THE ESTABLISHMENT OF A MULTIPURPOSE CADASTRE BASED ON DIGITAL ORTHOPHOTO TECHNIQUES

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ABSTRACT

With the advance in computer technology during the last decade digital photogrammety has become operational and is gaining more and more acceptability. Especially the ability to display geo- and height-refernced digital orthophotos on the monitor of digital workstations has given us a very powerful tool for multipurpose mapping. Screen-digitization offer a practically unlimited scope for data aquisition, as the full content of the aerial photograph is available for interpretation and mapping. The applicability of the digital orthophoto is demonstrated on some executed projects.

INTRODUCTION

Whenever some accumulations of human beings reached some cultural level, the **management of their available land** had to match their needs and was the **base of their economical, social and cultural progress**. If in some regions this landmanagement has been neglected for whatever reasons, great problems arose for the peoples concerned and the economies of these peoples have always been very negatively affected. The latest technology available at the relevant period was used to solve the tasks and problems of the landmanagement. One can deduct of historical evidence from ancient Egyptian times on till the very present, that the landmanagement systems, used during the particular period, consisted always of applied geometry combined with the then available computercapacity and performance.

Since some 50 years photogrammetric techniques are best suitable to solve the problems and tasks for the compilation of information of large areas and with the latest developments, digital photogrammetric procedures are presently the most powerful tools existing.

Photogrammetry was for a long period regarded as the **art and method of surveying, which avoids calculations** (1) and with the beginn of this century, when the first **analog photogrammetrical instruments** were built, they were actually **analog computers**, which solved the photogrammetric measurements of points and the drawing of plans and maps by mechanical devices avoiding the point by point numerical calculations. One, or possibly even the very first, stereoplotter was the Stereoautograph of v. Orel-Zeiss in 1911 for the plotting of terrestrial photographs (2). During the First World War when flying equipment became available, aerial photography was used to obtain information of the positions of the enemy. The next step, for a more peaceful and constructive applications, was then the development of instuments for the evaluation and plotting from aerial photographs. Hugerhoff and Bauersfeld developed the first **Stereoplanigraph** for the plotting from aerial photographs, in the early 20-ies of this century (3). These phantastic creations of high precision mechanics and optics were the standard instruments for the photogrammetric work until the late 70-ies and early 80-ies, when the analytical instruments had started to replace the analog plotters. (4)

A further boost in computer capacity and performance from about 1988 onward was necessary to handle the huge quantities of data, which are required to apply digital photogrammetric techniques and by the end of 1992 at least five instrument-makers offered digital photogrammetric plotters on an operational performance level.

The analytical plotters still use the original photographs, only the **"spatial analog computer"** of the "analog plotter" is **replaced by a powerfull electronic computer and**

program-system, which performs the huge quantity of complex calculations in near realtime. It feeds the servomotors, which move the still existing picture carriers according to the preset and stored orientationdata and to the movements of the operator in the stereomodell with a speed, that the operator can no longer detect any more the lagging behind of the stereomatching of the two pictures when viewing through the eyepieces of his instrument. The **digital techniques however require the scanning of the original photograph**, partially or completely, depending on the operations one wants to perform and the instrumentary which is used. The digital instrument or workstation is reduced to a powerful computer, a black or actually mostly grey box, standing somewhere underneath the table of the workstation, one or two monitors equipped with some stereoviewing devices, a keyboard or mouse which allows the operator to communicate with the digital photogrammetric instrument and a very complex and potent program-system. The glamour of the roomfilling, optical and mechanical high precision marvels has given way to a somewhat odd looking TV-set.

THE DIGITAL DATA

We should here spend some thougths on the requirements of the scanned data. The original photograph was and of course still is the base of the information, which can be intelligently processed in order to collect our wanted information for interpretation, measurement or mapping. What is not discernible on the photograph is not available for our activities. We all know, that the resolution of the photograph has some limitations. We want a very fine grain of the film emulsion and the filmspeed should be fast enough to allow us to have reasonable short exposuretimes, in order to minimize the picture-motion during the photoflight. Both requirements are contradictory, but have reached a performance level, with which we have learned to live. Everyone has already experienced, that enlargements when viewing at pictures, will reach limitations when the grain of the emulsion of the film is beginning to show and a further enlargement does not give us any more information. The grainsize of the films we use in aerial-photography ranges somewhere between 5 and 20 µ and so it is useless to scan the photoraphs with pixle-sizes which differ to much from the grainsize of the film emulsion. In addition we must have in mind, that the quantity of data increases enormously when the pixle-size decreases. An aerial photograph of 23 x 23 cmI scanned with a pixle-size of 10 µ will give us 529 MB or 0.53 GB, 20 µ 132 MB or 0.13 GB and this is for black and white photography only.

Pixle - size µ	pixles per Line of 23 cm	data of one completly scanned photograph ($23x23cm^2$) MB	GB
7.5	30667	940.4	0.940
10	23000	529.0	0.529
20	11500	132.3	0.132
40	5750	33.1	0.033
60	3833	14.7	0.015
100	2300	5.3	0.005

Table 1: Quantity of data of one completely scanned photograph of 23 x 23 cm^2

If we want to use colour photography we end up with data-sets of more than three times as much. We also have to bear in mind that the datastorage and handling of such dataquantities are still not without problems, as we have to manipulate and organize not just the data of one picture but rather those of a few hundreds or more likely a few thousands.

One more very important initial consideration is the expected accuracy, which is required for a particular project. Here the **pixle-size on the ground** is the limiting factor. Picture scale, scan-width, pixle-size on the ground and expected accuracy have to be balanced very carefully in order to obtain optimal results.

Measurements can be done in subpixle accuracy. In planning our projects we have so far assumed the relatively conservative value of 1/4 pixle-size. We cannot confirm readily results with much higher resolutions claimed to have been reached by other authorities.

pixle-size µ / Picture scale	7.5	10	20	40	60	80	100
1:2500	1.9	2.5	5.0	10.0	15.0	20.0	25.0
1:5000	3.8	5.0	10.0	20.0	30.0	40.0	50.0
1:7500	5.6	7.5	15.0	30.0	45.0	60.0	75.0
1:10000	7.5	10.0	20.0	40.0	60.0	80.0	1.0 m
1:15000	11.25	15.0	30.0	60.0	90.0	1.2 m	1.5 m
1:30000	22.5	30.0	60.0	1.2 m	1.8 m	2.4 m	3.0 m

Table 2: Pixle - size on the ground. [cm/m]

DIGITAL PHOTOGRAMMETRIC PROCEDURES

Digital photogrammetry of course enables us to perform all measurements and operations we have performed so far with the analog and analytical instruments. However digital techniques enlarge our capabilities of performance enormously, as a wide range of measurements can be automated by using correlation techniques and the progress of map compilations can be displayed elegantly on the monitor.

Any individual point of the left picture can be matched automatically with the corresponding point of the right picture if correlation procedures are incorporated in the programsystem of the digital plotter. Interior, relativ and absolute orientation, the transfer of carryover points in aerotriangulations, the measurement of terrain modells and the measurement of profiles are some of these applications. For the compilation of a line map the operator has still to do the actual work of interpreting and measuring point by point and here the advantages are not so much the faster performance in the pointcollection, but the higher accuracy as compared with the analog instruments. Here however one should also mention, that the viewingquality of the analog and analytical instuments is still superior to that on the digital workstations, which are momentarily offered by the photogrammetric instrument industry. This could be improved by using smaller pixle-sizes, but this of course sharply increases the size of the data-set.

THE DIGITAL ORTHOPHOTO

When the first analog orthophotos appeared in the mid-50ies the effort and expenditure for their production was rather high. The instruments were quite expensive and delicately to operate. The elevation information had to be in profiles. The computer facilities were still quite limited, so the management of the profile data was still rather awkward. This was especially the case, when the topo-graphy of the area to be mapped was creased and complex, then the width of the profiles had to be relatively narrow, consequently their number was quite large and particularly when objects with some extention in height were close to the profileedge the projection of the image was very often not satisfactory. Double images were rather common and the seams of the profile bands did show up. In order to reduce these disadvantages to a tolerable measure, the bandwidth had to be relatvely narrow and the measurement of many profiles was very time consuming. These were some reasons why the analog orthophoto technique was used very restrictively only, especially in ares where relatively good topographical maps did exist, covering the whole country. Regions where these maps were not available, were usually poor and developing countries, which could not afford such expensive procedures, unless they were financed by some outside institutions, such as World Bank, FAO or other foreign aid. (5)

Digital orthophotos have overcome these disadvantages to a great extent. They still need advanced technology, but this has become available during the last few years, thanks to the inflation in the computertechnolgy and to the still dropping costs at least in the hardware component.

THE PRODUCTION OF DIGITAL ORTHOPHOTOS

The raw material is of course still the aerial photograph. The first and basic considerations are the selection of the picture scale suitable for the project in mind to reach the required accuracy and consequently also the selection of the pixle-size which is necessary to meet these specifications.

Aerial photography and ground control has to be carried out. It is followed by an aerotriangulation (6) to control the models and by the collection of the height information or terrain model, which has to be measured or taken from some other existing sources and processed to match the orthophoto program module. Here again we have to balance the density of the height information with the expected or planned accuracy of the final result. These data have to be accomodated in a computer with sufficient storage capacity as we have seen above.

The pictures most suitable for the actual orthophotos are selected and then, with the scanning of these pictures, the actual production of the digital orthophoto commences. As the pixle-size will be in the magnitute of some 10 to 50 μ, the band width, as compared with the analog orthophoto, is of course the actual selected pixle-size. This analogy between profile-width and pixle-size is actually no longer valid. The profileslices are replaced by a regular raster area of small squares, the pixles. Each pixle has its individual picturecoordinate and can be moved in all directions by computation. The displacements in the photograph caused by the central perspective projection of the cameralens, the differences in elevation of the particular points on the ground and the deviation from the horizontal position of the camera at the moment of the exposure, are eliminated in the actual process of the production of the digital orthophoto by differential displacement of the pixle data according to the terrainmodel and the orientation parameters. This process is entirely performed by the computer and the **resulting manipulated data-set** represents the **actual digital orthophoto**. Any hardcopy, as screened diapositive or paper print is just a derivate, of the data-set, however useful it may be.

Needless to stress that the smaller the mesh of the terrainmodel is, the more precise the additional information of the break- and structure- lines are, or just simply, the more one has invested in the height information, the more precise will be the data-set or the digital orthophoto.

This data-set has still no scale and no orientation on the surface of the earth, however georeferencing or geocoding, is an easy computer process as groundcontrol data and data from the aerotriangulation, which had to be carreid out during the preparatory steps, are already existing, and can be introduced now. As also the terrainmodel is available it can be referenced as well with the data-set so every position in the **geocoded digital orthophoto will provide the three spatial coordinates X, Y and Z.**

The final steps are the addition of a frame, legend, informations, grid, coordinates and the writing of names of topographical objects and features. All these additional informations are organized on different layers and can be displayed and hardcopied if wanted.

MULTIPURPOSE USE OF DIGITAL ORTHOPHOTOS

The georeferenced data-set of the digital orthophoto is the ideal base for any mapping operation and can be used for any purpose which has to do with landinformation, recognizeable in the original aerial photograph. Displayed on the screen of the monitor it contains the full information of the original aerial photograph with that geodetical accuracy which was put into it, when the original picturescale, the pixle-size of the scanningprocess and the specifications of the terrainmodel have been chosen.

Here again we have a very noticeable improvement in accuracy as compared with any analog techniques, as all manipulations have been performed digitally by the computer and all mechanical deficiencies, limitations and shortcomings of the analog instruments (=analog computer) have been eliminated.

The applications of the digital orthophoto are limited only by the imagination of the user. All geo-informations can be extracted geometrically correct as long as they were discernible on the original aerial photograph.

It should be stressed here once more, that each point which will be interpreted and selected on the screen and clipped on (= digitized the data-set or digital orthophoto) has its coordinates with the previously specified accuracy and can be stored at the level of its category, thus creating one level of the multipurpose cadastre. Points may be digitized originally in the data-set or imported from outside, for instance from a development project and added to the data-set. The digital orthophoto with its geo-referenc represents the basic map, or basic maplayer for all additional activities or cadastrecategories. And we should get away from the opinion, that the expression cadastre is reserved for the connection with parcelboundaries and titledeeds only.

PRACTICAL EXPERIENCES WITH DIGITAL PHOTOGRAMMETRY

Here we may look at some projects which have been carried out within the last four years using digital photogrammertic techniques.

1. Photo-mapping of Sachsen-Anhalt.

Even in the so called "rich Western Countries" a total coverage with uniform large scale base maps in a regular lay-out for a "Land" or province is quite rare. Mapping was begun in the early 1800-s to create a uniform, accurate and concise base for the registering of the land and its owners and as a base for a general and equitable taxation in order to finance the dramatically increasing costs for the pressing improvements or new installation of the country's infrastructure. But only very few provinces or "Lqnder" really did finish this task in a uniform mapscale and a homogeneous mapframe. Many areas were covered by "island maps" only, of very differing scales and contents and what was left after 40-odd years of mismanagement or politically prevented actualisation or even planned destruction, was practically useless.

Sachsen-Anhalt, one of the "new Bundesländer", planned to remap practically its whole rural territory of economical interest to create a totally new base for these old and during some 45-odd years completely neglected cadastral maps.

Within a period of 4 years some 8 000 kml or nearly 40% of its total area had to be covered by photo-maps at the scale of 1:1000 on map-sheets of 500 x 500 ml.

The method adopted was:

1. Signalizing and measuring, sufficient ground control, mostly using GPS-techniques.

2. Coverage with aerial photography black and white, scale 1:3700 80% forelap, with a 30/23 camera.

3. Aerotriangulation, to control the whole area and to determin sufficient control-points for the rectification of the pictures for the photo-maps 1:1000.

4. Production of the photo-maps 1:1000 in map-sheets of 500 x 500 ml as screened diapositives.

The lots to be worked on were areas of some 500 to 2500 models (some 100 to 500 kml).

For the areotriangulation we used the **LEICA-HELAVA DSW-100** equipment. Pointtransfer and actual measurement was done by **picturecorrelation** with the **DCCS-program modul**. No premarking of points in the negatives or diapositives is necessary, points are selected, stored and recognized by their picturecoordinates only. The scanner in

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Bild: 0116

Control Points Report

Coordinate File:        g:\0116.xyz
Input Layer Name:       0116.cot
Design File Name:       g:\rahm_sac.dgn
Summary:   Number of Points:              11      (none withheld)
           Degrees of Freedom:            18
           Standard Error:                0.0208
           Point with Highest SSE:        4234832
           Model:                         HELMERT

Control Point List:
Point #:                      50000303
Control x, y ( m):        4522928.1800    5748447.1100
Input x, y (pix):             895.0000        889.0000
Weight x, y:                    1.0000          1.0000
Residual x,y ( m):            - 0.2579          0.0012
SSE ( m):                       0.2579

Point #:                        302005
Control x, y ( m):        4523037.2300    5747963.5900
Input x, y (pix):             848.0000       6897.0000
Weight x, y:                    1.0000          1.0000
Residual x, y ( m):             0.2532        - 0.1179
SSE ( m):                       0.2793

Point #:                        301010
Control x, y ( m):        4523346.0000    5748365.6500
Input x, y (pix):            5602.0000       3010.0000
Weight x, y:                    1.0000          1.0000
Residual x, y ( m):           - 0.0393          0.0922
SSE ( m):                       0.1002

Point #:                        302007
Control z, y ( m):        4523207.8200    5748498.7300
Input x, y (pix):            4340.0000       1053.0000
Weight z,y:                     1.0000          1.0000
Residual x, y ( m):           - 0.1281        - 0.1999
SSE ( m):                       0.2374

Point #:                        302008
Control x, y ( m):        4523282.4200    5748118.2700
Input x, y (pix):            4165.0000       5754.0000
Weight x, y:                    1.0000          1.0000
Residual x, y ( m):           - 0.1032          0.1966
SSE ( m)                        0.2220

Point #:                        302009
Control x, y ( m):        4523320.3200    5747971.7300
Input x, y (pix):            4206.0000       7586.0000
Weight x, y:                    1.0000          1.0000
Residual x, y ( m):           - 0.1465          0.0115
SSE ( m):                       0.1470

Point #:                       4234831
Control x, y ( m):        4523030.1400    5748459.3200
Input x, y (pix):            2133.0000       1029.0000
Weight x, y:                    1.0000          1.0000
Residual x, y ( m):           - 0.1555          0.0954
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Table 3: Record of residuals in digital rectification

the DSW-100 allows scans down till 7.5 μ and can be calibrated to any requested pixle-size. For the aerotriangulation only patches of 480 x 480 pixles are scanned and used for point tranfer and measurement by autocorrelation, thus reducing the accumulation of data to about 1/2000 as compared to procedures where the picture has to be scanned completely. For aerotriangulations we are using always the smallest pixle-size. The patches are stored to be used as correlation reference and may be hardcopied for documentation if wanted. We decided to produce the photomaps digitally. During the aerotriangulation the rectification points were selected and measured. For the photoplans we scanned only the required area of the selected photographs and the rectifications were calculated. The residual errors in the rectification points can be documented.

During the scanning process densitometric manipulations can be performed to enhance the contrast of the picture if necessary. Unwanted picture contents, such as reflections on water surfaces, can be cut out and replaced by other patches with no reflection. With the computation of the rectification the data-set was also geocoded, so the precise sheet size could be cut out on the monitor. The legend and sheet numbering was added by using some programs such as PICTURE PUBLISHER or CORAL DRAW. The final printing of the screened diapositive was done on a high precission laserplotter.

Several areas included also some large collective farms, which had to be reallocated to the previous owners. Our suggestion to produce digital orthophotos for these areas and use them for the resettle-ment operations was agreed upon by the client. Some 40 orthophotomaps were produced and used for this project. (figures 1 to 6)

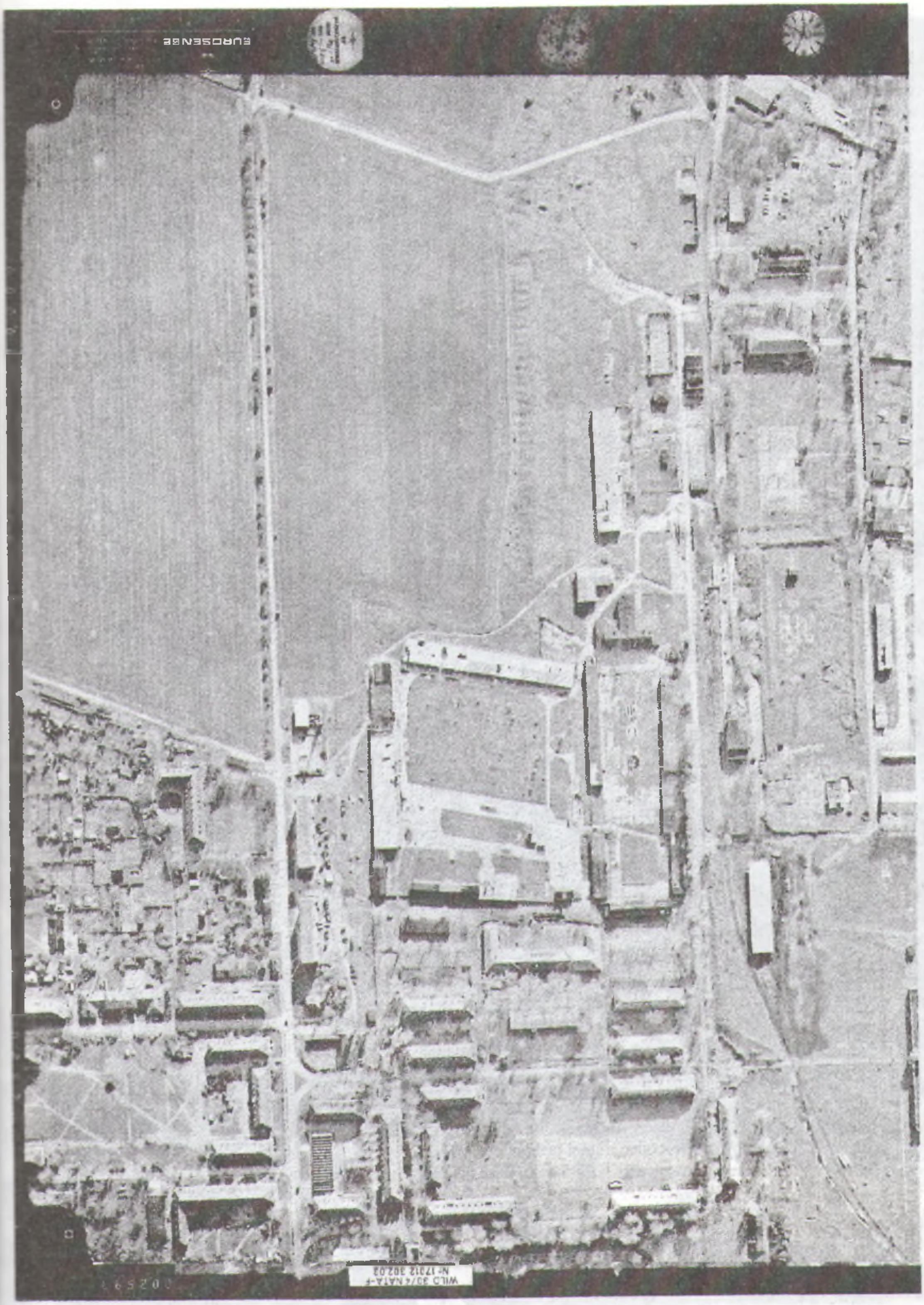

Figure 1: Original aerial photograph, scale 1: 3750, camera 30/23

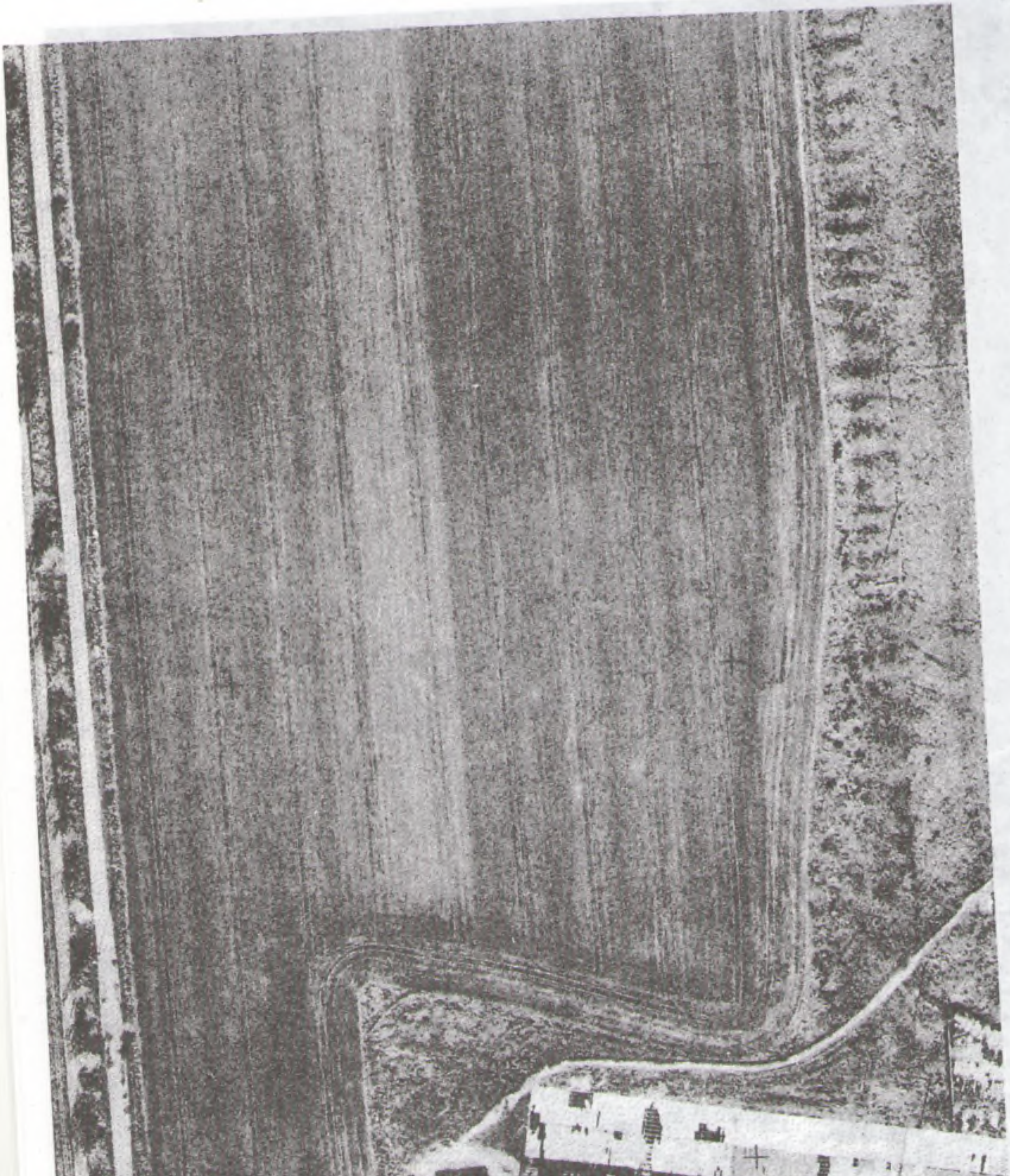

Figure 2: Hardcopy of geo-coded digital orthophoto, with 100 m - grid. Scale 1:1000. Base for multipurpose geo-information, base map for multipurpose use.

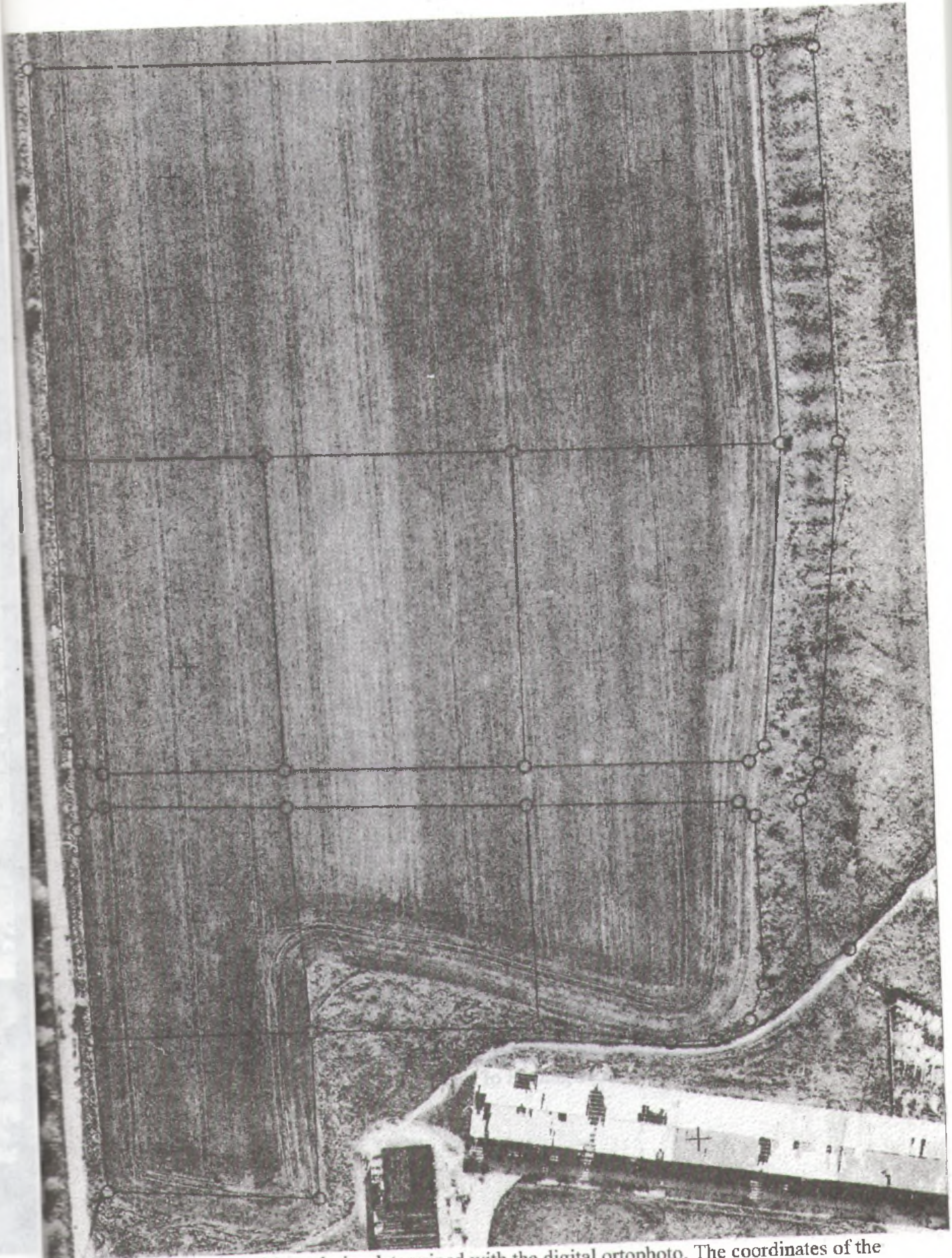

Figure 3: Cadastral boundaries determined with the digital ortophoto. The coordinates of the boundary-points were digitized on the monitor.

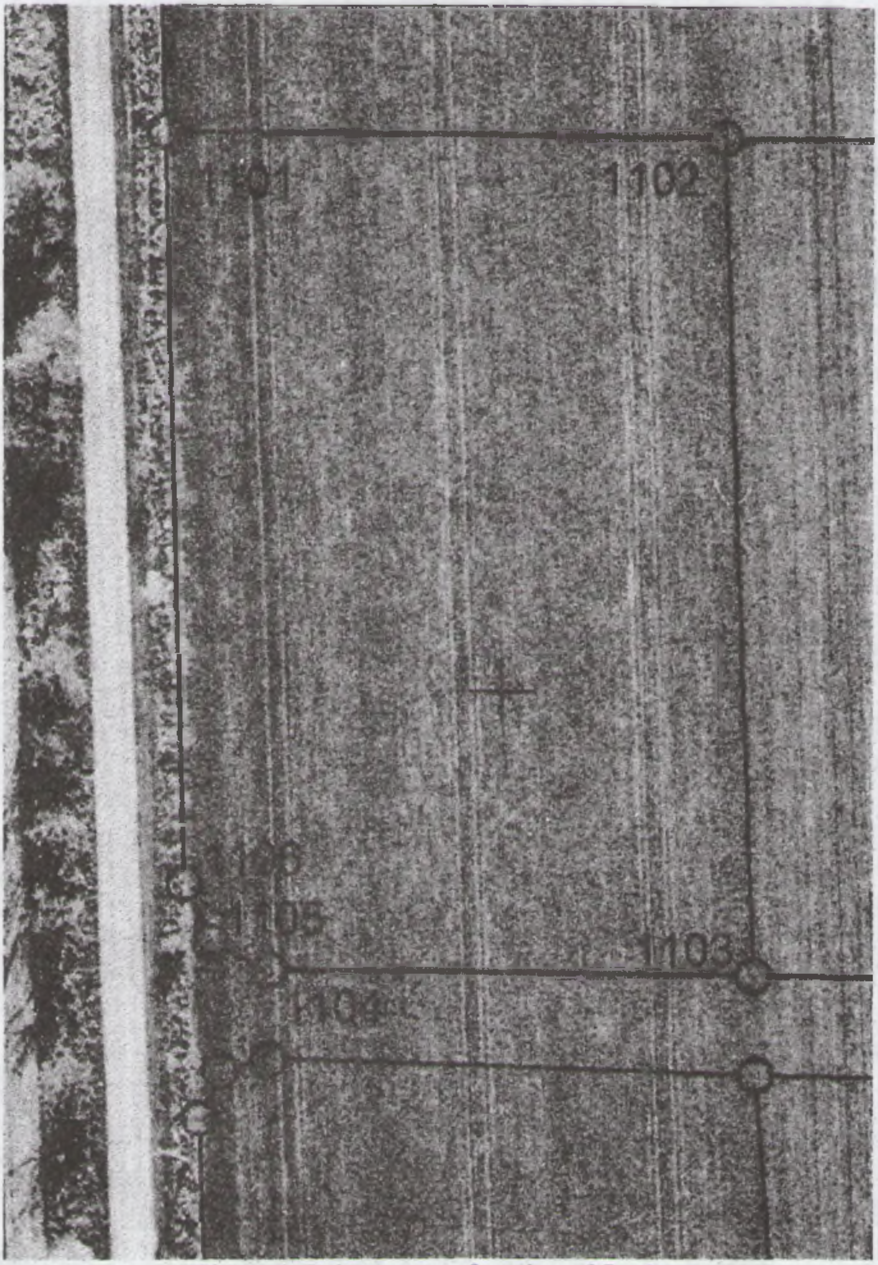

Figure 4: Enlargement of section of fig. 3.

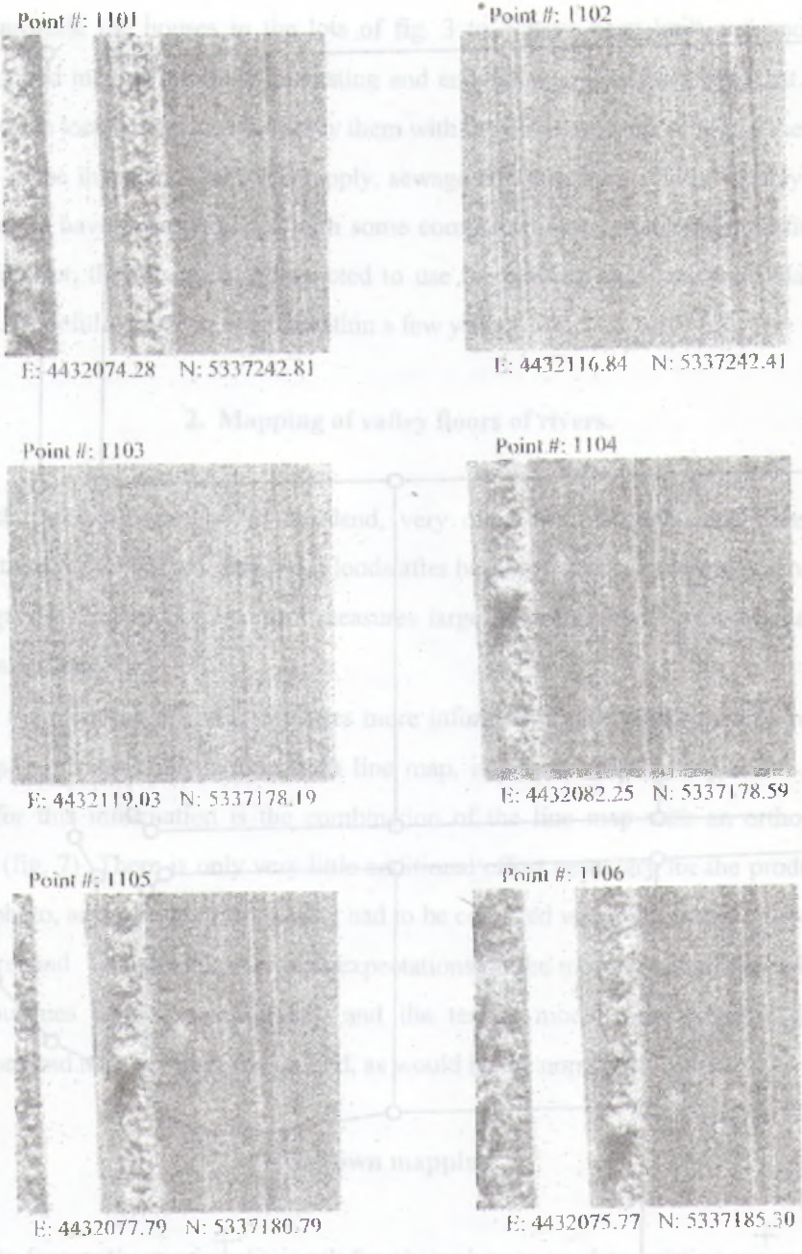

Figure 5: Determined boundery-points, with pointnumber and coordinates ref to fig. 3 and 4.

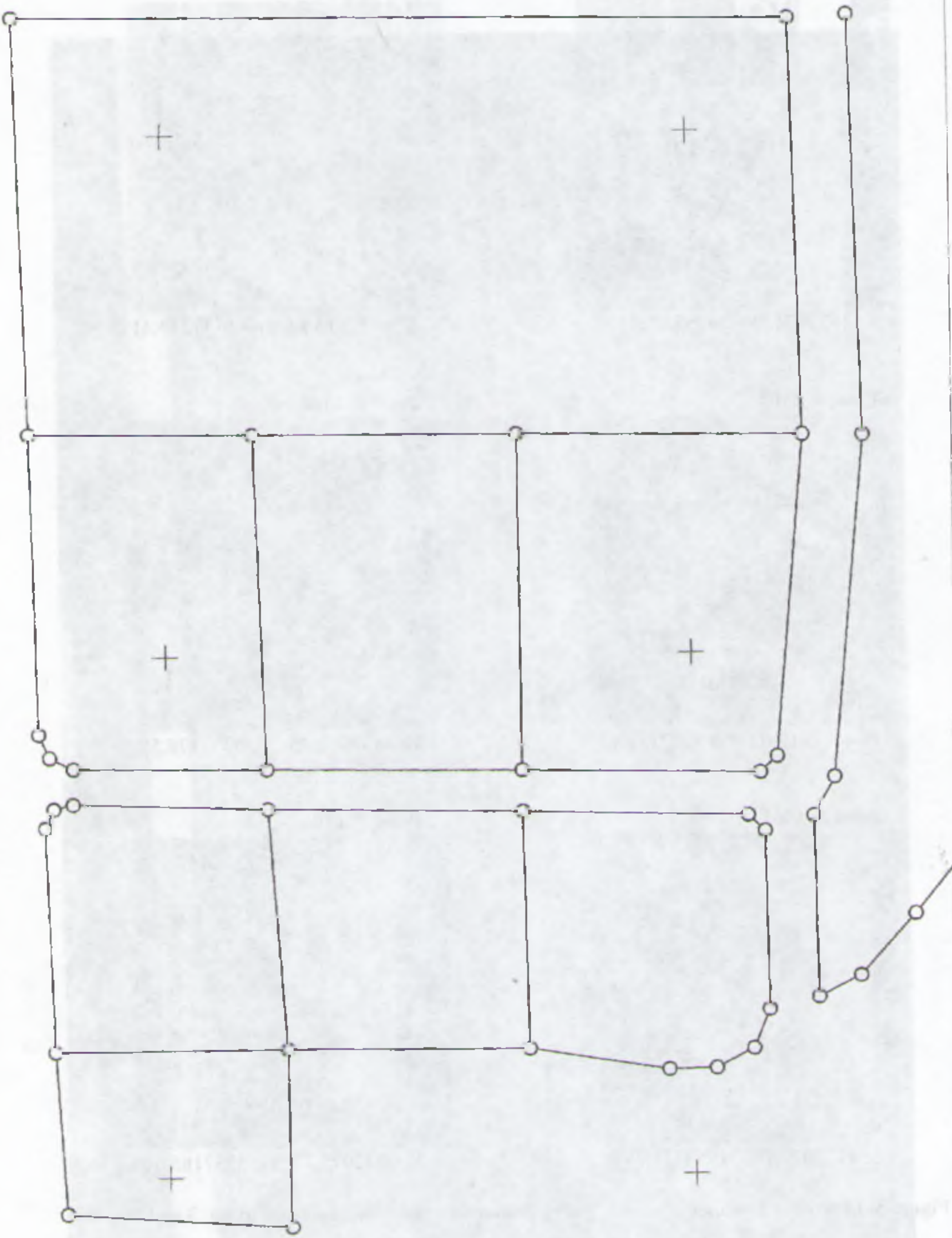

Figure 6: Cadastral map 1:1000, based on digital orthophoto.

Meanwhile the houses in the lots of fig. 3 to 5 have been built and people have already moved in. But the most interesting and encouraging sideeffect was, that we were asked by three local authorities to supply them with the maps as in fig. 6, to use them for the planning of the installation of watersupply, sewage and telephone. Unfortunately only the sewagepeople have been equipped with some computer hard and software, so they could use the data-set, the others were restricted to use the hardcopies as screened diapositives manually. Hopefully this will change within a few years.

2. Mapping of valley floors of rivers.

With the extensive use of the land, very often the retention capabilities of the catchment area of a river has chanced. Floods after heavier rainfalls have become noticeably more frequent. To plan flood-control measures large scale maps with very high altimetric accuracy are needed.

For the planning of these measures more information on the vegetation close to the riverbanks, as can readily be put into a line map, is very frequently requested. An ideal solution for this information is the combination of the line map with an orthophoto as underlay. (fig. 7) There is only very little additional effort necessary for the production of the orthophoto, as the height information had to be collected with high precision for the line map beforehand. To meet the very high expectations on the morphology of the valley floor the contourlines were drawn directly and the terrain model was extracted from the contourlines and not the other way around, as would be the normal procedure.

3. Town mapping.

Quite frequently municipalities ask for photoplans to up-date existing mapsystems or start to establish new ones. Here, till very recently, elevation differences in the areas were quite disturbing. But since some two years the digital orthophoto has overcome these hinderances and orthophotos are quite frequently ordered. Scales of 1:5000 and 1:1000 are more or less standard in Germany. Again the still lacking installation of some computer facilities in many municipalities is limiting the full exploitation of the digital orthophoto.

CONCLUSION

Digital photogrammetry and particularly digital orthophoto techniques are still relatively new and to a great extent not very much known outside of the specialists' circles who use and promote them.

Consequently their applications have by far not reached the distribution level which one would expect due to their inherent capacities and posibilities. But time will heal this within a very short period, especially if the progress in computer technology will expand as at the present rate.

There is however one more unfavourable and restraining current within the surveying circles and institutions.

Especially in the rich and wellmapped countries, entrenched and well established authorities are quite restrictive, be it by tradition, by law or only by unwillingness, to accept new techniques, for the fear of loosing importance and influence within the hierarchy of government institutions. Thus terrestrial surveymethods in legal survey are still used quite exclusively. GPS-techniques have opened up that restrictive trend to some extent.

The nearly religious reverence which is paid to the public acceptation of the boundary marker, or we may here use the German word "Grenzstein" and the officiality of the cadastral maps, in favour of the coordinate of the boundarypoint is well entreched in institutions and people, who are concerned with legal or cadastral surveys. However to be fair, one has to admit, that in the very densely populated areas of the "rich, wellmapped" countries, the very small parcel sizes and the outrageously high land value, which leads to an extraordinary extreme exploitation of the parcel sizes, cm-accuracies are absolutely essential. Here digital orthophoto techniques are not readily applicable.

But even in these densely populated countries, there do exist large areas which would be well suitable for digital orthophoto techniques and enormous chances are missed to complete or update existing cadastral mapsystems by clinging to entrenched and antiquated methods of legal surveying. One more very pressing application would be the use of digital

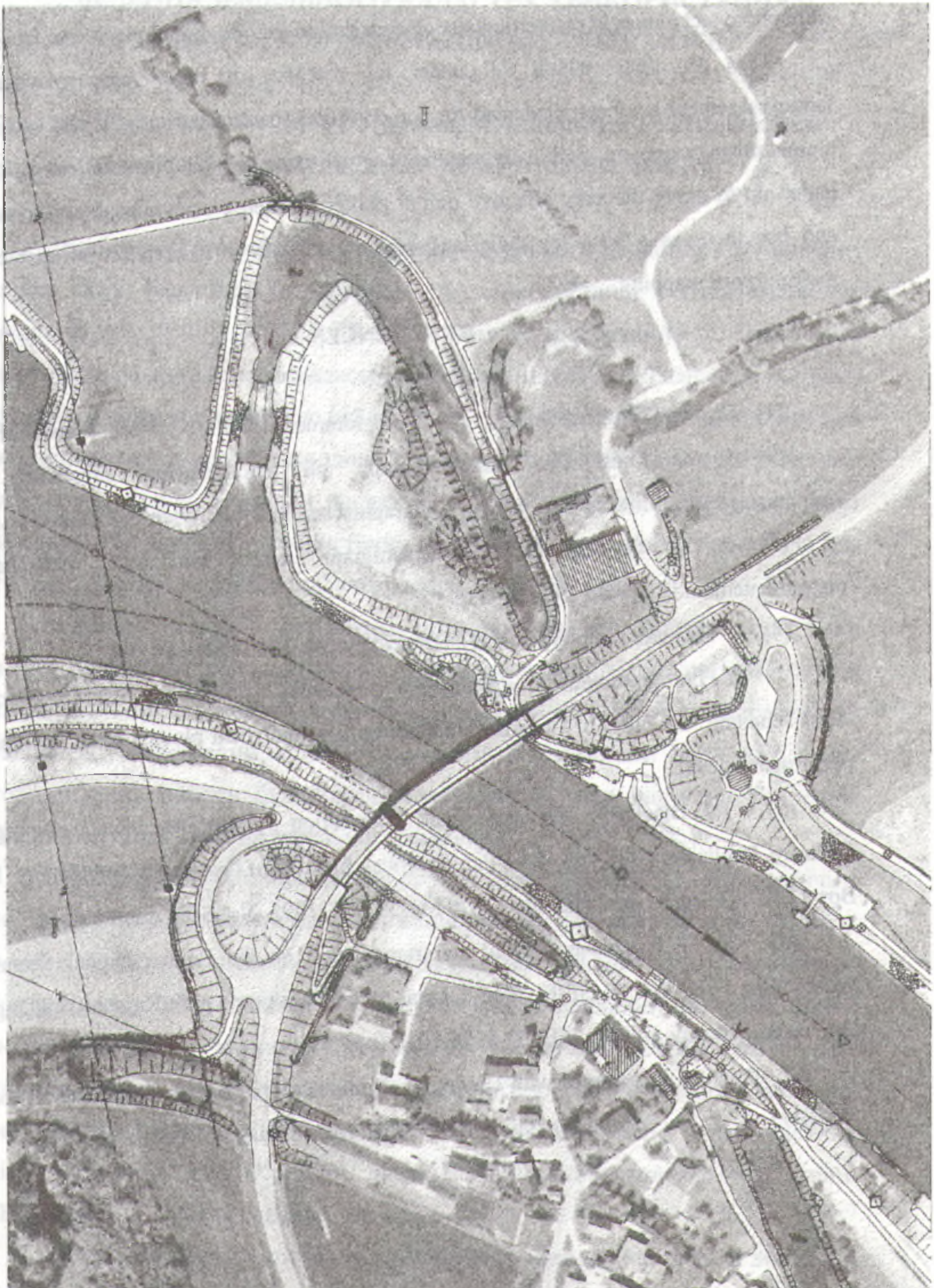

Figure 7: Section of Valley floor mapping with underlay of digital orthophoto.

orthophoto techniques in converting analog cadastral maps into digital maps and data-sets.

Thus all areas, which fall under the category of these regions, where the landmanagement has been neglected for some 40-odd years or more, be it just because of simple mismanagement, politically prevented actualisation or even planned destruction, are called up to apply the very effective digital photogrammetric and orthophoto techniques, and use them as a base for their land registration and as a base for all subsequent multipurpose mapping.

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