AERIAL PHOTOGRAPHY AS A MAP SUBSTITUTE*

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THE real value of aerial photographs is that they may be viewed and studied at any time, for different purposes, by different types of engineers, scientists, and technicians. When an engineer, scientist, or technician goes into the field to obtain certain information, he brings back only such data as he observes, consequently, without making additional field trips one can never know anything about the other items of interest in the area. Also the observations of the engineer, scientist, or technician cannot be checked without additional field trips. The data tabulated for one purpose will generally be entirely inadequate for other purposes, because the observer must concentrate his efforts upon those things he is endeavoring to determine or delineate. Once an aerial photographic mission has been completed, and suitable negatives are available, aerial photographs to almost any desired scale may be quickly and cheaply reproduced for the geologist, drainage engineer, highway engineer, soil scientist, and others. Aerial photographs, and a suitable stereoscope or plotting instrument, will furnish much of the information previously obtained by field methods. A great many bureaus of the United States Government have found aerial photography to be indispensable for efficient operation. A few of these bureaus are:

Agricultural Adjustment Agency
Forest Service
Soil Conservation Service
Soils & Agricultural Engineering
General Land Office
Bureau of the Mines
U. S. Geological Survey
Bureau of Indian Affairs
Coast & Geodetic Survey
Corps of Engineers
Army Air Forces
Quartermaster General
Navy Hydrographic Office
Interstate Commerce Commission
Grazing Service

The first aerial photographs taken in the United States were in 1915, however, it was not until 1929 that aerial photography was generally accepted and used appreciably, and not until 1934 that aerial photography was used on an extensive scale. The Soil Conservation Service of the Department of Agriculture was the first organization in the United States to use aerial photography for obtaining basic information of hundreds of thousands of square miles. These photographs were procured for the purpose of taking data directly from the photographs, and not primarily for using the photograph as an expedient for producing a line map. It is agreed that accurate large scale up-to-date maps would have been extremely valuable in our program, and that they are a necessity for most emgineering projects, but there are many cases where the photographs by themselves are of more value than a line map by itself. Obviously, the ideal situation would be to have both up-to-date photographs and accurate up-to-date maps available.

Late in 1933 sufficient data were available to cause the United States Government to become conscious of soil erosion, and to find that thousands of acres of agricultural, grazing, forest, and even irrigated land, were being destroyed annually. There are two types of erosion, (1) natural, and (2) man made. The

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first is generally a slow geologic process and seldom causes serious damage, while the second is much more rapid and also more serious. It starts with the improper development of natural resources and continues through improper land use. Since the theme of this meeting deals with the development of natural resources, I urge you to give serious consideration to the conservation of soil and moisture in connection with development. In the United States thousands of acres of land have been cleared and left to be destroyed by erosion. By 1933 erosion had reached an advanced stage in many areas. Other areas, though only slightly damaged at the time, showed indications that erosion was being accelerated by improper land use practices. The only possible solution to the erosion problem was the proper development of natural resources and the development and applications of land use plans which would prevent, or at least retard, erosion. Before such plans could be made, very detailed information regarding existing conditions had to be available.

The Soil Conservation Service was faced with two problems in securing these data: (1) the information was needed immediately, and (2) only limited funds were available. The compilation of line maps, showing the data required, would have taken many years and would have cost millions of dollars, therefore, line maps were considered impossible from the standpoint of both time and cost. After a brief investigation, it was decided to use aerial photography as a map substitute. The first few projects were flown with a negative scale of 1:15,840. The aerial photographs were used as a map base on which soil, slope, erosion, and present land use data were compiled. Using these data, it was possible to develop adequate land use plans and initiate a erosion control program. For the more intensely cultivated agricultural areas, a scale of 1:15,840, or 1 inch equals 1,320 feet, has been found most satisfactory for assembling data regarding existing conditions, while a scale of 1:7,920, or 1 inch equals 660 feet, has given the best results for land use planning. On a few areas where extremely complex problems existed, a scale of 1:4,800, or 1 inch equals 400 feet, has been used for physical surveys and planning. Smaller scales are used for range and mountainous areas. Fig. 1 shows examples of how aerial photographs are used by the Soil Conservation Service.

In 1935 several bureaus of the Department of Agriculture were making aerial surveys and others were becoming interested in aerial photographs. In addition, many other bureaus of the Federal Government and a few State Governments, as well as private industries were using aerial photographs. A variety of specifications were used, some of which did not even require stereoscopic overlap in line of flight. The American Society of Photogrammetry realized the necessity of having a standard specification for aerial photography which would assure photographs meeting the minimum requirements for most uses. Colonel H. H. Blee, then President of the American Society of Photogrammetry, served as Chairman of a committee which prepared a standard specification for Aerial Photography for General Map Work and Land Studies, and in a short time these specifications were completed and were approved for Federal use by the Procurement Division of the Treasury Department. These specifications, with a few deviations and additions have been used as a basis for most contracts for aerial photography awarded in the United States. In 1939 the Department of Agriculture secured the approval of the Secretary of the Treasury to make certain deviations and additions to the original specifications.

In 1935 some bureaus of the Department of Agriculture desired a negative scale as large as 1:12,000 for cultivated areas, while others preferred a scale as small as 1:24,000 for cultivated and forest areas. A series of conferences were held by all bureaus interested in aerial photography which resulted in the establishment of a standard or compromise negative scale of 1:20,000, for the entire Department of Agriculture which all bureaus agreed could be used for cultivated and timbered areas. For mountainous and range areas, a scale of 1:31,680 has been used rather extensively. The next subject to be discussed at these con-

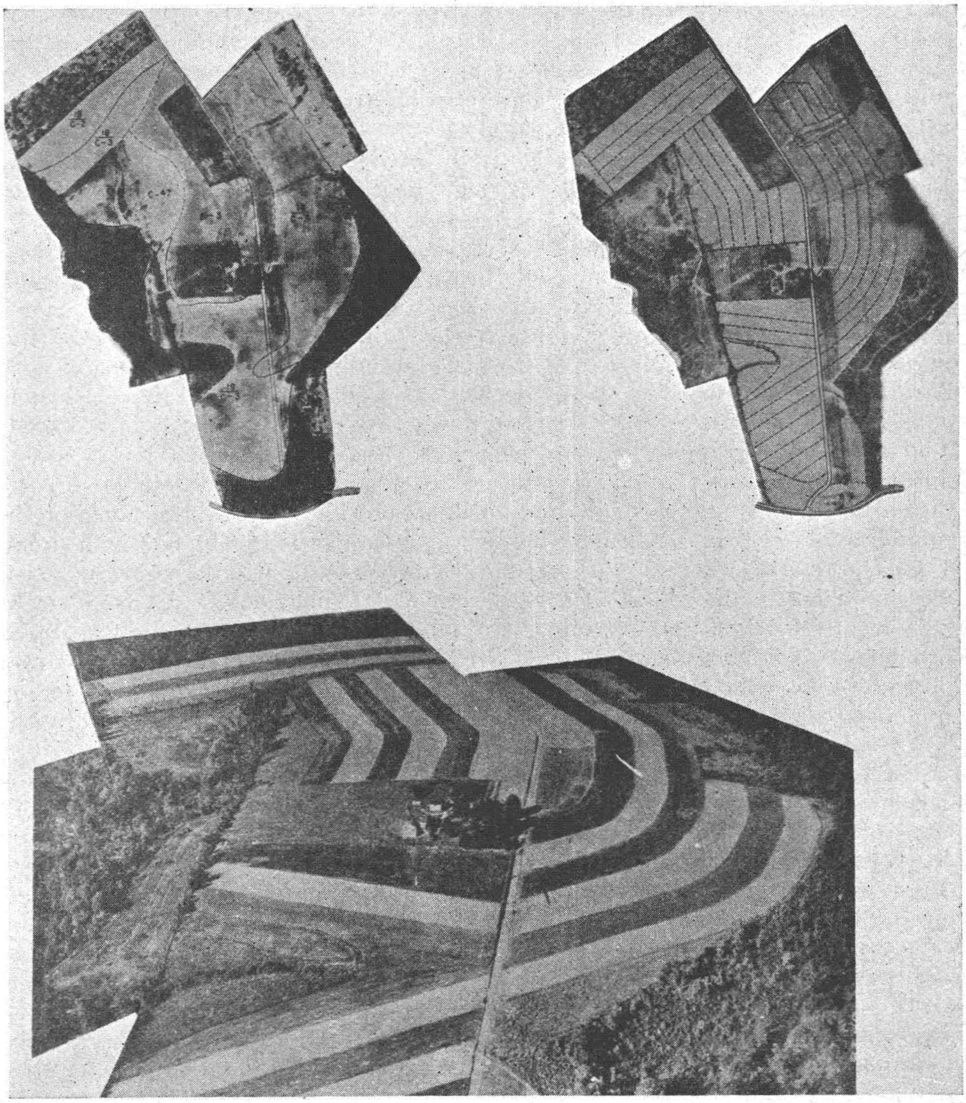


FIG. 1

ferences was the required focal length lens to be used in connection with the standard scale. This presented a more difficult problem than that of scale, since it materially affected the accuracy of the photographs. Several bureaus of the Department of Agriculture, including the Soil Conservation Service, find it necessaary to compile and reproduce various types of agricultural maps. For map compilation, by photogrammetric methods, perhaps the major requirements of lens are: minimum distortion due to faulty optics, adequate definition, exaggerated parallex distances, and the maximum satisfactory coverage possible without loss of quality. This combination of requirements indicates the desirability of using a wide angle, short focal length lens. Generally, such lenses have focal lengths of 6 inches or less. For land studies we desire to approach, within economic limits, a true orthographic projection in order to reduce distortion of images due to differences in ground elevation; definition of the highest quality is essential, and freedom from optical distortion is necessary. These requirements indicate the necessity of using a long focal length lens. Such a lens would be 12 inches or more in focal length.

In securing aerial photography at a given scale, the longer the focal length of the lens, the higher the photographic altitude; and the greater the photographic altitude, the greater the cost. The focal length lens finally selected for cultivated and forest areas was approximately $8\frac{1}{4}''$. This lens slightly handicaps some operation, but it has been found that the resulting photographs are adequate for most purposes. A lens having a focal length of approximately 6 inches is used for most mountainous and range areas. It was recognized that this type of photography would not satisfy all needs, particularly the requirement for planimetric and topographic mapping with certain types of photogrammetric equipment. In such cases special-purpose aerial photographs must be made.

The selection of a scale and the focal length of the lens are very important, however, there are many other items necessary to assure the best possible photographs. It is a well known axiom that lenses ground to the same formula differ considerably in optical quality. This has led to considerable research and the testing of many lenses in order to determine the minimum resolution and distortion that could be expected of the average lens. This research and test work was performed by the United States Bureau of Standards. The result was the establishment of lens specifications. For the $8\frac{1}{4}''$ lens, this specification established a maximum allowable distortion of plus or minus. 03 mm, and a minimum resolution of 20 lines to the millimeter in any orientation at the center of the field; 7 lines to the millimeter in any orientation at all 5 degree intervals, lying between the center of the field and the center of the shorter side of the negative, and at least 5 lines to the millimeter in one orientation at any angular distance from the center of the field which is a multiple of 5 degrees falling within the field and nearest the corner of the negative.

The lens specifications used for the shorter focal length lenses were similar, except the maximum allowable distortion was specified as plus or minus .10 mm at 30 degrees from the center of the field, and plus or minus .50 mm at 45 degrees from the center of the field. The required resolution for the short focal length lenses was the same as for the $8\frac{1}{4}''$ lenses, except that the requirements beyond the angle formed by the center of the field and the center of the shorter side of the negative was changed to the single requirement of resolving at least 5 lines to the millimeter in one orientation at 45 degrees from the center of the field.

In addition to lens specification, it was found that the camera used were sometimes of improper design. It was, therefore, necessary to develop a camera specification in order to assure that cameras of precision build would be utilized for securing the aerial photographs. The following are a few of the requirements of the specifications for a precision aerial mapping camera which will indicate the tolerances allowed:

The portion of the surface of the platten, against which the film is held to insure its planeness, shall not depart by more than plus or minus .0005″ from a plane.

For cameras in which the shutter curtain or blades do not operate between the lens com-

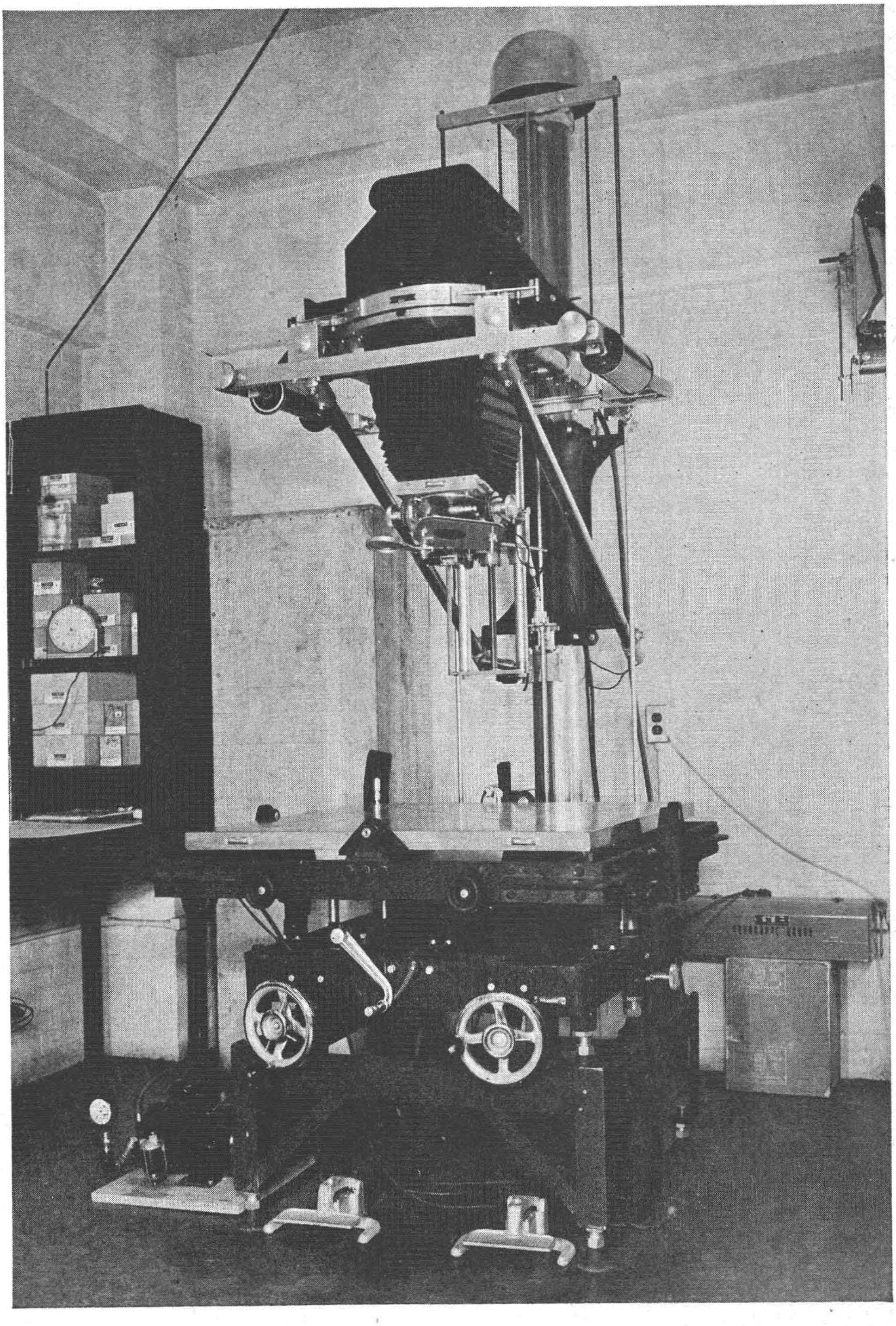


FIG. 2

ponents, the operation shall be such that the total duration of exposure for the entire plate is not greater than 1/50th second for an exposure 1/100th second.

The lines joining the opposite members of the two pairs of collimation markers shall intersect at an angle 90 degrees plus one minute and shall indicate the location of the principal point with a probable error not exceeding plus or minus .03 mm.

The dimensional changes arising from temperature or other variations shall not be inconsistent with the determination of the principal point with the probable error not exceeding plus or minus .03 mm.

Extreme care must be taken in handling aerial photographic film. Cold light must be used in contact printers and enlargers or they must be so designed that heat from the source of illumination is carried away and not allowed to come in contact with the film. Excessive heat causes film distortion. This distortion, while very small when measured across a 9 inch negative, is quite serious in the third dimension. I have seen film distorted in the third dimension, in a 1:12,000 model, as much as 40′. The enlarger shown in Fig. 2 has a mercury vapor tube for illumination and is the type now used for making enlargements.

Film storage space should be maintained at a temperature of 50 degrees and a relative humidity of 50 percent in order to preserve the film the maximum length of time. This, however, is impractical in many cases, because of the time required to condition the film before it can be used. The value of the film justifies fireproof storage. Figs. 3 and 4 are interior views of the film vault of the Department of Agriculture.

Most of the aerial photography obtained by the Department of Agriculture during recent years has been executed under contract by commercial companies. In awarding contracts, very definite and complete specifications must be prepared. The principal requirements of such specifications, in addition to camera, lens, and scale, are area to be covered, overlap, flight alignment, tilt, crab, type of film and paper to be used, quality of negatives and prints, and such legal and administrative requirements as may be necessary.

Photo-index sheets are prepared on practically all projects. These indexes are the crudest type of a mosaic and are prepared by stapling together a set of contact prints in such a manner to give a reasonable image match and show the arrangement of the individual photographs. These photo-index sheets were first compiled for use only as indexes, however, it has been found since that they are satisfactory for some types of reconnaissance work and, therefore, recent contracts require the image match to be within 2/10 inches at a scale of 1 inch equals 1 mile.

Each roll of film is numbered, starting with No. 1 for each project, and each exposure on each roll is numbered starting with No. 1. Each project is given an alphabetical symbol, starting with the letter "A" and continuing through the alphabet, then starting again with "AA," etc. In this manner it is possible to identify any photograph quickly.

In areas where reasonably accurate maps are not available, it is most difficult to determine the boundaries of a project from the air. In many cases, several reconnaissance flights have to be made and random strips of photographs taken before the required photographic operations can be started. In some poorly mapped areas several strips of photographs have been flown with a short focal length lens camera at a high altitude, and those photographs used in locating the boundaries and flight lines to be flown at a larger scale. One of the more recently developed cameras, that is particularly suitable for this purpose, is a camera with a focal length lens of approximately 4 inches with an angular coverage of about 100 degrees. The present cooperative photographic work between the U. S. Army Air Forces and the Royal Canadian Air Forces, using Tri-Metrogon

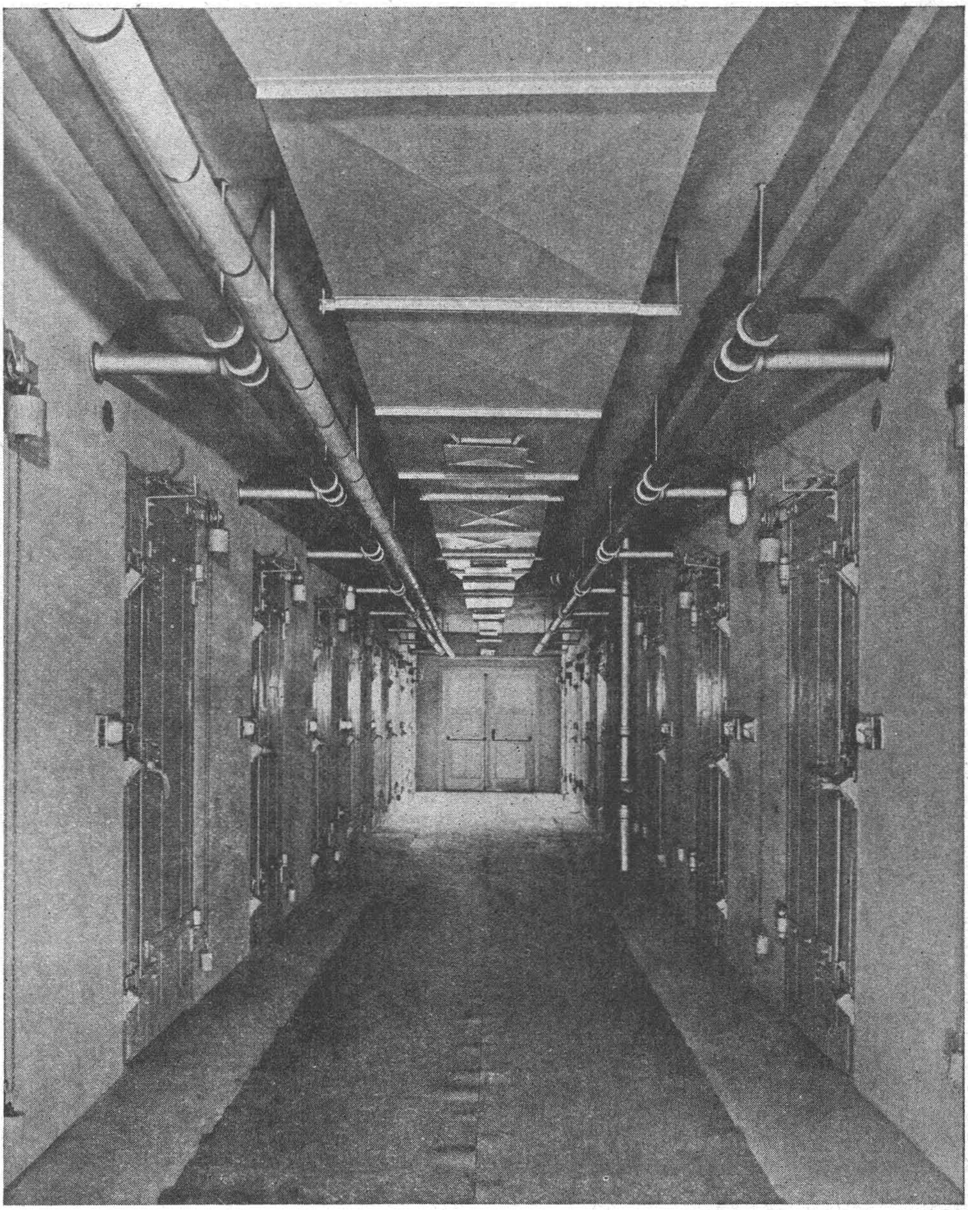


FIG. 3

cameras in connection with the preparation of aeronautical charts, would be particularly suitable to use in the location of the boundaries and flight lines for large scale aerial photographic work.

The following paragraph was written and furnished by the Aeronautical Chart Service of the U. S. Army Air Forces:

The U. S. Army Air Forces, in cooperation with the Royal Canadian Air Forces has, in the past two years covered with Tri-Metrogon photography vast unmapped areas of Canada which vitally affect the military air transportation lanes. This photography either has been or is being compiled into reconnaissance aeronautical charts by the Aeronautical Chart Service of the Headquarters, U. S. Army Air Forces. The astronomic control for this photography was established through the Royal Canadian Air Force by Canadian personnel. There are still large areas for which reconnaissance maps remain to be made through the medium of photography. It is also probable that a large percentage of the completed Tri-Metrogon photography will be reworked at larger scales upon the acquisition of more rigid control. In addition to serving the current needs of air transport, this photography will be of great value in later years from an economic development standpoint.

Most of this photography is flown at an altitude of approximately 20,000 feet. The focal length of the lenses used in the three cameras is approximately 6

FIG. 4

inches. Thus, the scale of the photographs made with the vertical camera is approximately 1:40,000. The scale of the two 30 degree oblique photographs, at the principal points is approximately 1:80,000. Obviously the scale of the obliques varies over the entire photograph. The spacing of the flight lines for Tri-Metrogon photography is usually about 20 miles.

Shortly after the initiation of the aerial photographic program of the Soil Conservation Service, and use of thousands of aerial photographs in the field, a demand for copies of these photographs arose. As a result of this demand, the 74th Congress made it possible to release aerial photographs made from negatives obtained in connection with the program of the Service, with certain restrictions. The following year, the 75th Congress authorized the entire Department of Agriculture to release aerial photographs obtained in connection with the authorized work of the Department. This legislation also had certain restrictions to assure that the aerial photographs did not fall into unfriendly hands.

The result of this legislation made possible the release of aerial photographs to other Federal agencies as well as State and local governments, educational institutions, private industries, individuals, and others who had definite need for such materials. In practically every case, contact prints or enlargements made from existing negatives have been sufficient for the expressed needs of the purchasers. A brief examination of the records of the scale of photographs indicated that they have been used for many purposes. The following are a few of the purposes for which photographs are purchased:

Pipe Line Location
Highway Location & Maintenance
Forestry
Drainage
Irrigation
Reclamation
Various Types of Construction
Power Development
City Planning
Tax Assessment
Geology
Exploration
Mining
Property Maps

Since January 1926 a gross area of approximately 2,900,000 square miles has been photographed by the Department of Agriculture. Of this total, approximately 700,000 square miles is duplicate coverage. Thus we have a net area covered by aerial photography of approximately 2,200,000 square miles. Approximately 400,000 square miles of aerial photography at a scale of 1:20,000 with an $8\frac{1}{4}''$ lens have been obtained by the Department of Agriculture each year since 1936. The following are the average costs per square mile for this type of photography for each year since 1936:

Scale 1:20,000
8.25″ Focal Length Lens
Approximately 400,000 Square Miles Per Year

Year	*Cost Per Square Mile*
1936	$4.54
1937	4.20
1938	3.09
1939	2.07
1940	2.03
1941	2.34
1942–43	2.31

In addition to the 1:20,000—8¼″ photography, other scales and focal lengths have been used for many areas. The following is a tabulation of areas covered, scales, focal lengths, and costs:

Scale 1:31,680
6.0″ Focal Length Lens
Approximately 200,000 Square Miles

Year	*Cost Per Square Mile*
1934–42	$1.60

Scale 1:40,000
5.2″ Focal Length Lens
Approximately 10,000 Square Miles

Year	*Cost Per Square Mile*
1939	$0.95

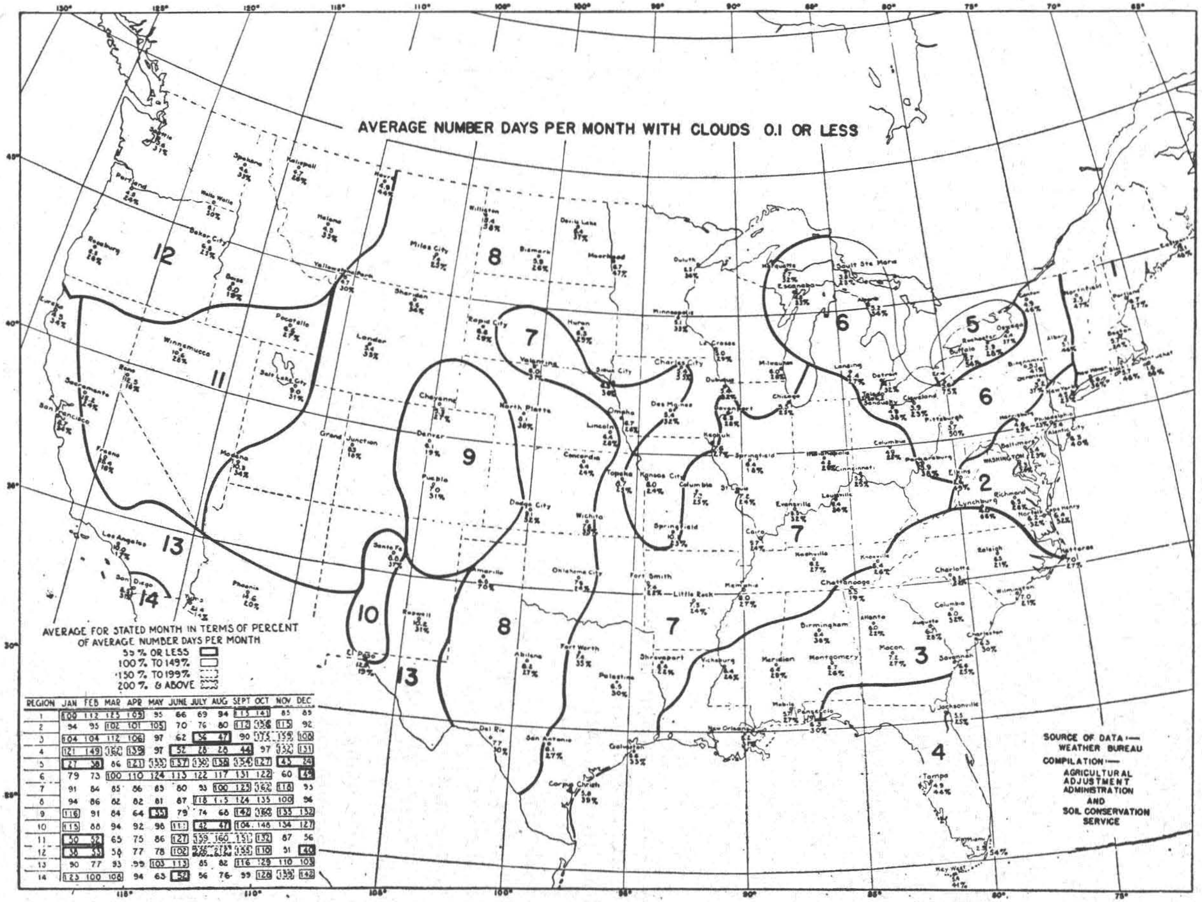
Scale 1:63,360
4.0″ Focal Length Lens
Approximately 6,000 Square Miles

Year	*Cost Per Square Mile*
1942–43	$1.53

The weather is the one item which has the greatest effect on the cost of aerial photography, and the time required to photograph a given area. Since nothing can be done to control the weather, it was decided to study it and obtain as much information about it as possible. The first study was based on weather records for a period of five (5) years. Later a study was made of all the weather data available and included 144 different stations for a thirty-seven (37) year period by Mr. F. J. Sette. The result was the preparation of a map which divided the United States into fourteen (14) zones having similar weather characteristics, and the tabulation of data which made it possible to program aerial surveys so that the airplanes were working in areas at times when the best weather could be expected. By using these data, it was possible to increase coverage and reduce the cost per square mile. The map and data shown in Fig. 5 are the result of the weather studies, and is the basis for planning and programming aerial photography.

In order to prevent duplication of aerial photography, within the Department of Agriculture, a procedure of clearing all projects prior to initiation was established. An application for clearance to make an aerial survey is prepared and forwarded to the Office of the Secretary of Agriculture. This office forwards copies of the application to all bureaus in the Department, interested in aerial photography, and also checks with other Departments. Any bureau within the Department of Agriculture, or any other Department, may contribute funds and have the boundaries extended to include areas in which they may be interested. It is only after copies of the application have been reviewed by all bureaus that the Office of the Secretary approves an aerial survey. In this manner unjustified duplication is avoided.

The map compilation program of the Soil Conservation Service involves the compilation of planimetric maps at a scale of 1:15,840 or 1:31,680 and surcharging thereon various soil, slope, erosion, land use, and land capability data. The slotted templet method of bridging ground control is used. Using the supple-



REGION	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
1	100	112	125	105	95	66	69	94	115	141	85	85
2	94	95	102	101	105	70	76	80	112	156	115	92
3	104	104	112	106	97	62	56	47	90	175	159	108
4	121	149	162	139	97	52	28	28	44	97	152	131
5	27	38	86	121	155	137	150	138	154	127	45	24
6	79	73	100	110	124	115	122	117	131	122	60	49
7	91	84	85	86	83	80	93	100	125	162	118	95
8	94	86	82	82	81	87	118	1,5	124	135	100	96
9	116	91	84	64	55	79	74	68	142	168	135	152
10	115	88	94	92	98	111	42	47	104	148	134	127
11	50	52	65	75	86	127	159	160	151	132	87	56
12	38	55	58	77	78	102	226	212	155	110	51	40
13	90	77	93	99	103	113	85	82	116	129	110	103
14	125	100	108	94	63	52	56	76	99	128	159	142

FIGURE 5. Average number of days per month with clouds 0.1 or less, 37-year Weather Bureau record, 1900–1936. The first figure under each station denotes the number of days per month in which clouds were reported as 0.1 or less; the second figure, the percentage below average which can be expected 1 year in 10. Regions embrace stations having similar seasonal characteristics.

mental control so established, multiplex stereo-projectors are used for plotting planimetry. Overhead reflecting projectors are used for transferring the soil, slope, erosion, and land use data from the aerial photographs to the map base.

Recently a number of tests have been made using a combination of small scale and large scale photographs to bridge ground control. For this purpose, photographs at a scale of approximately 1 inch equals 1 mile made with a 4 inch lens camera were used in conjunction with the standard 1:20,000 photographs. Templets were first laid with the 1 inch equals 1 mile photographs and then using *this* radial control, the templets from the 1:20,000 photographs were laid. Where a minimum of ground control is available, this method has great possibilities. A test completed just a few days ago covered an area of approximately 1,500 square miles. On this test, one control point was used at *each* corner of an area which was two 15 minute quadrangles wide and three 15 minute quadrangles long. Within this area there were approximately 20 points of which we had geographic positions. The templets were laid at a scale of 1 inch equals 1 mile, holding to only the four corner points and the other control points were located by radial control and their positions scaled. The maximum error was about 330 feet, or .06″, while the average error for all points was approximately 120 feet, or .023″. At a scale of 1 inch equals 1 mile, 95 percent of the points fell within .04″ of their third order position, 71 percent of the points fell within .03″, and 41 percent fell within .02″. This area was covered by five flights each containing approximately 20 photographs. The following diagram shows the distribution of the points tested, and the direction and amount of error found at each point. It will be noted that the errors greatly increase for the points which fall outside the control rectangle used on this test. Fig. 6 shows the location and distribution of the points used in this test.

The post-war plans of the Soil Conservation Service, regarding aerial photography, have not been completed to date, however, it is expected that in addition to keeping the 1:20,000 photography up to date, that many special-purpose aerial surveys will be required. Some of these may be at larger scales than 1:20,000, but, it is anticipated that most of them will be at smaller scales. It is expected that the larger mountainous areas in the western portion of the United States will be photographed at a scale of 1:31,680 with a 6 inch lens. Later certain portions of this area will probably be photographed at larger scales. With the improved aeroplanes, cameras, photographic material, and other developments together with highly trained personnel that will be available after the war, it is believed that the cost of aerial photography will be very low. Aerial photography will be used for many additional purposes. Color photography will undoubtedly be available in a few years. Daytime cloud conditions will be overcome by night photography. When we consider the cost of producing a topographic map, for example, we find that the cost of aerial photography is generally something less than five percent of the total cost. In many cases it will be found that more than this amount can be saved by rephotography in order to have the flight lines so located that only a minimum amount of additional ground control will be necessary.

New photography will definitely be required for most areas to be mapped with the multiplex or other types of stereoscopic plotting equipment.

We have found that controlled mosaics are very useful for many purposes. They give the engineer, scientist, and technician an overall veiw of an area that cannot be obtained from a single photograph. For delineating various data, the use of individual photographs presents a problem of matching which in many

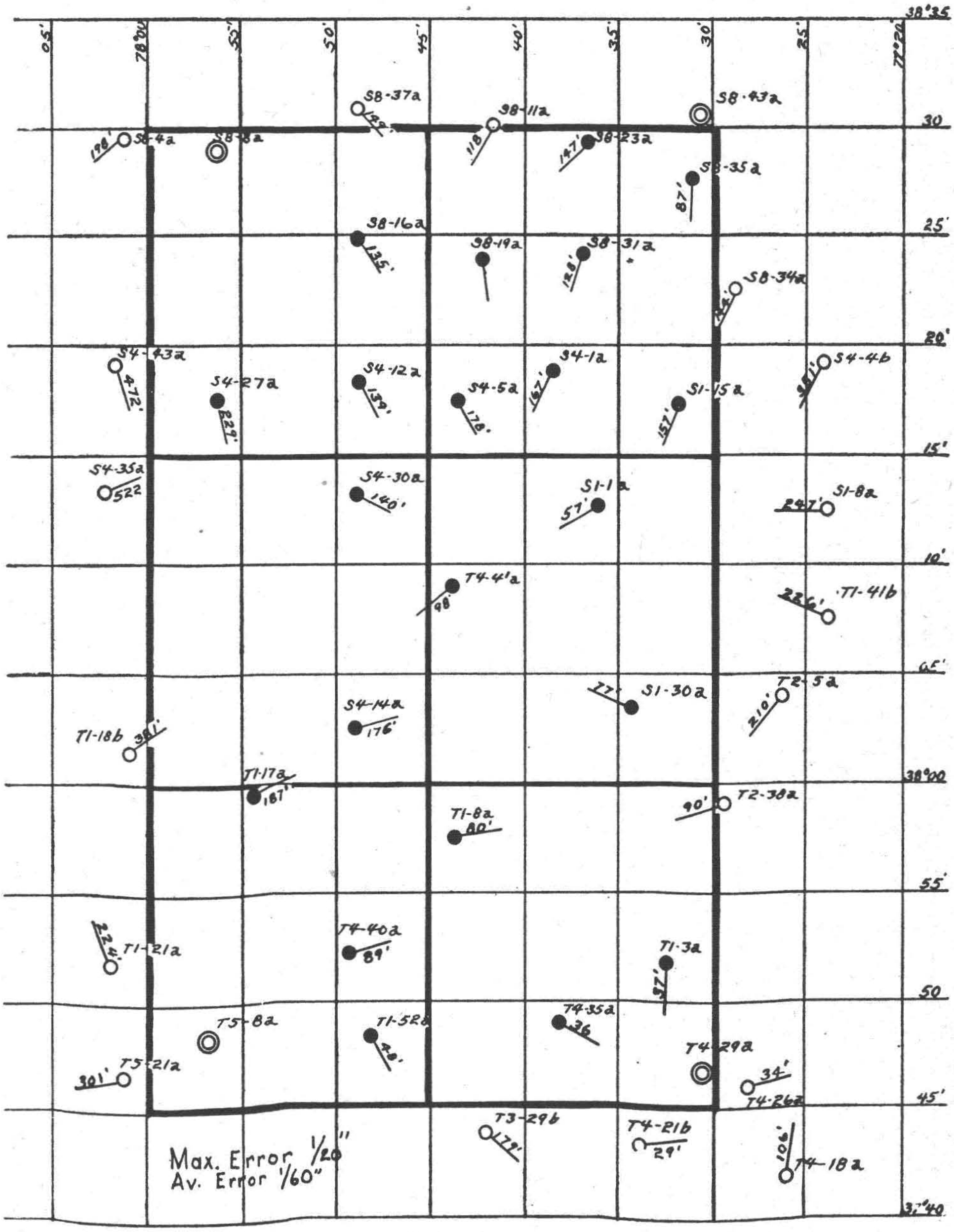


FIG. 6

cases can be overcome by using a mosaic. It is expected that our work in the post-war period will require the compilation of mosaics for many areas.

Our needs for more detailed and more accurate information of vast areas are continually increasing. For the more detailed information, aerial photographs at the present time seem to answer all needs. The solution to our need for more accuracy must come from some type of line map, accurately compiled mosaic, or combination map and mosaic because of the inherent errors in the individual aerial photographs. It is my opinion that eventually both up-to-date maps, and one or more up-to-date sets of aerial photographs will be a minimum requirement for most projects.

In closing, I would like to repeat a statement made by a very prominent engineer of one of the largest oil companies in the United States who said, "I believe that of all the developments and refinements added to the surveying and mapping science during the past century, aerial photogrammetry surpasses them all. As a matter of fact, it is an acceptable and indispensable phase of all branches of the petroleum industry."

EDITOR'S NOTE: The 37th Annual Meeting of the Canadian Institute of Surveying was held at Ottawa, Canada on February 2nd and 3rd, 1944. The attendance at each session was well over 100 which made this meeting one of the largest in the history of the Institute. The meeting was opened by R. H. Field, President. After welcoming the visiting representatives, the President gave a brief outline of the program to be followed which, he said, this year was unique in that by far the greater part of the two-day meeting would be given to an open forum for the discussion, by the visiting representatives of "Requirements of Air Photography in the Post-war Development of our Natural Resources."

As an introduction to this discussion, a paper was presented on "Aerial Photography as a Map Substitute," by Louis A. Woodward an employee of the U. S. Soil Conservation Service and President of the American Society of Photogrammetry. This paper pointed out how aerial photographs have been procured and used in the United States with particular emphasis to the methods of the Department of Agriculture. Sample contact prints, together with enlargements at various scales up to 400 feet to the inch, were exhibited.

After Mr. Woodward's paper, the discussion was opened by Mr. K. G. Chipman of the Canadian Department of Mines and Resources, who pointed out that the general subdivision of discussion would be (a) Forestry, (b) Agriculture, (c) Mining Development and Geology, (d) Mapping and Charting, and (e) Miscellaneous Developments. The discussion was carried on by representatives from all of the Provincial Surveyors' Associations, from Federal and Provincial Government Departments, and from industry as concerned with the development of Canada's natural resources. The visiting representatives throughout the two-day meeting carried on a very highly interesting discussion. Each one making his contribution and each one giving careful attention to the points of view expressed by the others.