Presented for commission No. : VII, working group : 3

O. Kölbl * and H. Trachsler **

* Institut de Photogrammétrie de l'Ecole Polytechnique Fédérale de Lausanne, Suisse

** Institut für Orts-, Regional- und Landesplanung, Eidgenössische Technische Hochschule Zürich, Schweiz

Regional Land Use Survey
Based on Point Sampling on Aerial Photographs

Abstract :

The paper discusses a concept for a new national land use survey of Switzerland. The existing statistics are mainly based on the cadastral survey. A renewal of the land use survey seems necessary as the cadastral survey is accomplished only for 65 % of the country and its revision is rather incomplete. The proposed method will be based on point sampling in aerial photographs using essentially a 100 m grid. The position of the sample points on the aerial photographs is determined analytically; a procedure which takes into account the relief as well as the position and inclination of the individual photographs. Thereafter the points are plotted automatically on a film which is used as overlay of the aerial photographs for the purely visual photointerpretation. For practical work aerial photographs in scale 1:25'000 are used. The preparatory phase includes a survey of 50'000 ha spread over different test regions. Accuracy estimations and comparisons with the cadastral survey show that the method is very appropriate to furnish the data for a national land use statistic. The volume of the work allows to estimate reliably cost and time needed for such a survey.

Zusammenfassung :

Grossräumige Landnutzungserhebungen mittels stichprobenweisen Auswertungen von Luftbildern.

Die Arbeit gibt einen Ueberblick über die Vorbereitung einer nationalen Landnutzungserhebung für die Schweiz. Die bisherigen Erhebungen basierten im wesentlichen auf der Grundbuchvermessung. Eine Erneuerung drängt sich auf, da die Grundbuchvermessung erst zu ca. 65 % fertiggestellt ist und auch die Nachführung nur sehr lückenhaft erfolgt. Das vorgeschlagene Ver-

fahren beruht im wesentlichen auf der Erhebung von Punktstichproben in Luftbildern mit einem 100 m Raster. Die Lage dieser Stichprobenpunkte im Luftbild wird analytisch bestimmt, ein Verfahren welches sowohl die Orientierungselemente der Bilder als auch das Geländerelief berücksichtigt. Anschliessend werden die Punkte mittels eines automatischen Zeichentisches auf eine Folie kartiert. Diese dient dann als Referenz für die eigentliche Luftbildinterpretation, welche rein visuell unter einem Stereoskop erfolgt. Für die praktischen Untersuchungen wurden im wesentlichen Luftbilder im Massstab 1:25'000 verwendet. Diese Vorbereitungsarbeiten umfassten Erhebungen über 50'000 ha in verschiedenen Testgebieten. Genauigkeitsabschätzungen und Vergleiche mit der Grundbuchvermessung zeigen, dass dieses Verfahren bestens geeignet ist um die nötigen Daten für eine nationale Landnutzungsstatistik zu liefern. Auf Grund der umfangreichen Voruntersuchungen lassen sich auch die Kosten für eine derartige Erhebung recht zuverlässig abschätzen.

Sommaire :

Relevé régional de l'utilisation du sol à l'aide d'un échantillonnage sur des photographies aériennes.

L'article donne un aperçu de la préparation d'un relevé national de l'utilisation du sol pour la Suisse. Les statistiques actuellement disponibles ont été essentiellement basées sur la mensuration cadastrale. Une rénovation s'impose, parce que la mensuration cadastrale officielle est achevée au 65 % seulement et la mise à jour est assez lacuneuse. La méthode proposée est basée principalement sur un échantillonnage sur des photographies aériennes. La position de ces échantillons sur les photographies aériennes est déterminée par voie de calcul, procédé qui prend en considération le relief du terrain, ainsi que les éléments d'orientation des photographies individuelles. Ces points sont ensuite reportés sur un film par un coordinatographe automatique. L'interprétation de l'utilisation du sol s'effectue purement visuellement à l'aide d'un stéréoscope. Les travaux pratiques ont été effectués essentiellement sur un réseau d'échantillons de 100 m. L'échelle des photographies aériennes utilisées était de 1:25'000. La phase préparatoire comportait des expériences pratiques, sur une région de 50'000 ha., réparties sur différentes régions de test. Les estimations de précision et les comparaisons avec la mensuration officielle montrent que ce procédé est particulièrement approprié pour fournir les données d'une statistique nationale de l'utilisation du sol. Les importants travaux préparatoires permettent aussi d'estimer de manière très fiable les prix d'un tel relevé.

1. Introduction

Land use surveys and inventories form an essential basis for spatial planning and for the management of the natural resources. Consequently great efforts are made to meet this need for information. Aerial photographs and the modern means of remote sensing are an essential tool for land use surveys. Another important source of information is provided at least for central Europe by the cadastral survey. The measurements are taken in general on the ground, aerial photographs are also partially used.

Although the cadastral survey represents an extremely dense information net, these measurements are of limited value for a land use survey on a national base. On the one hand the number of categories are in general very limited for technical reasons; on the other hand the description of the objects are liable to regional particularities which cause the loss of the uniform aspect. However, for additional surveys for regional inventories the parcels as smallest land use unit seem far too small.

Previously the land use statistic of Switzerland has been based exclusively on the cadastral survey. The first edition was published in 1912/13 later publications followed in 1925, 1952 and 1972. The heavy economic development of the post war period demanded much higher requirements of such statistics and severe deficiencies of the existing land use statistic became evident. They are mainly due to the fact that the cadastral survey is completed only for 2/3 of the country. The revision is performed with a certain time delay as far as the property boundaries are concerned, whereas hardly any revision is done for the natural boundaries.

Already in the sixties a project was started to create a new land use information system. This information system has been based purely on the topographic maps. The project was accomplished in 1970 and served as a base for the official land use statistic of 1972 beside the cadastral survey. As this information system has been based exclusively on the existing topographic maps, the number of land use classes has been very limited. The categories have been determined for complete hectars as smallest units, but only the dominant land use of a hectar was registered. This particularity causes small land use categories such as roads or rivers to be systematically suppressed.

To avoid the difficulties of the preceeding experiences, a new regional land use survey should be based principally on the use of aerial photographs. It is also possible to take into consideration other means of remote sensing such as scanner registrations or the use of satellite imageries. However, a more detailed analysis shows that the methods which are principally connected with automatic image processing are too expensive and not reliable enough to furnish a land use statistic of a heavy industrialized country in central Europe.

It was therefore decided to foresee essentially aerial photographs as a base for the renovation of the official land use statistic. The restitution should be accomplished by point sampling. Sampling techniques permit very rational working methods and avoid a cumbersome survey of the individual parcels. Even the density of the sampling net can be adapted to the degree of precision effectively required.

For the practical realisation of this concept, it is planned to effect the point sampling directly on the aerial photographs. That requires the transfer of the individual sample points into the image plane of the aerial photographs. The calculation can be completely automated, provided that the orientation elements of the aerial photographs and the heights of the sample points are known. For the present land use survey the terrain heights are taken from a digital terrain model, whereas the orientation elements of the photographs have to be determined beforehand with the help of control points. Afterwards the grid of the sample points adapted to the geometry of the photographs are plotted on a film with the help of an automatic drawing table. The interpretation of the aerial photographs is carried out, purely visually, by an operator who registers the interpretation results directly on to the interpretation film. These data are prepared for computer handling in a special phase; the statistic itself and the combination of these data with other information systems is effected by the means of electronical data handling.

The described method has been tested and compared with different other sampling methods as well as with terrestrial measurements. Recently, a test over 500 km^2 has been undertaken in order to achieve a rather safe estimation of cost and precision. These investigations proved that sampling techniques on aerial photographs are a reliable mean to build up a relatively detailed land use statistic.

In the following chapter it is tried to define a standard of a national land use statistic. Thereafter the particularities of the geometric restitution and of the photointerpretation are discussed. The chapter 5 is dedicated to considerations on the sampling precision and finally it is tried to give cost estimations on the proposed method.

The procedure presented in this article has been elaborated within an interdepartmental working group presided by the Topographic Service. In this working group practically all federal offices interested in this statistic were joined such as the Federal Statistical Office, the Federal Office of Comprehensive Planning, the Federal Directorate for Cadastral Survey, the Federal Office of Agriculture, the Swiss Federal Forestry Office as well as a number of research institutes.

2. Required standard of a regional land use statistic

The principal objective of a regional land use statistic is to furnish the information required for the supervision and the planning of the land use on a provincial or national basis. These data should be collected according to a well defined land use classification system. Furthermore it should be possible to compare them with other land use information, which implies that the data are well defined in the space. Finally a periodic revision should enable to follow the development in land use; this concerns specially the loss of agricultural terrain or the increase of urban areas.

It is obvious that the classification system for such a land use statistic must be worked out in close co-operation with the effective user of the information system. The classification system presented in figure 1 has been elaborated within the interdepartmental working group mentioned in the introduction. It is also based on the findings of two question polls

FOREST

Ordinary forest
Crown closure ≥ 0,2
Minimum width 25 - 50 m
Minimum height > 3 m

Small forest
Width = 25 - 50 m

Open forest

Grazing forest

Brush forest

Bushes
Crown closure ≥ 0,8
Height < 3 m

Field wood land & hedges

MEADOWS & ARABLE LAND

Swiss plateau | Alps | Jura mountains

Favourable meadows & arable land
Size of parcels > 1 ha
Average minimum width > 50 m
Inclination ≤ 25 %

Other meadows & arable land

Pastures

Mountain pastures

Wooded pastures
1 - 4 trees per 1/4 ha

Mountain pastures covered with bushes
(more than 80 % covered with bushes)

RESIDENTIAL, COMMERCIAL, RECREATION

Building surfaces
All buildings (except industrial buildings > 1 ha)

Courtyards, housegardens
Maximum surface ≤ 25 a

Public gardens & parks
Minimum surface > 25 a

Allotments

Marshland

Building sites

Camping & caravan sites

INDUSTRIES
Minimum surface > 1 ha

Industrial buildings

Industrial areas

FRUIT - GROWING

Intensive commercial orchards
(≥ 300 trees per hectare)

Orchards
(trees in rows)
Minimum area 25 x 25 m
(> 50 trees per hectare)

Scattered fruit trees
At least 3 trees

VINE GROWING

Intensive vineyards

Other vineyards
Distance between rows > 6 m

MARKET GARDENING
Including greenhouses
Minimum area 25 x 25 m

TRAFFIC AREAS

Motorways
Separate lanes

Roads & paths
Passable for cars (minimum width 1,5 m)

Railways

Airfields

Parking areas
Minimum surface > 25 a

LAKES, RIVERS & PONDS

QUARRIES, GRAVEL PITS, DUMPS

SUPPLY & DISPOSAL AREAS

UNCULTIVATED AREAS

Fig. 1 Table of the land use classification system, as it is proposed for a national survey of Switzerland at public and private planning offices.

Besides the specific wishes of the users it is also necessary to take the technical possibilities and their limitations into account. These technical possibilities are principally defined by the aerial photographs and the sampling method. The aerial photographs which are primarily available in Switzerland are black and white photographs in 1:25'000. These pictures are flown by the Topographic Service for the revision of the national topographic maps. The pictures are taken during the summer season and cover the whole country in a cycle of 6 years. Evidently these pictures cause certain limitations in the photointerpretation which is specially remarkable in the built-up area.

The sampling technique allows a rather large number of land use classes. Contrary to a complete survey the number of classes itself does not really influence the time needed for the survey; only the precision gets fairly limited if surfaces of relatively small extension are to be determined.

Apart from the classification system it would also be necessary to specify the precision required for a land use statistic. But in reality it is very difficult to find criteria for the precision which is actually needed. The smallest unit represented in the official land use statistic of Switzerland is the community (size between 30 and 28'000 ha). It would not be very meaningful to define purely on this level absolute values for the precision as the main aim of the statistic must be to furnish information on a regional base. Even the definition of the classes might be liable to considerable systematic differences. For example the cadastral survey defines the surface of a building according to the rising masonry whereas on aerial photographs only the roofs are visual. Therefore the built-up area will be overestimated on aerial photographs. Unlike the roads which are in general underestimated. The cadastral survey gives the surface of the road according to the property bounderies, which includes slopes and ditches; on the aerial photographs only the paved surface is recognized.

Under these conditions it was decided to effect the sampling of the test region by a 100 m grid and to study on the obtained results the necessity for further densification of the sampling pattern. Furthermore it was decided to use permanent sample points to ensure maximum precision for the detection of changes for a periodic revision of the survey.

3. Metric restitution of the aerial photographs

The interpretation of sample points given by their coordinate values requires their exact localisation on the aerial photographs. Photogrammetry offers different methods for this task such as stereoplotting, the use of orthophotos or a projective transformation of the sample points into the image plane (cf. Fig. 2). The stereorestitution and the production of orthophotographs are well known techniques which are, however, too expensive and time consuming for the present task. It is more efficient to plot the transformed sample points on a film and to superimpose them on the original aerial photographs; the photointerpretation is then effected under a simple stereoscope. In this way the point position is unambigously fixed and it is assured that any subsequent interpretation and verification will allways occur on the same spot. A condition for such a

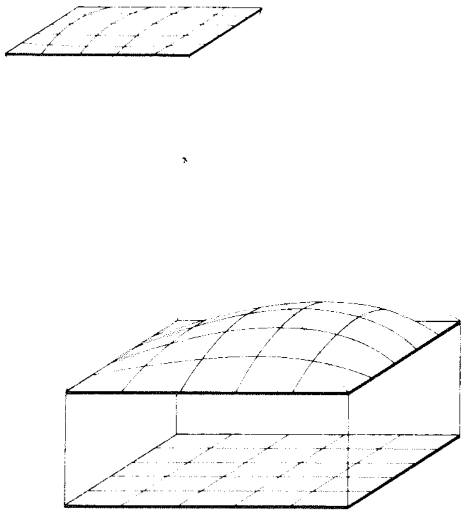


Fig. 2

Transfer of a regular sampling grid onto an aerial photograph. For this point transfer the orientation elements of the photographs as well as the terrain heights of the sample points have to be taken into account. The height information could be taken from a digital terrain model.

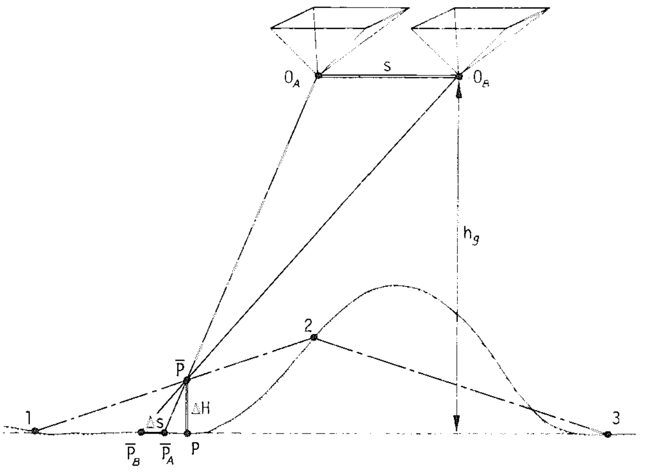


Fig. 3

Point displacement due to interpolation errors in the digital terrain model. A linear interpolation between point 1 and 2 raises the point P for ΔH. This height error influences the reproduceability in successively flown pictures. The displacement Δs corresponds to the initial height error ΔH reduced by the factor s/h_g (s : distance between the projection centres of picture A and B ; h_g : flying height above terrain)

method is that the individual working processes are automated to a high degree and that the data manipulation is rationalized as far as possible. In detail the following working processes can be distinguished :

1) Determination of the orientation elements of the aerial photographs
2) Calculation of the terrain heights of the sampling points with the help of a digital terrain model
3) Projective transformation of the sample points
4) Plot of the interpretation film
5) Storage of the interpretation results, compilation of the land use statistic and combination of the data with other information systems.

As already indicated the aerial photographs used for the practical experiences were principally the black and white photographs in the scale 1:25'000 taken for the revision of the topographic maps. The orientation elements of the photographs were determined with the help of control

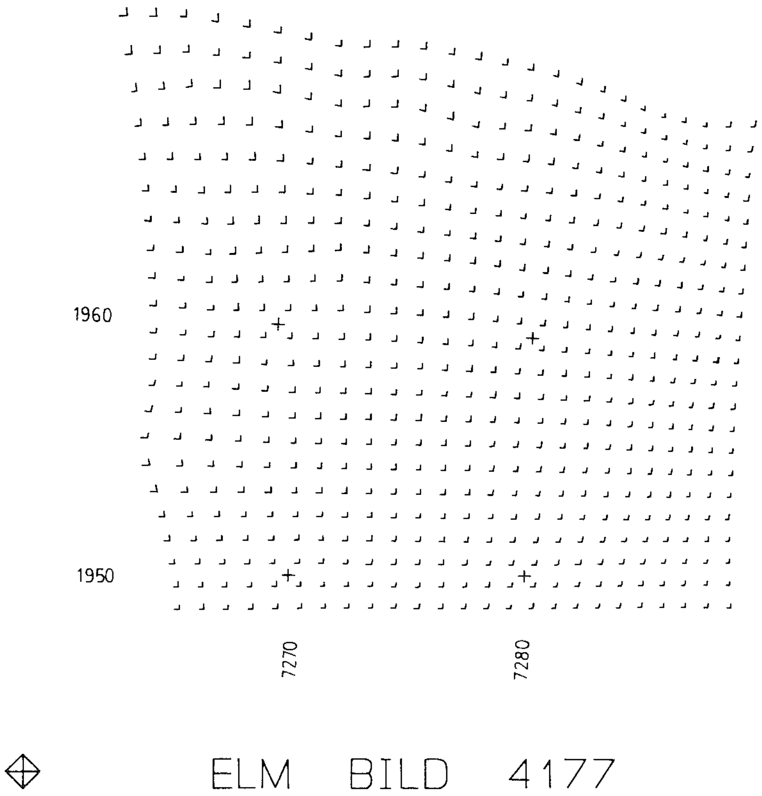


Fig. 4

Section of an interpretation film, slightly modified for reproduction. The land use interpretation is done at the top of the angles. The side length corresponds to 25 m. in the terrain and the angle to 90° (the heavy deformations are due to height differences of nearly 2000 m. in the terrain). The kilometer grid with inscription was used for the registration of the interpretation results, the rhomboids (only one in the picture) correspond to the fiducial marks of the respective photograph and are used for the exact location of the film.

points, taken from the topographic map in 1:25'000. The necessary measurements of the picture coordinates have been effected on a monocomparator (Kern MK2), whereas a digitizer was used to determine the corresponding point coordinates in the map. On an operational base it should be possible to omit this operation as the aerial photographs have already been orientated in a stereoplotter for map revision and it would be easy to retain the orientation elements already in this stage.

The subsequent data manipulation was completely automated as for the height-determination of the sample points, the projective transformation of the grid and the plotting of the interpretation film. The whole of Switzerland is covered by a digital terrain model, the heights are stored for a regular grid with a distance of 250 m. Consequently it has been necessary to interpolate the heights of the sampling points spaced 100 m only. The precision of the interpolated heights depends on the terrain. According to statistical investigation in the lowland of Switzerland a standard error of ± 25 m can be expected whereas in the mountain region the standard error raises till ± 75 m. The corresponding errors in planimetry of the sample points are much smaller and are only of importance when the same sample points are reconstructed on another aerial photograph, as is necessary for the revision of the statistic. From figure 3 it can be deduced that planimetric position of the sample points in photo A and B depends on the ratio formed by the distance between the two projection centres and the flying height. When one assumes that the photographs of the subsequent flights are flown according to the same flight plans, it should be possible to conserve the initial flying lines within 10 % of the flying height. In the same proportion the planimetric errors reduce to 1/10 of the initial height errors and should stay within the precision of the control points taken from the map.

The plotting itself was done on an automatic drawing table (Coradi : Coradomat MK 3). The sample points including some annotations (fiducial marks of the photographs, used control points and the national grid system) were scribed on film which has been coloured and washed afterwards (cf. Fig. 4). In this way the interpretation film is a highly transparent document which practically does not degrade the interpretation of the aerial photographs. An interpretation film contains approximately 1000 sample points.

4. Photointerpretation

The interpretation of the aerial photographs should be principally performed under a stereoscope. The perception of a three-dimensional model allows the inclusion of the relief and the height of the objects into the interpretation process. Futhermore, the possibility to recognize small details is sensibly raised by the binocular observation of homologue photographs.

In the present case the picture scale (1:25'000) is already on the upper limit and certain precautions are necessary to obtain optimum conditions for the interpretation. All interpretation was effected on transparencies (contact prints). Various stereoscopes have been used with different optical characteristics. It turned out that a stereoscope with variable optical magnification (zoom) of up to at least 10 times was necessary. Evidently this strong magnification only makes sense if a good contrast transfer of the optic for all frequencies up to 50 to 100 lines/mm is assured.

The work of the operator is considerably facilitated when the oculars of the stereoscope rest fixed and the photographs are displaced with the help of a parallel guiding mechanism. For verification and discussions it proved extremely useful for the stereoscope to be equipped with a second binocular. The interpretation technique itself is relatively simple, although the operator should be quite experienced in photointerpretation as well as in agronomy. It proved of great importance that the operator indicated directly on the interpretation film the results of the interpretation (cf. Fig. 5). Such a procedure allows a permanent control by the operator himself, the documents can be taken on to the field for verification and an easy and efficient supervision is possible.

The gain of experience and the control of the classification system were one of the outstanding objectives of the practical tests. Therefore the complete interpretation was controlled by one or two interpreters and numerous verifications in the field were performed. It showed up, that a

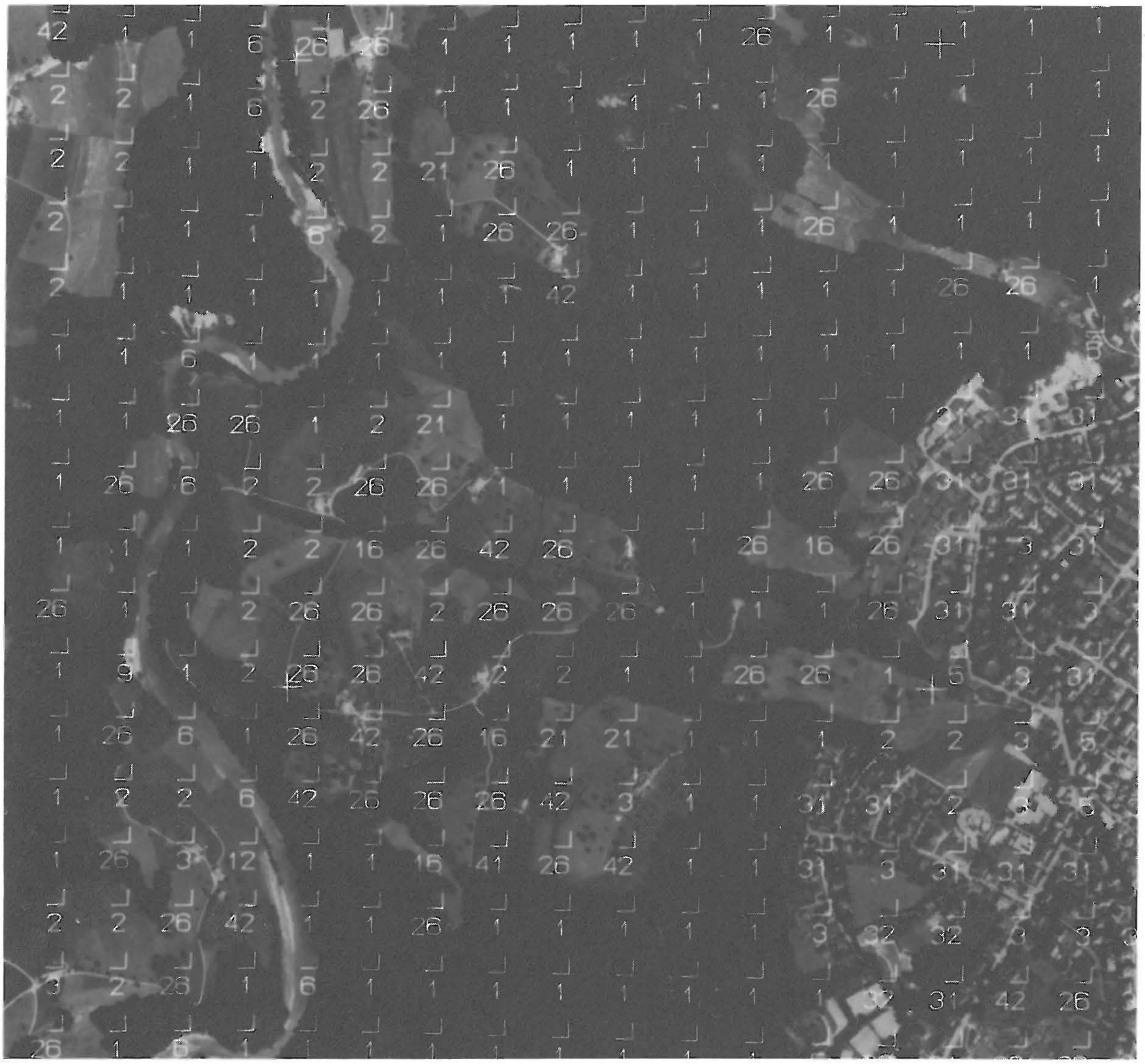


Fig. 5

Aerial photograph with superimposed land use interpretation as it would be used for revision purposes (picture scale 1:25'000, 2 times enlarged).

1 : ordinary forest, 12 : open forest, 16 : field wood land & hedges,
2 : favourable meadows & arable land, 26 : other meadows & arable land,
3 : building surfaces, 31 : courtyards & housegardens, 41 : orchards,
42 : scattered fruit trees, 6 : lakes, rivers & ponds, 9 : uncultivated areas.

Photograph reproduced by courtesy of the Topographic Service of Switzerland

detailed classification system assures rather consistent interpretation results as the scope for personal judgment is relatively small. Evidently the 34 land use classes must be considered as a working tool and certain contractions will be necessary for publication. Nevertheless the original survey stored in a computer will remain easily accessible and can be consulted on demand.

The land use survey is conceived as pure point sampling. It is therefore necessary to define a distinct point in its mathematical sense on the interpretation film. This point symbol had to be large enough in order to assure easy recognition even in dark areas of a photograph; on the other hand the symbol should hide a minimum of the proper interpretation surface. The solution was found in plotting an angle of 90° on the interpretation film and defining the top of the angle as sample point (cf. Fig. 5). The dimensions of the angle were chosen with 25 m in the terrain system and the projective deformation was also applied to the end points of this figure. This figure served at the same time as reference distance used for the definition of certain objects as for example the minimum size of a forest area.

5. Precision estimations

The precision of a land use survey based on point sampling on aerial photographs is determined by the interpretation error and the sampling error. An overall estimation of the precision can be obtained by comparing the results obtained by sampling with those of a terrestrial survey. This was one of the main objectives of the practical test. Parallel to these empirical investigations the sampling error is estimated according to statistical laws.

A relatively simple method for the estimation of the theoretical sampling error is based on the binomial distribution (cf. 1). This method allows to estimate the error in percent (σ_G) of one individual land use class in relation to the total surface (equal to 100 %) chosen as reference (e.g. surface of a community)

$$\sigma_G[\%] = \pm k \sqrt{\frac{p(100-p)}{n_G}} \tag{1}$$

(k is a constant with $k=1$ the standard error is obtained, $k=2$ corresponds to a confidence interval of 95 % and $k=3$ to a confidence interval of 99 % ; p is the part in % of the land use class under consideration in relation to the total surface and n_G is the number of sample points on the total surface).

The formula presumes that the sampling pattern is random with respect to the distribution of the object. Furthermore, it is presupposed that the surface of the total area is known and that the individual surface parts are adjusted according to the total.

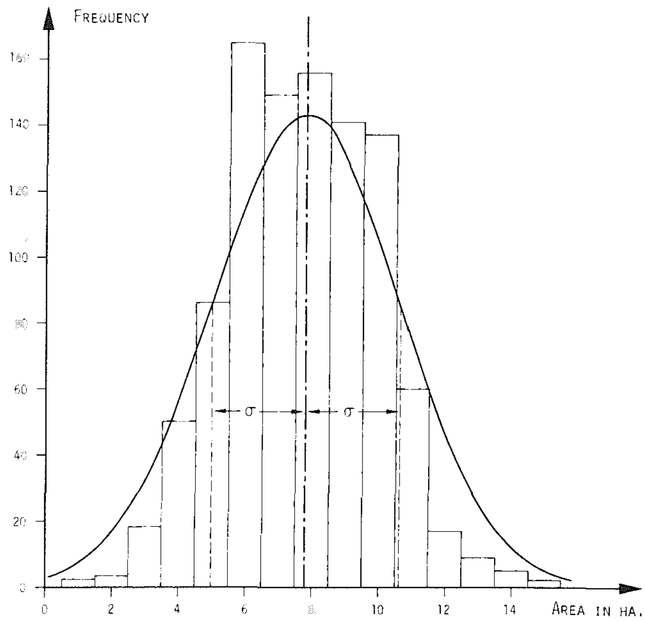
In certain cases however the error percentage referring to the "total surface" is less significant than the relative error with respect to the surface of an individual object. The transformation of formula 1 gives :

$$\sigma_M[\%] = \pm k \sqrt{\frac{100(100-p)}{n_M}} \tag{2}$$

(n_M is the number of sample points which fall on the area under consideration)

Fig. 6

Frequency distribution of a sampling survey accomplished by computer simulation. The surfaces of buildings (exact value 7,8 ha) were determined within a municipality of 200 ha ; grid spacing 100 m. The comparison with the Gaussian distribution shows good coincidence with the theoretical value and as expected in more than 2/3 of the cases the obtained value lies within the standard deviation σ.



For small surfaces with $p < 30$ % formula 2 can be approximated by :

$$\sigma_M[\%] = \pm k \frac{100}{\sqrt{n_M}} \qquad (3)$$

The reference to the total surface is lost by this approximation, consequently the formula can also be used if no adjustments of the surfaces are performed.

The binomial formula is relatively easy to handle and allows error estimations without any knowledge on the configuration of the object. However it is presumed as already mentioned that the sample points are completely random with respect to the object. As a regular grid is used for sampling this condition is only met for objects which are randomly distributed (irregular road net or housing pattern, cf. Fig. 6). The surface error is more or less overestimated by the binomial formula when the probability that successive sample points will fall on the same object is large. Different authors recommend the introduction of a form factor f and the augmentation of the exponent of n_M to 2/3 or 3/4 (cf. 2, 3 and Fig. 7).

$$\sigma_M[\%] = \pm k \frac{100 \cdot f}{n_M^{3/4}} \qquad (4)$$

A more rigourous approach would be the explicite calculation of the correlation for adjacent sample points (cf. 4, 5). A detailed analysis of this technique is given in (3), but these accuracy estimations are of limited value for general considerations.

It was originally intended to base the empirical accuracy estimations on a comparison of the photointerpretation with the cadastral survey. Earlier in this paper it has been indicated that the description of a parcel in the cadastre is specifically orientated to the requirements of a property cadastre developed out of a fiscal cadastre. Therefore it must not

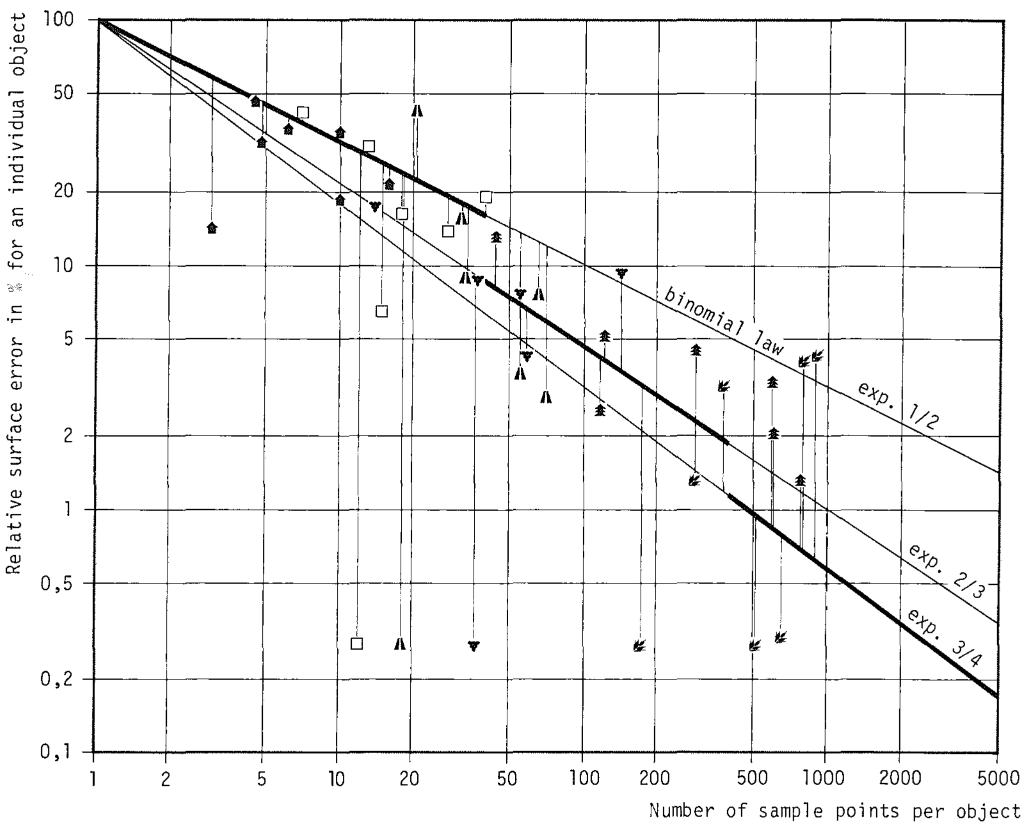


Fig. 7

Comparison of the theoretical accuracy estimation of sampling with the practical experiences for 7 different municipalities (▲ buildings, □ courtyards, meadows, ▼ vineyards, forest, Λ traffic areas). The binomial law is applicable only for small surfaces randomly distributed whereas for continous surfaces (meadows, forests) smaller errors can be expected. According to their size (more than 40 sample points resp. more than 400) an exponent of 2/3 resp. 3/4 is used.

surprise that as a whole, only reference values were available for buildings, vineyards and orchards. This comparison shows that these surfaces correspond very well and the deviations are within the estimated sampling error (cf. Fig. 7). Only the buildings are systematically over-estimated by about 20 %. These few results confirm that the sampling error is relatively well estimated by the theoretical considerations and these laws can also be used for the determination of the density of the sampling pattern.

6. Cost estimations and conclusions

It is a delicate problem to derive cost estimations from experimental works. Nevertheless the volume of the investigation effected up to now allows relatively reliable expenditure estimations. According to the practical experiences the time needed for the interpretation of a single sample point varies between 5 to 10 seconds. For the preparation of an interpretation film, including all preparation work as the determination of the orientation elements of the photographs and the location of the flight lines nearly one hour is required. Finally a relatively large part of the actual working time (40 %) falls on field verifications. This gives the following time partition for the planned national survey :

10 % for the preparation of the interpretation films, including photogrammetric measurements

35 % photointerpretation

40 % field verification

15 % punching of the interpretation results and data-manipulation.

For the whole country (surface of Switzerland 41'200 km^2) it is estimated that 3 to 4 operators are necessary over a period of 6 years (the revision cycle of the topographic map). The working capacity of one man can be indicated with 2000 km^2 per year. 400 pairs of photographs would be necessary to cover this surface (it is evident that the interpretation film must be prepared only for each second photograph).

The procedure would allow the establishment of a new national land use statistic with relatively modest means. The presented sampling technique on aerial photographs seems to be an extremly economic alternative to a complete survey realized in connection with the cadastral survey. Evidently the precision is less high than with a complete survey, but sampling with a 100 m grid should be largely sufficient for practically all land use information needed on a regional basis. However the sampling method is in no way restricted to the 100 m grid. A densification of the grid even for a few specific classes, for example buildings or roads, would not present a large amount of extra work, provided that no additional field verifications are required.

The method would also allow a simple revision, as the originally used sample points could be transferred relatively simply on to other photographs including the previously determined land use interpretation.

The proposed procedure for a renovation of the official land use statistic is presently being studied by the political authorities and it is hoped that the method can be realized for the whole country in the very near future.

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