.	7.3	5.8	6.0
Nov.	8.6	8.0	7.4
Dec.	9.0	8.8	8.0
Year Avg. =	7.4	6.1	6.0

State Avg. = 6.8

SOUTH DAKOTA

	Aberdeen	Huron	Rapid City	Sioux City
Jan.	5.9	6.5	6.4	6.5
Feb.	6.4	6.6	6.6	6.5
Mar.	7.2	7.2	6.6	7.1
Apr.	7.6	6.7	6.7	6.6
May	6.1	6.3	6.4	6.3
June	6.7	5.8	5.7	5.8
July	4.9	4.6	4.3	4.8
Aug.	5.6	4.8	4.3	5.0
Sept.	6.4	5.1	4.6	5.2
Oct.	4.9	5.0	4.7	5.0
Nov.	6.4	6.5	6.2	6.4
Dec.	6.8	6.7	6.3	6.6
Year Avg. =	6.2	6.0	5.7	6.0

State Avg. = 5.9

TABLE 26(Cont.)

ILLINOIS

	Cairo	Chicago	Moline	Peoria	Rockford	Springfield
Jan.	6.7	7.0	6.6	6.8	6.7	6.9
Feb.	6.3	6.8	6.5	6.7	6.5	6.5
Mar.	6.2	7.0	6.8	6.8	6.8	6.8
Apr.	6.3	6.8	6.6	6.8	6.6	6.7
May	6.2	6.3	6.3	6.2	6.2	6.0
June	5.8	6.0	6.1	6.0	6.0	5.8
July	5.6	5.3	5.3	5.3	5.5	5.4
Aug.	5.0	5.3	5.3	5.2	5.6	5.0
Sept.	4.9	5.3	5.1	4.8	5.3	4.6
Oct.	4.3	5.1	4.6	4.8	5.1	4.6
Nov.	5.7	7.0	6.5	6.4	6.6	6.0
Dec.	6.5	7.0	6.7	6.8	6.9	6.7
Year Avg.=	5.8	6.2	6.1	6.0	6.2	5.9

State Avg. = 6.0

MISSOURI

	Columbia	Kansas City	St. Joseph	St. Louis	Springfield
Jan.	6.3	6.2	6.0	6.8	6.5
Feb.	6.1	6.2	6.1	6.5	6.3
Mar.	6.3	6.4	6.8	6.7	6.5
Apr.	6.1	6.3	6.2	6.6	6.3
May	5.9	6.1	6.0	6.1	6.2
June	5.6	5.9	5.5	5.9	5.8
July	4.8	4.8	5.0	5.6	5.4
Aug.	4.7	4.7	4.3	5.2	5.0
Sept.	4.4	4.6	4.6	4.7	4.6
Oct.	4.4	4.9	4.2	4.6	4.5
Nov.	5.6	5.5	5.3	5.8	5.4
Dec.	6.4	6.2	5.9	6.7	6.3
Year Avg. =	5.6	5.6	5.5	5.8	5.7

State Avg. = 5.6

TABLE 26(Cont.)

OHIO

	Akron	Cincinnati	Cleveland	Columbus
Jan.	7.9	7.5	8.1	7.7
Feb.	8.0	7.4	7.9	7.7
Mar.	7.5	7.5	7.4	7.4
Apr.	7.4	7.3	7.0	7.3
May	6.6	6.7	6.5	6.5
June	5.9	6.1	5.8	5.9
July	5.7	5.9	5.4	5.8
Aug.	5.7	5.7	5.4	5.6
Sept.	5.6	5.3	5.5	5.3
Oct.	5.4	5.1	5.6	5.2
Nov.	7.4	6.8	7.7	7.1
Dec.	7.8	7.4	8.1	7.6
Year Avg. =	6.7	6.6	6.7	6.6

	Dayton	Mansfield	Toledo	Youngstown
Jan.	7.6	7.5	7.3	8.1
Feb.	7.3	8.1	7.5	8.0
Mar.	7.4	7.7	7.6	7.6
Apr.	7.3	7.7	7.2	7.4
May	6.6	6.6	6.3	6.6
June	6.1	5.5	5.7	5.8
July	5.7	5.6	5.6	5.7
Aug.	5.4	5.9	5.6	5.6
Sept.	5.7	5.5	5.5	5.7
Oct.	5.1	5.4	5.4	5.6
Nov.	7.0	7.3	7.4	8.0
Dec.	7.4	7.8	7.6	8.0
Year Avg. =	6.5	6.7	6.5	6.8

State Avg. = 6.6

TABLE 26(Cont.)

INDIANA

	Evansville	Ft. Wayne	Indianapolis	South Bend
Jan.	7.1	7.6	7.2	7.9
Feb.	6.7	7.2	6.9	7.7
Mar.	6.7	7.3	7.1	7.6
Apr.	6.6	7.1	7.1	7.0
May	6.3	7.2	6.5	6.3
June	5.8	6.1	6.1	6.0
July	5.5	5.7	5.7	5.5
Aug.	5.1	5.5	5.4	5.5
Sept.	4.9	5.3	5.1	5.4
Oct.	4.6	5.3	4.9	5.5
Nov.	6.2	7.1	6.7	7.6
Dec.	6.9	7.5	7.1	7.9
Year Avg. =	6.0	6.5	6.3	6.7

State Avg. = 6.4

IDAHO

	Boise	Lewiston	Pocatello
Jan.	7.5	8.2	7.9
Feb.	7.2	8.2	7.5
Mar.	6.7	7.5	6.8
Apr.	6.3	7.6	6.6
May	5.9	6.5	6.2
June	4.8	5.9	4.7
July	2.5	3.0	3.2
Aug.	3.1	3.9	3.6
Sept.	3.5	4.7	3.9
Oct.	5.0	6.3	4.8
Nov.	6.8	8.2	6.7
Dec.	7.6	8.5	7.7
Year Avg. =	5.6	6.5	5.8

State Avg. = 5.9

TABLE 26(Cont.)

OREGON

	Astoria	Burns	Eugene	Meashaw	Medford
Jan.	8.5	7.6	8.5	8.5	8.2
Feb.	8.4	7.2	8.2	8.4	7.6
Mar.	8.1	6.7	7.9	8.0	7.2
Apr.	8.1	6.3	7.2	7.6	6.6
May	7.7	6.1	6.7	6.9	5.9
June	7.8	5.0	6.2	6.1	4.8
July	6.7	2.5	3.6	3.1	2.1
Aug.	6.6	3.4	4.4	3.9	2.3
Sept.	6.3	3.3	4.9	4.7	3.3
Oct.	7.4	4.9	7.1	6.5	5.6
Nov.	8.0	6.5	8.3	8.0	7.5
Dec.	8.6	7.3	8.9	8.4	8.6
Year Avg. =	7.7	5.6	6.8	6.7	5.8

	Pendleton	Portland	Salem	Sexton Summit
Jan.	8.2	8.5	8.3	7.7
Feb.	8.0	8.4	8.2	7.7
Mar.	7.2	8.2	7.9	7.7
Apr.	6.6	7.6	7.3	6.8
May	6.6	7.2	7.0	6.2
June	5.2	6.9	6.5	4.8
July	2.6	4.6	4.0	2.3
Aug.	3.3	5.3	4.7	2.8
Sept.	4.0	5.6	5.1	3.5
Oct.	5.7	7.2	6.9	5.6
Nov.	7.7	8.2	8.0	7.3
Dec.	8.4	9.0	8.8	7.7
Year Avg. =	6.1	7.2	6.9	5.8

State Avg. = 6.5

TABLE 26 (Cont.)

MICHIGAN

	Alpena	Detroit	Flint	Grand Rapids	Haughton Lake
Jan.	7.6	7.6	7.6	7.6	7.0
Feb.	7.3	7.4	7.4	7.5	7.8
Mar.	7.0	7.3	7.4	7.9	7.9
Apr.	7.0	7.0	7.2	7.2	7.4
May	6.3	6.4	6.6	6.0	6.3
June	5.5	5.9	5.7	5.4	5.1
July	5.3	5.5	5.6	5.2	4.8
Aug.	5.8	5.4	5.6	5.9	6.2
Sept.	6.4	5.5	5.9	6.6	6.7
Oct.	6.5	5.5	6.0	5.8	6.6
Nov.	8.2	7.6	6.0	8.1	8.7
Dec.	8.3	7.6	8.0	8.4	8.7
Year Avg. =	6.8	6.6	6.8	6.8	6.9

	Lansing	Marquette	Muskegon	Sault Ste. Marie
Jan.	7.8	8.1	8.7	7.7
Feb.	7.4	7.8	8.1	7.4
Mar.	7.4	7.3	7.3	7.0
Apr.	6.9	6.7	6.6	6.7
May	6.1	6.6	6.1	6.6
June	5.6	6.3	5.7	6.2
July	5.2	5.7	4.9	5.7
Aug.	5.3	6.0	5.1	6.1
Sept.	5.7	6.6	5.5	7.0
Oct.	5.5	6.9	5.8	7.0
Nov.	7.5	8.4	8.3	8.6
Dec.	7.7	8.2	8.7	8.3
Year Avg. =	6.5	7.0	6.7	7.0

State Avg. = 6.9

TABLE 26 (Cont.)

MINNESOTA

	Duluth	Int'l Falls	Minneapolis St. Paul	Rochester	Saint Cloud
Jan.	6.7	6.5	6.2	6.3	6.3
Feb.	6.4	6.0	6.1	6.5	6.0
Mar.	6.7	6.4	6.7	7.2	6.8
Apr.	7.0	6.7	6.5	7.0	6.7
May	6.7	6.5	6.3	5.7	6.3
June	6.6	6.5	6.0	5.9	6.0
July	5.9	6.0	5.1	5.2	5.2
Aug.	6.2	6.2	5.2	5.6	5.3
Sept.	6.7	6.9	5.4	6.2	5.7
Oct.	6.4	6.7	5.3	5.2	5.6
Nov.	7.6	7.9	6.9	6.9	7.0
Dec.	7.2	7.1	6.9	7.0	7.0
Year Avg. =	6.7	6.6	6.0	6.2	6.1

State Avg. = 6.3

(Note: "Sky cover is expressed in a range of 0 for no clouds or obscuring phenomena to 10 for complete sky cover. The number of clear days is based on average cloudiness 0-3; partly cloudy days 4-7; and cloudy days 8-10 tenths." The mean sky coverage is predicated upon the number of years the stations have been in operation.)

"Local Climatological Data", Annual Summary with Comparative Data, 1966, U. S. Department of Commerce, Environmental Science Services Administration.

REFERENCES

1. Colwell, R. N., "Uses and Limitations of Multispectral Remote Sensing", Proceedings of the 4th Symposium on Remote Sensing Of Environment, April, 1966, Institute of Science and Technology, University of Michigan, June 1966.

2. Sadacca, R. and Brainard, R., "Development and Evaluation of a New Technique for Measuring Image Quality", The Human in the Photo-optical System, Seminar Proceedings, SPIE, 25-26 April 1966.

3. Hoffer, R. M. and Holmes, R. A., "Remote Multispectral Sensing in Agriculture", Semi-Annual Progress Report - May 1, 1966, Purdue University, 1966.

4. Frey, Thomas H., "Potential Agricultural Applications of Remote Sensing from Space Platforms", U. S. Department of Agriculture, Economic Research Service, July 1966 (Unpublished report).

5. "Aerial Photography Specifications", USDA, Agricultural Stabilization & Conservation Service, ASCS-AP-210 (Review1) May 22, 1963.

6. "Statistical Reporting Service of the U. S. Department of Agriculture, Scope - Methods", USDA Miscellaneous Publication 967, December, 1964.

7. "The Master Sample of Agriculture", Part I- Development and Use by A. J. King, and Part II - Design by R. J. Jessen, Journal of the American Statistical Association, Vol. 40, March 1945.

8. "ORL Experiment Program", Vol. B, Part I, Agriculture/Forestry, Contract NASw-1215, International Business Machines Corporation, 21 February 1966.

9. Mullins, Bill, "Phase III, Final Report, Analysis of Results", Waterways Experiment Station Terrain Analysis Radar (Project WESTAR), Contract No. DA-22-079-eng-295, Texas Instruments Incorporated, January 1965.

10. "The Human in the Photo-optical System", Seminar Proceedings, The Society of Photo-optical Instrumentation Engineers, 25-26 April 1966.

REFERENCES (Cont.)

11. "A Graphic Summary of World Agriculture", USDA Miscellaneous Publication No. 705, September 1964.

12. Royen, William Van, "The Agricultural Resources of the World", Prentice-Hall, Inc., 1954 (By permission of Prentice Hall, Inc. Englewood Cliffs, New Jersey).

13. Hansen, Morris, H., Hurwitz, William N., and Madow, William, G., "Sample Survey Methods & Theory", Vol. II - Theory, John Wiley & Sons, 1953.

14. Cramer, Harald, "Mathematical Methods of Statistics", Princeton University Press, 1946.

15. Arkin, Herbert & Colton, Raymond R., "Statistical Methods", Fourth Edition Revised, Barnes & Nobel, Inc., New York, 1960.

16. Katz, Amron, H., "Observation Satellites: Problems and Prospects", Astronautics, April 1960.

17. Lowman, Paul D. Jr., "Space Photography - A Review", Photogrammetric Engineering, Vol. XXXI, Vo. 1, January 1965.

18. "Space Planners Guide", U. S. Air Force, July, 1965 (For Official Use Only).

19. Fujita, Tetsuya, "Evaluation of Errors in the Graphic Rectification of Satellite Photographs", Journal of Geophysical Research, Vol. 70, No. 24, December 15, 1965.

20. "Orbiting Solar Observatory Satellite", OSO I, The Project Summary, NASA SP-57, National Aeronautical & Space Administration, 1965.

21. Widger, Jr., William K., "Orbits, Altitudes, Viewing Geometry, Coverage and Resolution Pertinent to Satellite Observations of the Earth and its Atmosphere", Proceedings of the Fourth Symposium on Remote Sensing of Environment, 12, 13, 14 April 1966, The University of Michigan, June 1966.

22. King-Hele, D., "Satellite and Scientific Research", Routledge and Kegan Paul, London, or Dover, New York.

REFERENCES (Cont.)

23. Sears, Francis Weston, "Optics", Addison-Wesley Press, Inc., Cambridge, Mass., 1949.

24. Dalenius, Tore, "Use of Sampling Methods for the Estimation of Areas", Estimation of Areas in Agricultural Statistics, Food and Agriculture Organization of the United Nations, Rome, 1965.

25. Tsukibayashi, S., "Area Surveys in Japan", Estimation of Areas in Agricultural Statistics, Food and Agriculture Organization of the United Nations, Rome, 1965.

26. "Applications of Earth-Observation Space Craft and Manned Earth Orbital Experiments", Vol. II, U. S. Department of Agriculture.

27. Reference Unknown

28. Wilson, R. C., "Forestry Applications of Remote Sensing", Proceedings of 4th Symposium on Remote Sensing of Environment, April 1966.

29. Natrella, M. G., "Experimental Statistics", NBS Handbook 91, August 1, 1963.

30. Parker, D. C., Woeff, M. F., "Remote Sensing", International Science and Technology, July, 1965.

31. Olson, C. E., "Spectral Reflectance Measurements Compared with Panchromatic and Infrared Aerial Photographs", Institute of Science and Technology, University of Michigan, September 1964.

32. "Usual Planting and Harvesting Dates", U. S. Department of Agriculture, Handbook No. 283.

33. "Forester's Guide to Aerial Photo Interpretation", U. S. Department of Agriculture, Handbook No. 308.

34. Sokolnikoff, I. S. & E. S., "Higher Mathematics for Engineers and Physicists", McGraw-Hill Book Company, 1941.

35. "Feasibility Study on Surveying & Mapping From Lunar Orbiter", University of Michigan, Autometrics Corporation, Contract No. DA 018-eng-2133(E), December 1959 - December 1960, AD 253456.

36. "A Graphic Summary of Land Utilization", Final Report, Vol. V, Part 6, Chapter 1, U. S. Census of Agriculture: 1959.

REFERENCES (Cont.)

37. Wilson, R. C., "Forestry Applications of Remote Sensing", Proceedings of 4th Symposium on Remote Sensing of Environment, April 1966.

38. Davenport, William B., Jr., and Root, William L., "An Introduction to the Theory of Random Signals and Noise", McGraw-Hill Book Company, Inc., 1958.

<u>Additional References</u>

1. Frost, Robert E. and Woods, K. B., "Airphoto Patterns of Soils of the Western United States", Technical Development Report No. 85, U. S. Department of Commerce, Civil Aeronautics Administration, August 1948.

2. "Satellite Meteorology 1958-1964", NASA SP-96, National Aeronautics and Space Administration, 1966.

3. Light, Donald L., "The Orientation Matrix", Photogrammetric Engineering, Vol. XXXII, No. 3, American Society of Photogrammetry, May 1966.

4. Frick, R. H., Rumer, W. I., & Sharkey, E. H., "Trajectory and Orbit Plotter Instruction Manual", The Rand Corporation, R-418-PR, October 1963.

5. Meier, Dr., -Ing. H.-K., "Angular Field and Negative Size", Photogrammetric Engineering, Vol. XXXII, No. 1, American Society of Photogrammetry, January, 1966.

6. "Investigation of Background Discrimination Techniques for Missile Guidance (U)", Vol. I, Prepared for Bureau of Naval Weapons, Texas Instruments Incorporated, 9 June 1965, AD 466777.

7. Ray, Richard G., "Aerial Photographs in Geologic Interpretation and Mapping", Geological Survey Professional Paper 373, 1960.

8. Zwick, Daan M., "The Meaning of Numbers to Photographic Parameters", 10th SPIE Technical Symposium, 17 August 1965, SPIE Journal, Vol. 4, June-July 1966.

9. "Agricultural Production and Efficiency", Vol. 2, Agriculture Handbook No. 118, U. S. Department of Agriculture, 1957.

10. "Types of Farming in Texas", Texas Station Bulletin 964, October, 1960.

REFERENCES (Cont.)

11. Jabine, T. B., Hurley, R., and Hurwitz, W. N., "Sample Design and Estimation Procedure for the 1960 Sample Survey of Agriculture in the United States, Estimation of Areas in Agricultural Statistics, Food and Agriculture Organization of the United Nations, Rome, 1965.

12. Hendricks, W. A., Searls, D. T., and Horvitz, D. G., "A Comparison of Three Rules for Associating Farms and Farmland with Sample Area Segments in Agricultural Surveys", Estimation of Areas in Agricultural Statistics, Food and Agriculture Organization of the United Nations, Rome, 1965.

13. Wrigley, J., and Mazumdar, S., "Area Statistics Under Conditions of Mixed Cropping", Estimation of Areas in Agricultural Statistics, Food and Agriculture Organization of the United Nations, Rome, 1965.

14. Waddell, John H., "Resolution - A Study in Semantics", Research/Development, September 1963.

APPENDIX A

PUBLICATIONS OF THE U. S. DEPARTMENT OF AGRICULTURE

APPENDIX A

PUBLICATIONS OF THE U. S. DEPARTMENT OF AGRICULTURE

1. Agricultural Statistics (Annual)

Principal agricultural series on acreage, yield and production of crops; prices paid and received by farmers; livestock production; market supplies and prices; imports and exports; farm resources, income and expense; consumption and farm living; and agricultural programs.

2. Major Statistical Series of the U. S. Department of Agriculture

Agriculture Handbook No. 118 (published 1958-60). Ten volumes describing: concept and definition; methods of obtaining, tabulating and analyzing data; accuracy and reliability of data; comparison with related series.

a. Agricultural prices and parity.
b. Agricultural production and efficiency.
c. Gross and net farm income.
d. Agricultural marketing costs and charges.
e. Consumption and utilization of agricultural products.
f. Land values and farm finance.
g. Farm population, employment and levels of living.
h. Crop and livestock estimates.
i. Farm cooperatives.
j. Market news.

3. Statistical Bulletins

Handbooks (some periodic, others occasional) presenting all available Department of Agriculture data on specific subjects such as livestock, cotton, wool, dairy products, feed, etc. Many serve as statistical supplements to Situation Reports.

4. Technical Bulletins

These reports present the results of research work done in the Department of Agriculture and its cooperators. Statistical research in supply and demand, productivity, marketing, etc. are included.

5. Agriculture Handbooks

Agriculture Information Bulletin
Miscellaneous Publications

APPENDIX A (Cont.)

These series contain statistical manuals, guidebooks, and reference works of general interest covering such subjects as food consumption, supply and use of farm commodities, projections of future farm output, farm-retail price spreads, etc.

6. Periodic Reports of Agriculture Economics (Annual)

7. Checklist of Reports (Monthly)

8. Agriculture Economic Research (Quarterly)

9. Situation and Outlook Reports (Periodic series)

   Supply and demand, prices, etc.

10. Changes in Farm Productivity and Efficiency (Annual)

    Major statistical series on farm production, production inputs and efficiency, with a brief digest of what each series shows to date and explanation of methods used.

11. Statistical Summary (Monthly)

    Four-page summary of current agricultural statistics.

12. Crop Production (Monthly)

    Data on acreage, yield and production of major crops and production of fruits; production of milk and eggs.

13. Livestock and Poultry Inventory - January 1 (Annual)

14. Other monthly production reports.

APPENDIX B

OPTICAL RESOLUTION LIMITS

APPENDIX B

OPTICAL RESOLUTION LIMITS

A. LENS RESOLUTION LIMITS

Rayleigh Criteria for Limit of Resolution assumes that two equally bright point sources can be resolved by an optical system if the central maximum of the diffraction pattern of one source coincides with the first minimum of the order.[23]

Theoretical analysis of the Fraunhofer or far field diffraction pattern from 2 point sources gives the limiting minimum angle of resolution for a circular aperture

$$\sin \alpha = \frac{1.22\,\lambda}{D}$$

where

D = diameter of lense
λ = wavelength

and α is the angle subtended at the lens by 2 just resolvable object points. For small angles, $\sin \alpha$ is approximately equal to α as shown below.

α	$\sin \alpha$	α (radians)
10°	.17365	.17453
5°	.87160	.87266
1°	.01745	.01745
$1'$	.00029	.00029

The linear distance (Z) between two just resolvable points for a circular aperture is:

$$Z = \frac{1.22\,\lambda_o F}{ND}$$

where:

F = focal length
D = diameter of objective lense
N = index of refraction = 1

The angular resolution limit (r) for a circular aperture is given by:

$$r = \frac{1.22\,\lambda \text{ (radians)}}{ND}$$

where:

N = index of refraction = 1
D = diameter of the objective (Cm)
λ = wavelength (Cm)

$$r(\text{seconds}) = \frac{4.5}{D(\text{inches})} \qquad \lambda = 454 \times 10^{-7} \text{ cm}$$

$$r(\text{seconds}) = \frac{9.93 \times 10^{4} \lambda \text{ (cm)}}{D(\text{inches})}$$

$$r(\text{min}) = \frac{1655 \lambda \text{ (cm)}}{D(\text{inches})}$$

The distance Z to the first Fraunhofer diffraction minimum of a slit is given by:

$$Z = \frac{\lambda F}{D}$$

where: $\frac{F}{D} = f/n$

The f-number (f/n) is a measure of the light gathering power of a camera objective.

The number of lines/mm (line pairs) or limiting resolution(r)in the focal plane for a photographic system is given by:

$$r = \frac{1}{2Z} = \frac{1}{2\lambda f/n} \text{ line pairs/mm}$$

The resolution and corresponding wavelength are commonly given by the following equations subject to the selection of a standard wavelength[16]:

$$r = \frac{2000 \text{ (lines/mm)}}{\text{f-number}} \qquad \lambda = 250 \text{ mu}$$

$$r = \frac{1750 \text{ (lines/mm)}}{\text{f-number}} \qquad \lambda = 572 \text{ mu}$$

$$r = \frac{1500 \text{ (lines/mm)}}{\text{f-number}} \qquad \lambda = 666 \text{ mu}$$

$$r = \frac{1426 \text{ (lines/mm)}}{\text{f-number}} \qquad \lambda = 700 \text{ mu}$$

B. SYSTEM RESOLUTION

The total system resolution (R_s) as a function of firm resolution R_f and lense resolution R_F is given by[16]:

$$\frac{1}{R_s} = \frac{1}{R_f} + \frac{1}{R_F}$$

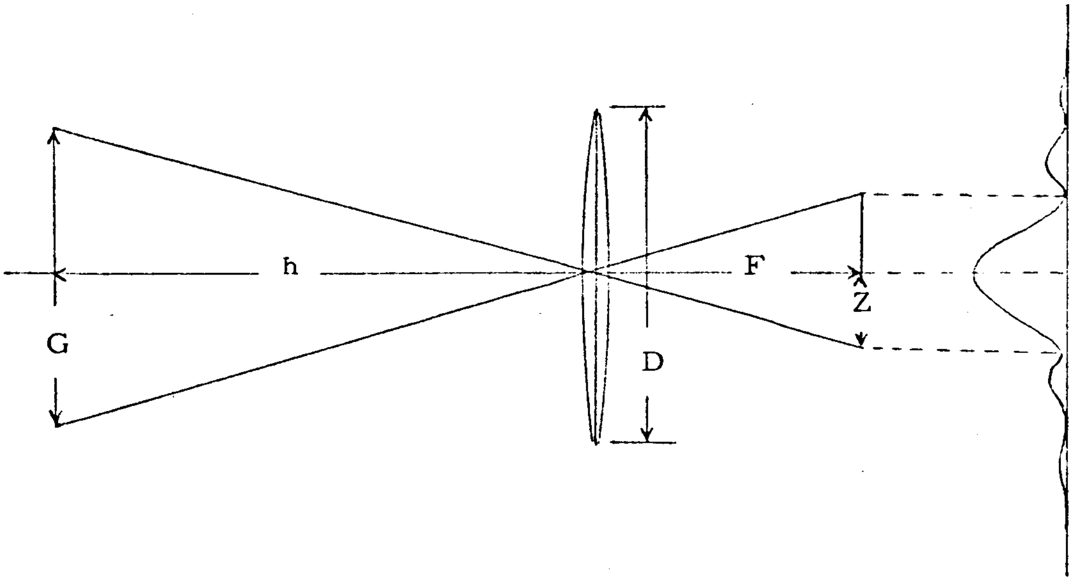
$$\frac{1}{R_s} = \sum_{i=1}^{n} \frac{1}{R_i}$$

where:

R_s = system resolution in lines/mm
R_f = film resolution
R_F = lense resolution

C. GROUND RESOLUTION (G)

The expression for the ground resolution of an optical system in terms of the focal length, altitude, lense diameter, and lense resolution can be developed as follows using the following geometric relationships and the Rayleigh criteria for resolution limits.



(Based on first diffraction minimum for a slit, the distance Z to the first diffraction minimum is given by:

$$Z = \frac{\lambda F}{D}$$

From the geometry of the figure,

$$\frac{Z}{F} = \frac{\lambda}{D} = \frac{G}{h}$$

and the ground resolution G is given by:

$$G = \frac{hZ}{F} \quad \text{or} \quad G = \frac{\lambda h}{D}$$

If a film scale factor S is defined by

$$S = \frac{h}{F} \quad \text{and } Z = \frac{1}{R} \text{ (resolution in lines/mm)}$$

where R denotes the width of a line pair, then:

$$G(\text{ft}) = \frac{S}{304.8R}$$

$$R(\text{lines/mm}) = \frac{1}{Z}$$

D. FILM AREAL COVERAGE

The ground area coverage of a film is given by:

$$\frac{\text{Ground Area } (A_g)}{\text{Film Area } (A_f)} = (\text{Scale factor})^2$$

or

$$A_f = \frac{A_g}{S^2}$$

where the scale factor S is:

$$S = \frac{h}{f} = \frac{\text{altitude}}{\text{focal length}}$$

Since S = 304.8G(ft) R(lines/mm)

then: $$A_f = \frac{A_g}{(304.8)^2 G^2 R^2}$$

where:

$A_f = ft^2$
$A_g = ft^2$
$G = ft$
$R = lines/mm$

The following equations hold for film area in square inches or square feel and ground coverage in square miles.

$$A_f(in^2) = \frac{4.33 \times 10^4 A_g\ (mi^2)}{G^2(ft^2)R^2(lines/mm)^2}$$

$$A_f(ft)^2 = \frac{300\ A_g(mi^2)}{G^2R^2}$$

E. LIMIT OF RESOLUTION OF THE EYE

The Rayleigh criteria for the linear separation (Z) of two just resolvable objects at a distance of 25 cm from the eye is:

$$Z = \frac{.61\ \lambda}{NA}$$

where NA is the maximum numerical aperture of the eye for a pupil radius of 1 mm. The numerical aperture of the eye in terms of the near point and the pupil diameter is given by:

$$NA = n\sin\alpha = \frac{1\ mm}{250\ mm}$$

where:

n = index of refraction = 1
λ = 550 mu or 10^{-7} cm

Substituting these values gives the minimum resolvable object separation as:

$$Z = 6.6 \times 10^{-3}\ cm = .066\ mm \text{ or } \quad .1\ mm$$

The limiting angle α or the angle between two points just resolvable by the eye is given by:

$$\alpha\,(\text{min}) = \frac{4194\,\lambda\,(\text{cm})}{D(\text{cm})}$$

where: D = pupil diameter

Table A-1 shows the angular resolution of the eye as a function of pupil diameter and wavelength. Included are the limiting distance which can be resolved by the eye at 25 cm.

TABLE A-1

Resolution (R) of Eye in Minutes of Arc

Pupil Diameter	λ=	400	500	600	700 mu
2 mm		.84	1.05	1.26	1.47 minutes
4 mm		.42	.52	.63	.74 minutes
8 mm		.21	.26	.32	.37 minutes

Limiting Resolvable Dimensions (X) at 25 cm

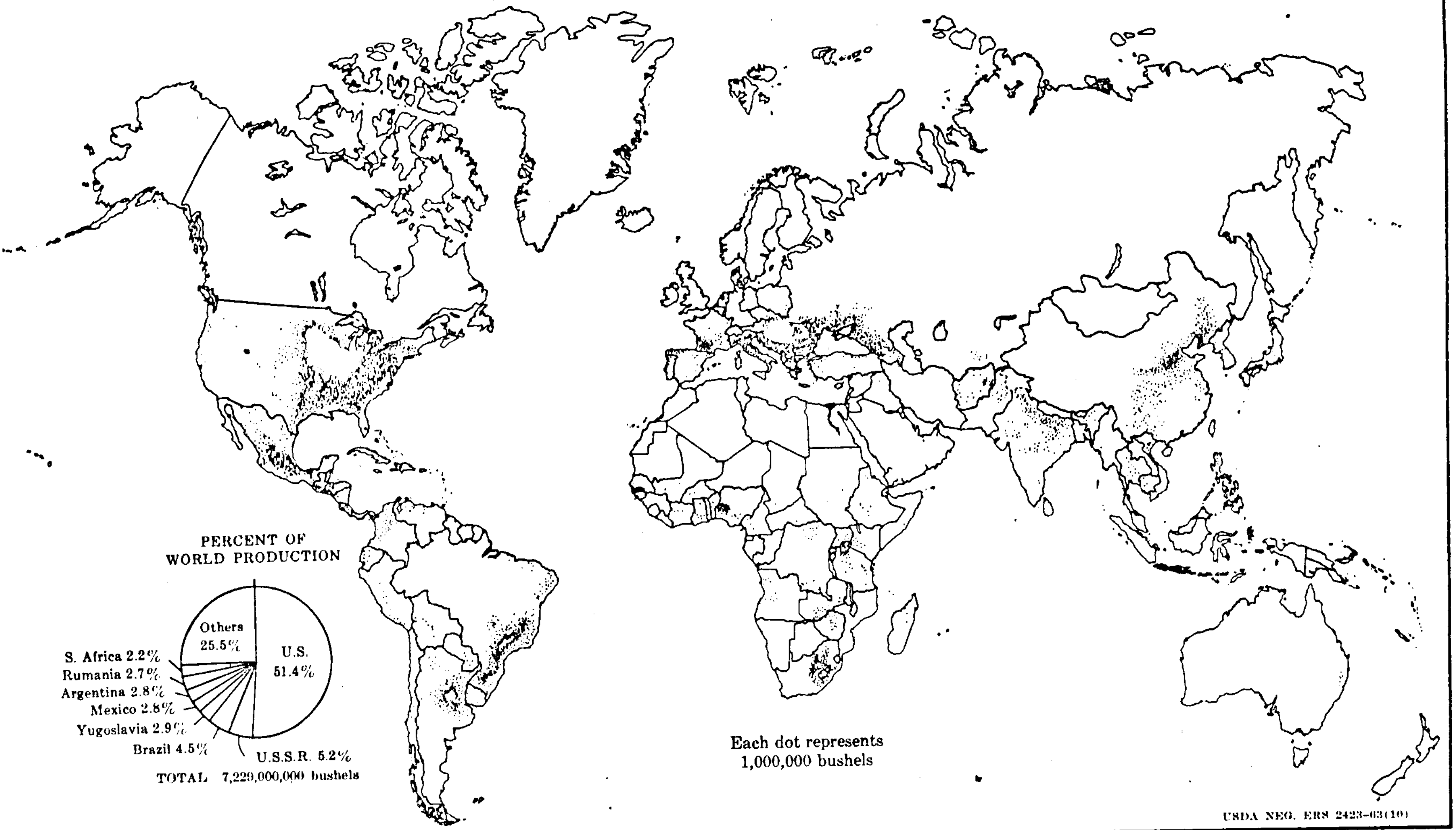
(min)	(mm)
1.4	.10
1.2	.087
1.0	.0725
.8	.058
.6	.0435
.4	.029
.2	.0145

(Note: .1 mm is equivalent to 1/254 inch, given 1 sq in of film with scale 1" = 5280' the observor would have a theoretical ground resolution on the film of $\frac{1}{254}$ x 5280 = 20.8 feet without magnification or film blow-up.)

APPENDIX C

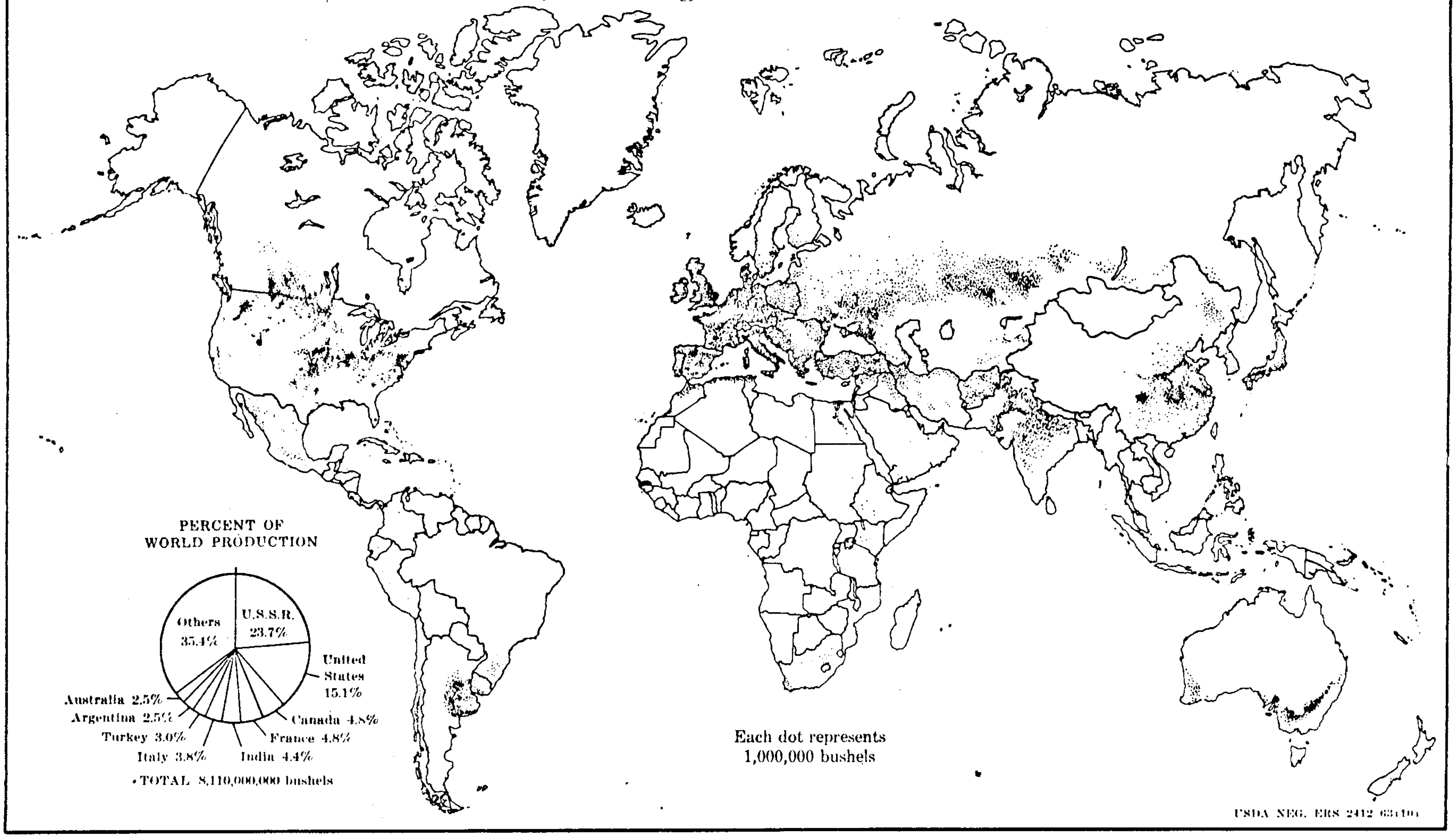
WORLD CROP PRODUCTION, AVERAGE 1957-61

World Corn Production, Average 1957–61



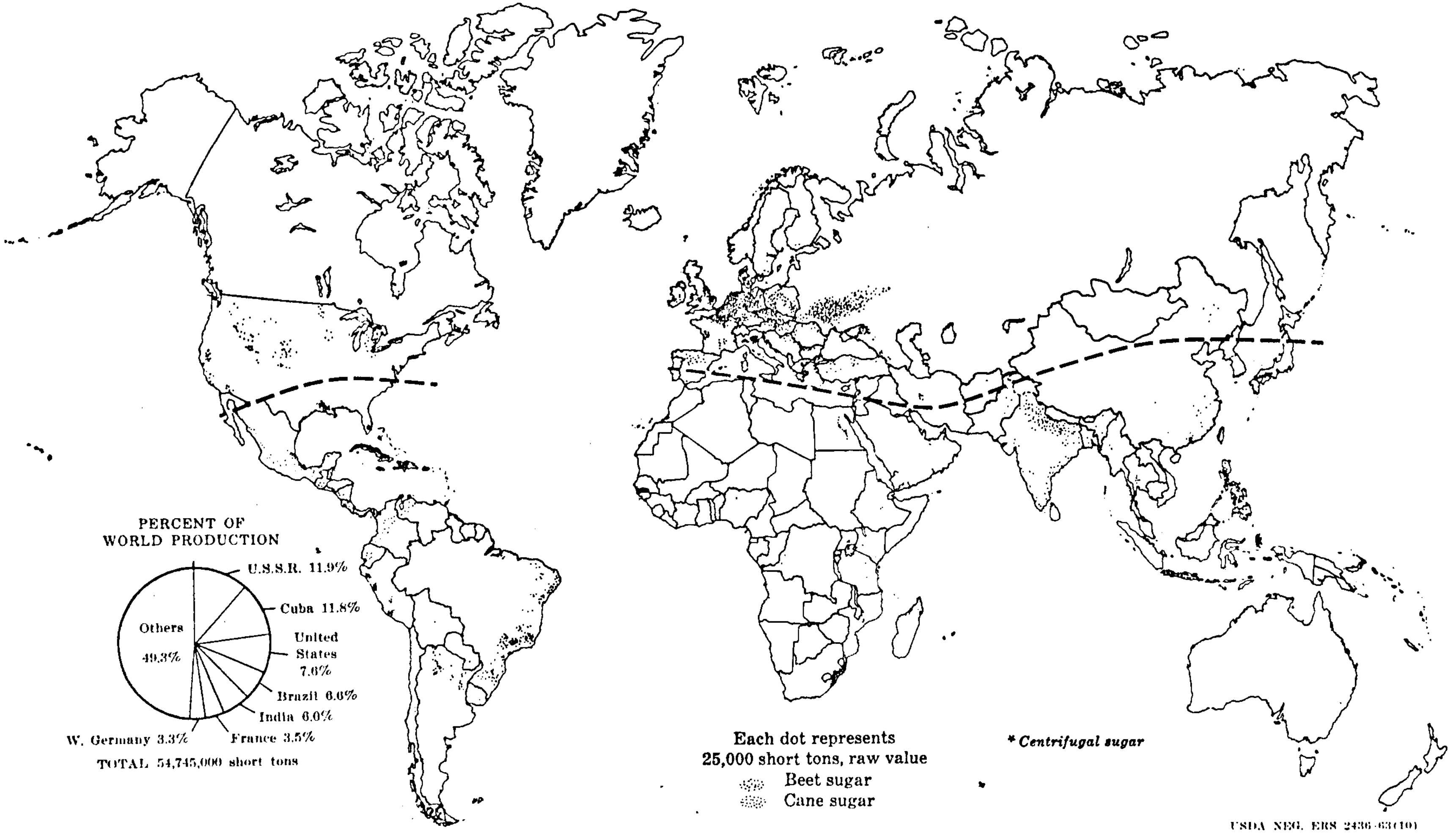
USDA NEG. ERS 2423-63(10)

World Wheat Production, Average 1957–61



USDA NEG. ERS 2412 63(10)

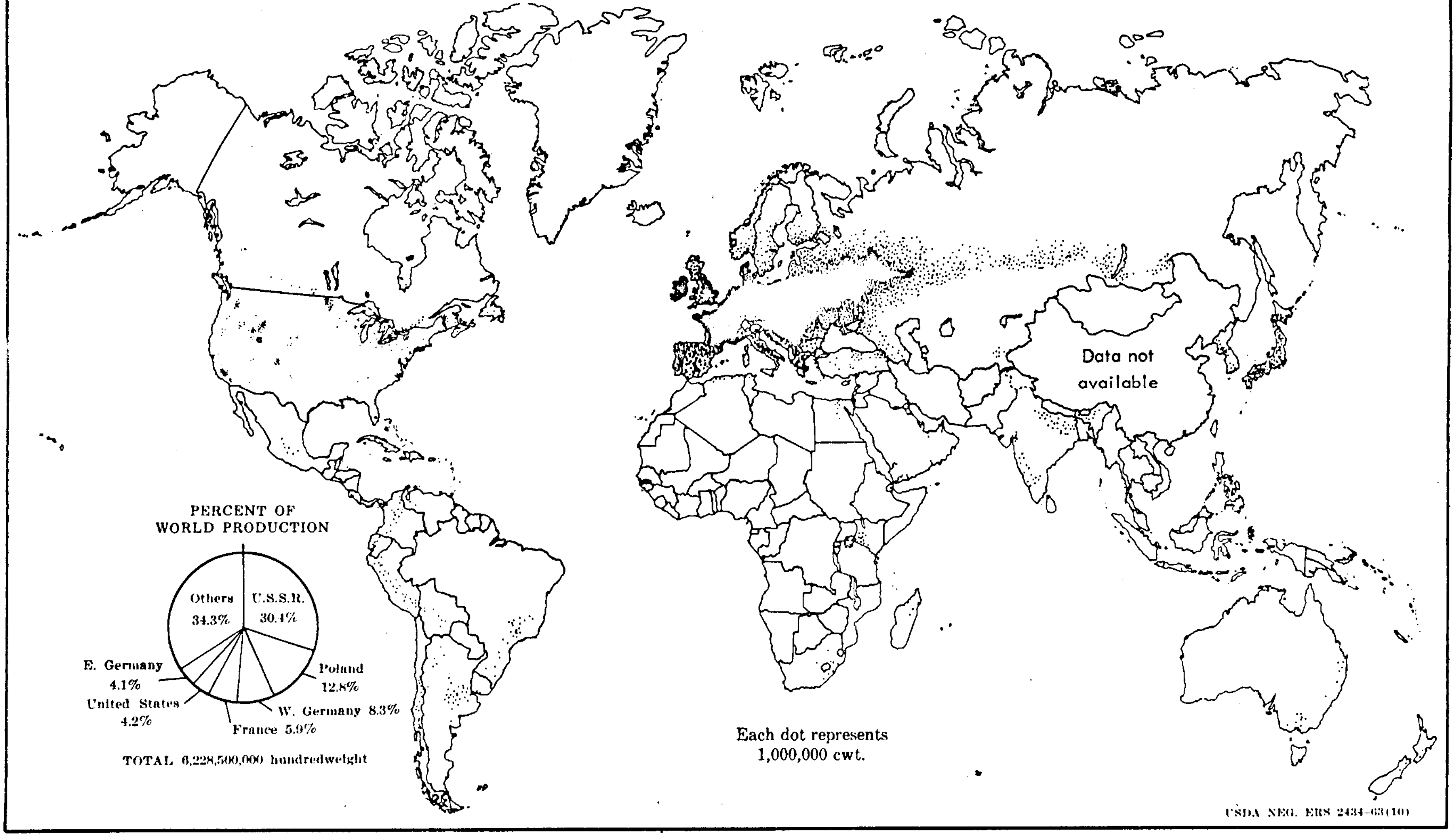
World Sugar Production, Average 1957–61*



* Centrifugal sugar

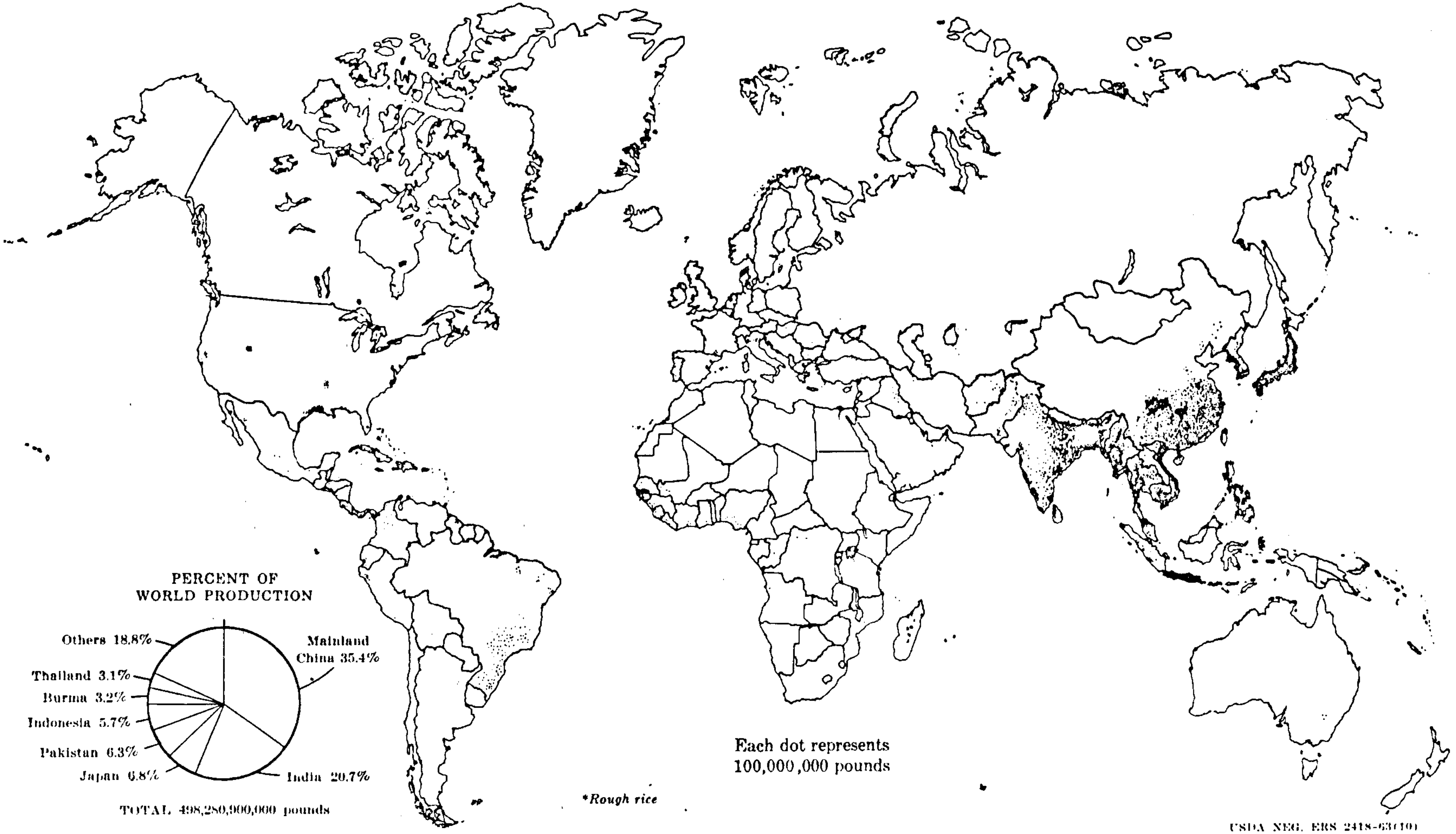
USDA NEG. ERS 2436-63(10)

World Potato Production, Average 1957–61



USDA NEG. ERS 2434-63(10)

*World Rice Production, Average 1957–61**



*Rough rice

USDA NEG. ERS 2418-63(10)

APPENDIX D

A RATIO METHOD OF ESTIMATING TOTAL CROP ACREAGE

APPENDIX D

A RATIO METHOD OF ESTIMATING TOTAL CROP ACREAGE

It is possible to use ancillary reported crop acreage information or historical list survey data in conjunction with a sampling procedure applied to imagery over the same region. For example, from ancillary survey data in the form of list information, let C be the total reported crop area in the i^{th} region. Let Y_{ijk} be the reported crop area in the i^{th} region in the j^{th} cell of the k^{th} sampled field. Let N_{ij} be the number of reported fields in the j^{th} cell of the i^{th} region. Then the total reported crop acreage (C) in the i^{th} region in the j^{th} cell is given by:

$$1. \quad C = Y_{ij1} + Y_{ij2} + \dots Y_{ijN_{ij}}$$

Let n_{ij} be the number of sampled fields in the j^{th} cell of the i^{th} region for which area measurements were made by the ground survey. Then an estimate (b) of the total reported crop area (C) could be made by:

$$2. \quad b = \frac{N_{ij}}{n_{ij}} (Y_{ij1} + Y_{ij2} + \dots Y_{ijn_{ij}})$$

Using only imagery from an aerial survey and subject to the assumption that crop identification is 100%, another estimate (a) of crop acreage can be made.

Let Z_{ijk} be the area as measured from the imagery of the k^{th} field in the j^{th} cell of the i^{th} region. Let n'_{ij} be the number of these measured fields in the j^{th} cell of the i^{th} region. Let N'_{ij} be the number of fields in the j^{th} cell of the i^{th} region as counted from the imagery. Then:

$$3. \quad a = \frac{N'_{ij}}{n'_{ij}} (Z_{ij1} + Z_{ij2} + \dots Z_{ijn_{ij}})$$

To estimate the total crop acreage in a region (T), it seems reasonable to weight the total reported crop acreage (C) as obtained from a list survey by the ground estimate (a) and the photographic or aerial estimate (b). We don't know a priori if $a > b$ or $a < b$, but it seems reasonable for (a) to be more reliable than (b) because of tighter control in obtaining (a). The total reported crop acreage (C) will contain a variety of possible errors due to the complex exchange of communication designed to yield (C). We choose to estimate T by:

$$4. \quad T = \frac{a}{b} C$$

which for the j^{th} cell in the i^{th} region (T_{ij}) would be given by:

5. $$T_{ij} = \frac{\frac{N'_{ij}}{n'_{ij}} (Z_{ij1} + Z_{ij2} + \dots . Z_{ijn'_{ij}})}{\frac{N_{ij}}{n_{ij}} (Y_{ij1} + Y_{ij2} + \dots . Y_{ijn_{ij}})} \times (Y_{ij1} + Y_{ij2} + \dots . Y_{ijN_{ij}})$$

or

6. $$T_{ij} = \left| \frac{\frac{N'_{ij}}{n'_{ij}} \sum_{k}^{n'_{ij}} Z_{ijk}}{\frac{N_{ij}}{n_{ij}} \sum_{k}^{n_{ij}} Y_{ijk}} \right| \cdot \sum_{k}^{N_{ij}} Y_{ijk}$$

The estimated total crop area (T_i) in the ith region would be given by:

7. $$T_i = \sum_{j=1}^{m} T_{ij}$$

and for the region:

8. $$T = \sum_{i=1}^{M} T_i$$

The assumptions pertinent to a ratio estimate based upon the use of historical information and information obtained from imagery are:

- List information and ground survey area measurements can be associated with an ith region and jth cell.
- The boundary of the ith region, jth cell can be located on the imagery.
- The crops can be identified from the imagery.

APPENDIX E

TABULATION OF SATELLITE SYSTEM SPECIFICATIONS

APPENDIX E

TABULATION OF SATELLITE SYSTEM SPECIFICATIONS

SURVEYOR I: LUNAR PROBE

(Reference: Science, Vol. 152, No. 373D, Surveyor I: Preliminary Results, June, 1966)

Weight: 2190 lbs.

Power: Solar Panel, 85 watts

Inertial Reference: Sun sensor, canopus tracker, rate gyros, nitrogen thrusters, for attitude control.

TV System: Vidicon tube, optics, shutter, filters, iris, 200 & 600 line pictures.

Normal exposure: 150 msec (extendible on command)

Focal length: 25 to 100 mm

Field of view: 25.3° & 6.4° square

Calibrated angular resolution: (1/2 milliradian at 15% relative response); approximately half angular resolution of average eye.

Ground resolution: Distance 1.6 meters, compensated modulation, transfer function, is about .5 mm.

Dynamic range of vidicon tube: (normal) 25 to 1 to 800 to 1, 150 msec exposure.

Log of video voltage: Linear function of scene luminance over a range of 5 to 1.

Dyanmic range achieved with iris, filters, alternate modes of shutter operation, electron beam scanning cycle, and provided nominal focal ratios of f/4 to f/22.

Rotation of color filters can be used to increase dynamic range 3000 to 1. Use of 1.2 second exposure (open shutter mode) dynamic range increased 25, 000 to 1.

Sensitivity of camera to very faint objects increased by factor of 40 over open shutter mode by means of several minutes exposure (integration mode).

Photometry & Colorimetry:

Film: So-337 can record on the linear portion of film the entire video transfer function calibration. Photograph photometric target variation was reduced to approximately 2% by fitting measured scene luminance to the photometric function derived from Fedorets using a lunar albedo estimate of 7.7%.

Radar frequencies: 9300; 12,900; 13,300 mc/sec

TV CAMERAS FOR SPACE EXPLORATION

(Reference: M. H. Mesner & J. R. Staniszewski, Astronautics, May, 1960)

Bandwidth vs. TV frames/sec for 25,000 bit picture.

Picture frame time increased from 1/30 sec to 2 sec to reduce bandwidth and hence transmitter power by 60. Therefore only slowly changing scenes can be imaged.

For spin rates 10-20 rpm, shutter time of 1 millisec satisfactory for 500 lines pictures. For slower spins, shutter times of 1/100 sec are practical.

TIROS I: TERRAIN SCAN FROM T.I.R.O.S.

(Reference: Merifield, Rannelkamp, Photogrammetri Engineering, Vol. XXXII, No. 1, January 1966)

Field of View: 104° and 76° or 12.7°

Image focused on .5" vidicon at focal planes scanned with 500 line, raster, signals stored on tape and transmitted.

Spectral response of vidicon tube: 450-850 millimicrons (peak 550 millicons)

Resolution limited primarily by electronics.

TIROS I: SPIN STABILIZATION

(Reference: H. Perkel, Astronautics, June, 1960)

Carrier Rocket spin 120 rpm.

Satellite spin requirement for good pictures is 12 rpm.

Tilt can be limited to 1/2 degree.

TIROS I: METEOROLOGICAL SATELLITE

(Reference: S. Sternberg & W. C. Stroud, Astronautics, June, 1960)

2 TV cameras, wide & narrow angle, photograph swath 800 miles wide covering 10^7 sq mi each orbit.

Orbit 48.3° inclination, altitude 400 n.m., period 99.13 minutes. The spin axis is fixed in space so that the cameras are aligned parallel to the axis sweep across the earth for only a portion of the orbit. The system is timed to coincide with periods of favorable sun illumination and provide fairly continuous coverage within a latitude of 50° N & S.

Tiros TV and APT Camera Parameters

Parameter	Wide - angle camera	Medium - angle camera	Narrow - angle camera	Automatic picture transmission camera
Picture size, n.m.*	700x700	420x420	70x70	800x800
Lines per frame	500	500	500	800
Frame readout time, sec	2	2	2	200
Video bandwidth, kc	62.5	62.5	62.5	2.4
Stored pictures per orbit	32	32	32	None
Percent picture overlap in the direction of motion	50	10	None	None
Peak power, watts	9	9	9	40^+
Lens	Elgect, 105° f/1.5	Tegea, 78° f/1.8	Cinegor, 12° f/1.8	Tegea, 105° f/1.8

*Based on camera looking down vertically from a 400-nautical mile orbit.
+ This includes 18 watts for the camera and 22 watts for the transmitter.

SATELLITE NIMBUS (WEATHER SATELLITE)

(Reference: NASA SP-96, Satellite Meteorology, 1958-1964)

Science Subsystems

1. High resolution infrared scanner (HRIR)
2. High resolution television (AVCS - Advanced Vidicon Camera System)

Infrared Scanner (HRIR)

Frequency: 3.4 to 4.2

Cell Type: lead selenide

Reference Temperature: 198° K

View Angle: 27 minutes of arc

Video B/W: 280 cps

Scan Rate: 0.83 rps

Scan Angle: 120° from horizon to horizon

Resolution: 8.0 kilometers

Television (AVCS)

Resolution: 0.8 kilometer (one half mile per line)

Line Rate: 800

Field of View: 37°

Speed: variable f/4 to f/16

Dynamic Range: 14 to 11,400 foot-lamberts

Focal Length: 17 millimeter

Vidicon Size: 1 inch

Area of Coverage: 830 kilometers by 2700 kilometers

RANGER 6

(Reference: Bernard P. Miller, "Ranger TV Subsystem", 10th Annual Meeting, May 4-7, 1964, American Astronautical Society)

Characteristics	TV Cameras F_a and F_b	 P1, P2, P3, and P4
Scan Area	Full scan 0.44 x 0.44"	Partial scan 0.11 x 0.11"
Real Resolution Lines	800 lines	200 lines
Line Rate	450 cps	1500 cps
Horizontal Scanning Lines	1150 lines	300 lines
Horizontal Blanking	0.22 millisec	111.1 microsec
Frame Rate	0.39 cps	5 cps
Frame Time	2.56 seconds	0.2 seconds
Vertical Blanking	46.6 millisec	6.6 millisec
Horizontal Line Time	2.22 millisec	666.6 microsec
Group Vertical Blanking	-	40 millisec
Video Bandwidth	200 kc	200 kc
Erase Time	2.24 seconds	360 millisec
Exposure Time (Shutter speed)	4 millisec	2 millisec
Field of View	$F_a = 25^\circ$ $F_b = 8.4^\circ$	P1 & P2 = 2.1° P3 & P4 = 6.3°
Focal Length	F_a = 25 mm f/0.95 F_b = 76 mm f/2.0	P1 & P2 = 76 mm f/2.0 P3 & P4 = 25 mm f/0.95

RANGER VII CAMERA SPECIFICATIONS (NASA, 1964)

(Reference: Seventh Ranger ready for launch on moon photo flight, NASA News Release, 64-176, NASA, Washington, D. C., July 23, 1964)

Altitude: 1120-1/2 mi.

Resolution: 1 mi. - 1/2 meter features identified comparable to large telescopes looking at moon.

Areal Coverage: f camera, 180,000 & 19,000 mi^2 to 3.5 and .38 mi^2 for last frame.
P cameras, 12,500 & 1200 mi to (37,500-4350 ft^2) at impact.

Camera	F1	F2	P1	P2	P3	P4
Scan	Full	Full	Part.	Part.	Part.	Part.
Focal Length	25 mm	75 mm	75 mm	75mm	25 mm	25 mm
Aperture	f/1	f/2	f/2	f/2	f/1	f/1
View Angle	25°	8.4°	2.1°	2.1°	6.3°	6.3°
Exposure Interval	2.56 s	2.56	0.2	0.2	0.2	0.2
Exposure Time	1/200s	1/200	1/500	1/500	1/500	1/500
Vidicon Target Area	.44 in^2	.44	.11	.11	.11	.11
Vidicon-Frame	1152	1152	300	300	300	300