*Cadastral Engineering and Mapping**

LOUIS A. WOODWARD,
Chief Engineer, Fairchild Aerial Surveys Div.,
Fairchild Camera and Instrument Corp.

ABSTRACT: *The current world wide population explosion indicates serious food shortages in the near future. Presently known land suitable for profitable food production is insufficient to meet future requirements. Government owned land, approximating 40% of the world total land area, combined with large private holdings not presently used effectively, may have to be subdivided or otherwise made available for food production. Numerous cadastral surveys will be required both for subdivision and to establish the boundaries of adjacent land. All cadastral surveys should be perpetuated by monuments and made to accuracies in keeping with present and forecasted land values. Cadastral surveys subdividing the land should be made subsequent to natural resources surveys which establish land capability in order to assure economic agricultural units.*

IN 1900 the population of the earth approximated 1.55 billion. Between 1900 and 1920, the increase was about 260 million or 16%. Between 1920 and 1940 the increase was about 400 million or 22%. In the next 20 years, 1940 to 1960, the population increase was about 700 million or 32%. Forecast for the present 20 year period indicated an additional increase of about 1.3 billion or 44%, for a total population of 4.2 billion by 1980. Predictions for the period 1980 to 2000 indicate an increase in the magnitude of 2 billion for a total of about 6.25 billion. This is about four times the 1900 population.

Here in the United States, where we presently have a surplus of most food products, it is difficult, if not impossible, for us to realize that hunger may be the world's number one problem by the year 2000. Data presently available indicates that unless some more pleasant way is soon found to control or solve the problems associated with the present world wide population explosion, starvation and strife may be among the distasteful solutions. These are hard and frightening alternatives.

The underdeveloped nations of the world have about 70% of the earth's adult population and about 80% of the world's children. It is in these areas that population growth far exceeds food production.

In almost every case the best and most immediately exploitable resource of the underdeveloped countries is the land. In every case it is the only permanent source of the immediate need—FOOD: yet the inventory and development of this resource and its exploitation is all too often neglected.

In a recent analysis by Lester R. Brown, of the United States Agriculture Department, grain production was used to measure the ability of various regions to feed themselves, since grain provides about half of the energy in the average diet, and grain is also a major item in feeding livestock. The United States and Canada were found to be the only two major bread baskets in the world today. These two countries export about 39 million tons of grain per year, which is about 86% of the world's total grain exports. These exports are expected to more than double before the year 2000. Mexico has made great progress in recent years in developing agriculture and now dwarfs its neighbors to the south. Latin America, in general, was a large exporter of grain prior to World War II. The Soviet Union and Eastern Europe had a sizeable grain surplus, until toward the end of the 1950's. By the end of the 1950's the Soviet Union became deficient in grain.

We cannot sit idly by and wait for nature's solution. Presently known land suitable for

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profitable food production is insufficient when related to future needs. Natural resources must be inventoried, new agricultural land must be found and food crops must be found or developed that will produce on land presently classified as marginal or submarginal. The agricultural "know-how" of the higher developed areas must be made available in understandable form to the underdeveloped areas.

Statistics are not available on a world wide basis concerning government owned and private owned land; therefore, assumptions and guesses will be made based on data available for the United States.

The total land area of the United States is about 3,549,000 square miles. Of this, the Federal Government owns approximately 1,203,000 square miles, while non-federal land is 2,346,000 square miles. In other words the Federal Government owns about 34% of the total land area of the United States. It is probable that states, counties and cities own somewhere in the neighborhood of 5% or 6% of the total area. Thus, privately owned land is only about 60% of the total area of the United States.

In Canada and Mexico it is probable that the percentage of Government owned land exceeds that of the United States. In all probability the percentage of Government owned land in Latin America, Africa, and Asia is somewhat higher than in the United States. In summary, I would guess that on a world wide basis, Governments own at least 50% of the total land area.

The fact that data could not be found regarding private and federal ownership of land for most countries could, and probably does, indicate a dire need for cadastral maps. The fact that I could only find data regarding the United States does not guarantee that these data are correct. For example, in comparing the total area of Alaska with data concerning total Federal ownership, it was interesting to note that the Federal Government owns 100.004% of the State.

I firmly agree with the desirability of having National Forests, National Parks, National Monuments, and many of the reasons why Governments own land. Based on present world political conditions, there can be no question regarding our need for military reservations, although some of us may question the number and size of some of these areas.

As food production becomes more critical, consideration will have to be given to the need of Government ownership of such a large percentage of our land resources. I believe much of the land presently owned by governments will have to be released to private ownership, or at least made available for food production. This will involve many millions of square miles.

What does all of this have to do with Cadastral Engineering and Mapping? As available land per person decreases, the law of supply and demand will most certainly apply and something similar to an old fashioned land boom will occur. Cadastral surveys, perpetuated by good markers and good descriptions, will become increasingly important. There will be many new problems to solve.

These are numerous reasons why good cadastral maps are necessary, however, their primary purpose is to show the size and shape of each piece of property and its relation to roads, rivers, towns, cities, etc., and to serve with other data as an equitable basis of taxation.

Cadastral data can be developed by a wide variety of methods and procedures and each combination of methods and procedures will result in different accuracies. Many people, and some of them hold high non-professional government positions, believe that when property boundaries are transferred from existing records to aerial photographs and the area measured, the precise area within such property boundaries is determined. This is most certainly not true, and I am sure that all Society and Congress members agree on this point. Depending upon the scale of the photograph, the amount of relief within the area and other factors, property areas so determined can be substantially in error. Possibly in some cases, cadastral data developed by this method are satisfactory. Should this be the case, this is by far the fastest and cheapest method of preparing cadastral maps. At least this method should be limited to areas of low relief. In some cases the immediate requirement is to account for all land and property owners within a given area in a very short period of time with little or no consideration given to accuracy of boundaries, or accuracy of area.

Identification of approximate boundaries on aerial photographs will well meet this requirement.

Another method of Cadastral Mapping is by use of stereoplotting equipment for determining coordinates of field identified or panelled property corners.

As all experienced surveyors know, the actual property boundary may or may not be the location indicated by physical evidence appearing on the aerial photographs. Fences, walls, crop lines, etc., are frequently several feet off the property lines. There are many cases where property boundaries have not been fenced, and visible evidence of surveys does appear on the aerial photographs. Many cases exist where original property corners have been destroyed and little or no evidence can be found concerning the original survey.

The first basic problem in Cadastral Mapping is to locate property corners and property boundaries. In most areas, aerial photographs are of tremendous value in recovering property corners. Accuracy in Cadastral Mapping will always be improved if aerial photography is accomplished after property corners have been recovered and panelled. By this method there can be no doubt concerning the location of the property corner if the surveyor places the panel on the corner. Locating property corners is frequently a difficult job.

Original property records in many cases are incomplete and vague. The following are portions of classical legal descriptions:

July 11, 1794—"together with a piece of land lying in Wallfleet to the eastward of George Brown's dwelling house and to the westward of the county road—,".

February 27, 1818—"then north as the fence now stands until you come to a stone in the ditch—".

February 7, 1862—"on the north by Edward Brewer 82 paces, on the east by Nathan A. Gill 150 paces, on the south by Nathan A. Gill 106 paces, on the west by the road 106 paces, containing 31 acres—".

October 11, 1950—"said stake being about 160 feet northerly from a pile of old stakes and stones lying on said ridge, said stakes and stones being about 31 feet north of the horsepath of the old wood road which leads westerly from its intersection with Wash Pond Road, and said stakes and stones being about 23 feet north of an old galvanized pail hanging on a small pine tree—".

Fortunately many of these problems have been resolved in the United States; however, numerous similar problems still exist in other parts of the world. It is truly amazing that the records of so many property surveys do not show closure. There is no proof of a survey where last course is only listed as "Thence to the point of beginning."

Many unkind things have been said concerning the original land surveys in the western part of the United States which were made under contract about the turn of the century. I must agree that many section corners are difficult or impossible to find today. There undoubtedly was some fraud connected with these early surveys. However, I am confident errors in compass heading, measuring, etc., at least equaled, if not, greatly exceeded fraudulent corners. Careful interpretation of aerial photographs and analysis based on a few found corners will frequently disclose evidence indicating the original corner was actually set, even though some distance from where it should be.

First order stereoscopic plotting equipment, such as a Zeiss C8 or Wild A7, have certain advantages in determining accurate positions. Both of these instruments have readout equipment to accurately record the X and Y coordinates of the identified or panelled property corners. Incidentally, the size of the panel in relation to the floating mark in the plotting instrument has a considerable effect on accuracy of position. From X and Y coordinates, the azimuth and distances of each course of the property boundary may be determined, and from these data, the area may be computed.

During the past year, I have reviewed many of the articles and papers presented to the Photogrammetric Society and to the Congress, on Cadastral Surveying and Mapping. In this review one name, I believe more than any other, came to notice. I believe we all owe Jack King a vote of thanks for his early work in combining photogrammetry and cadastral surveying. The first article on this subject that came to my attention was one entitled "How far does precision of Aerial Photogrammetry satisfy the demand of Cadastral Survey" by O. von Gruber of Jena, Germany. This article was published in the November, 1934, issue of "News Notes," of the American Society of Photogrammetry. This article of 30 years ago, discusses many of the same problems and restrictions that we have today. Mr. von Gruber said "The precision of measurement with stereoscopic instruments, is largely governed by the flying height." Several papers published during the past 5 years came to the same conclusion. Mr. von Gruber's article points out the advantages of sharply defined points such as marked stones, posts and the like, as have several recent papers. At that time, Mr. von Gruber was concerned with the high speed of the aircraft. This has largely been overcome today by faster films, shutters, and lenses. Error in control was a problem in 1934, the same as it is in 1964.

I believe serious consideration should be given to the required accuracy of cadastral data under various conditions. How much can we afford to pay for Cadastral Data? How soon must the data be available? As engineers and surveyors, we all have great pride in our work and as a matter of personal preference would prefer to develop accurate and reliable data, but are these accuracies economically justified under all conditions?

Many of the papers I have reviewed have reported on research, and tests made to determine the accuracy of positions developed by photogrammetric methods under various conditions. A wealth of very valuable data have been developed which conclusively proves that positions can be determined to a high degree of accuracy by photogrammetric methods. I believe the statement made in the paper prepared by Professor Bryner of the University of Utah, which was published in the September, 1963 issue of PHOTOGRAMMETRIC ENGINEERING, probably expresses the present state of the art. "With relatively flawless control of second order, at all points, and a proper mathematical solution to bridging problems and with control on every fourth model, the adjustment problem will produce a random error of not more than one and a half feet." I believe this statement was based on the use of photography at a scale of 1:6,000. To achieve this accuracy, every step in the process must be well controlled. Proper aerial photography, control points panelled, second order or better positions, and last but not least, the property corners must be panelled if this accuracy is to be achieved.

For greater accuracy, good panelled control can be established for each stereoscopic model. Fairchild Aerial Surveys recently conducted tests using a flight height of 6,000′ and a 6″ focal length RC-8 camera photography. A test area was photographed which included 15 panelled points in one model. The control was all second order. The model was set in a C-8 stereoplanigraph. These tests indicate that little, if anything, is gained by holding more than 5 points per model, i.e., four corner points and one in the center. By holding 5 points and reading coordinates of the other 10, the RMS error was .56′, average error .45′ and a maximum error .92′, when compared to the ground control. Considering that second order ground control had a probable error of 1 foot in 10,000′, a considerable part of the recorded error may be in the ground control.

Based upon the above, I believe by use of proper scale photography and proper accuracy and density of panelled control, that photogrammetric positions can be guaranteed correct within about one half foot. For areas that are relatively highly developed or where conditions are favorable for development, I believe this accuracy is sufficient for cadastral work. In other types of areas it is doubtful if the cost of this accuracy can be economically justified.

In downtown city areas, greater accuracy is required. In such areas due to tall buildings and relatively narrow streets and alleys, photogrammetric methods are generally not applicable.

Photogrammetric bridging and electronic computations to extend control over large areas will greatly reduce ground control. As the number of stereoscopic models increase in relation to the number of ground control points error will increase in the X and Y coordinates. The accuracy of the ground survey data used for controlling the stereoscopic models is an important consideration. If an accuracy of one foot is required for property corners, third-order control will not be sufficient, as third-order control includes an error of about one foot per mile. Thus, when maximum accuracy is desired, consideration must be given to the use of second-order or first-order horizontal control.

Based on research and test data presently available, I believe we can well state the control, scale, methods, and procedures required to develop specified accuracies. It is expected that analytical bridging will very soon play an important part in determining positions.

Looking at cadastral data from an administrative or economic standpoint, the accuracy of cadastral data should be considered in relation to the present or early potential value of the property. For the determination of property boundaries and area of downtown business property, it is probable that ground surveys alone should be used.

In urban areas, economics will probably specify the development of cadastral data by a combination of ground survey and photogrammetric methods, with an allowable error in the neighborhood of $\frac{1}{2}$ to 1 foot. In agricultural land of relatively high value, it is possible that cadastral data to an accuracy of from 1′ to 2′ may be sufficient. Agricultural land of low value or range land of relatively high value would probably justify an accuracy of 2′ to 10′. In desert and jungle areas, corners to an accuracy of from 10′ to 500′ may be sufficient. Regardless of accuracy, I believe surveys should be adequately monumented and referenced.

Those responsible for developing overall programs which include cadastral work should relate specified accuracies to present or foreseeable land values. Specified accuracy will define the methods and procedures to be used. Where a high degree of accuracy is required, this should be specified. On the other hand, it should be remembered that a position accuracy of $\frac{1}{2}$ foot costs substantially more than an accuracy of 3′.

Accuracy of surveys and maps is something that can be specified and achieved. However, in subdividing large public and private land holdings into economical agricultural units, the condition of the land is far more important than the accuracy of surveys. I know of one large land reform program in Asia where large private land holdings were acquired by the government and accurately divided into units comprised of about 100 hectares. After the subdivision was complete, prospective farmers were found in the villages and cities and moved on to the land. They were each given crude agricultural implements, a burro, a few sacks of seed and limited credit at the neighborhood store. Aside from the fact that many of the prospective farmers had little or no experience in farming, the primary difficulty was that soil and moisture conditions were not satisfactory. It was impossible to sustain life on the land assigned. In a large percentage of the cases, before the end of the second season the prospective farmer had eaten the burro and drifted back to town. All such programs of land subdivision should first consider land capability and on this basis cadastral surveys made to establish appropriate parcels.

In the overall program to increase food production, there will be many reclamation projects. A good example of reclaiming abandoned farm lands and putting them to economic use, is in progress in Eastern France at the present time. This farm land was abandoned many years ago and is presently covered with a dense growth of brush and more or less worthless trees. This land was abandoned for several reasons; however, basically it was because of the exaggerated division of the land into smaller and smaller parcels by the inheritance laws.

Plot maps of the areas, surrounding villages in Eastern France, resemble the subdivison of land made for residential building lots. A typical unit of about 100 hectares, or 250 acres, would be divided into 1,000 parcels and owned by 100 or more individuals. The holdings of one individual were often scattered over large areas. There are many areas where very small parcels are being farmed on a starvation basis. These areas should be acquired by government, efficiently grouped on the basis of land capability, released for effective agriculture. A substantial cadastral surveying problem is involved in acquiring existing land and in subdividing. The project in Eastern France is just such a project. This project involves acquiring possession of the land, removing the scrub and brush, preparing the land for cultivation, regrouping the small parcels into contiguous area farms of from 50 to 250 acres, each based on soil type, topography, water and other factors.

There are countless cases where photogrammetry and ground surveying are combined to establish boundaries of various types to meet the requirements of government and private enterprise. I know of one case where the petroleum law of a country required the establishment of concession boundaries in extremely remote areas. All concessions were bounded by latitude and longitude lines. To establish the concession boundaries by ground survey methods would have cost a fantastic amount of money, to say nothing of the time required. No basic control existed within the area. Officials of the government concerned and representatives of the oil companies agreed to have reasonably well controlled mosaics compiled of the entire area involved and that the latitude and longitude lines on the mosaic, regardless of the probable error in position, would establish the concession boundary. The allowable maximum error was about 400′. The latitude and longitude lines on the mosaic could be identified on the ground in relation to drainage, trees, bushes, rock out-crops, camel trails, etc. For many areas and many purposes, such a method would not meet requirements. In this case, considering time and cost, the error was considered acceptable.

I have outlined a problem rapidly becoming serious and reviewed methods and accuracies possible by a combination of aerial photogrammetric and ground survey methods. I do not believe there is any possibility of solving future cadastral problems except by this combination of methods and procedures.

In closing I would like to emphasize the necessity of making resources inventories in connection with land subdivision. Intelligent subdivision and lasting agricultural production is not possible without proper consideration of such land capability factors as soil type and moisture conditions. Cadastral surveys are necessary to provide a systematic base for establishing property boundaries and these data must be delineated on maps as a record for use as a base for fair taxation. To avoid the hazards and devastating results of a land boom, now is the time to start serious planning and development of basic information. In the long run, the dividends of a resources inventory, proper land subdivision and cadastral data will exceed by far the glamour of steel mills, chemical plants or similar enterprises in areas without skilled manpower, raw materials and markets for products.

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cient for the final location of certain roads. However, a more efficient and conclusive on-the-ground materials survey can be conducted if a photo-materials investigation is performed first. This investigation denotes problem areas that should be looked at more carefully on the ground and isolates problem conditions as they relate to a geologic formation or some other type unit. In addition, aggregate material sources are more readily located through this method than through random on-the-gound searching.

In conclusion it is stressed that photo interpretation of materials problems does not replace on-the-ground materials surveys. However, it is a vital reconnaissance tool and a means of planning more efficient materials surveys in support of the highway program of the Intermountain Region, U. S. Forest Service.