Evaluation of Historical Aerial Images in a Landslide Area

ADRIAN WENG[1], FRANZISKA WILD[2] & EBERHARD GÜLCH[3]

Abstract: Cadastral photogrammetry was approved in Baden-Württemberg in 1971 and was used in the 1970s and 1980s to determine coordinates for the real estate cadastre from land consolidation areas. In these former land consolidation areas, the boundary and survey points of the real estate cadastre today have an inferior coordinate quality. In the Eberstadt I R procedure from 1972 a photogrammetric re-evaluation has been carried out 50 years after Prof. Fritz Ackermanns early innovations in cadastral photogrammetry with the aim of determining final UTM coordinates.
A workflow for photogrammetric re-evaluation of historical aerial images was being developed by the surveyor's office Heilbronn and applied in the Eberstadt I R project. In addition, the known landslide has been investigated. This involves comparing a current terrain model to a historical terrain model, which results in elevation differences for the landslide area. In the Eberstadt I R procedure, it was thus possible to locate a clear break-off edge of the landslide and to precisely delimit an 87,500 m² landslide area with changes in elevation.

1 Introduction

Since 2021 the Surveying Office of the county of Heilbronn develops methods to evaluate historical aerial images which were used for land consolidation in the 70s and 80s of the last century and were also part of Prof. Fritz Ackermanns early innovations in cadastral photogrammetry. Cadastral photogrammetry has been applied to scope with the huge number of new real estate cadastre- and surveying points in the land consolidation projects. In the state of Baden-Württemberg cadastral photogrammetry has been applied between 1970 and 1983 in 142 project areas. In the county of Heilbronn approximately 60 historical projects for vineyard clearing are known. About 6.000 to 7.000 surveying points have been determined as well as between 80.000 and 100.000 real estate boundary points. These points have been determined in the former Soldner coordinates of the former states of Württemberg and Baden. Due to the geodetic network stresses they are only available in the lower coordinate quality level UTM-G (graphical coordinates) as described by (WILD-PFEIFFER 2018).
The aim of the recent developments at the Heilbronn Surveying Office is to generate cadastre-compliant state coordinates by re-evaluating the historical aerial images. This requires not only the aerial images and historical camera and flight data, but also control points signalized at the time, whose markings are still unchanged today and can thus be determined on site by surveying.
The project area Eberstadt I R has been selected, as in the western part of the area landslides are suspected. These landslides are known from past surveys of the Heilbronn survey office in this

[1] Siemensstraße 240, D-53121 Bonn, Germany, E-Mail: adrian.weng@web.de
[2] Vermessungsamt am Landratsamt Heilbronn, Lerchenstraße 40, D-74072 Heilbronn, E-Mail: franziska.wild@landratsamt-heilbronn.de
[3] Stuttgart University of Applied Sciences (HFT Stuttgart), Center for Geodesy and Geoinformatics, Schellingstraße 24, D-70174 Stuttgart, Germany, E-Mail: eberhard.guelch@hft-stuttgart.de

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area, since extreme network stresses were repeatedly noticed. Some of the landslides amount to more than 2 meters downslope and can even be recognized in current orthophotos. However, the extent and exact area of the landslides is not known and was supposed to be clearly defined by the bachelor thesis of the principal author.
For a new evaluation, the analogue aerial photos must be scanned with an aerial photogrammetric scanner and be available digitally. In addition, a sufficient number of control points must be available, which are signalized in the aerial images and determined by surveying in the field. Additional data, such as camera calibration, has to be collected for the initial situation. The re-evaluation of the aerial images is performed with Erdas Imagine. After the interior orientation, an aerial triangulation is evaluated to subsequently calculate coordinates for signalized points. A specified accuracy of the coordinates has to be achieved that they are suitable for transfer to the real estate cadastre. For the detection of the landslide area further photogrammetric methods and software modules for the processing of point clouds are used.

2 Development of Cadastral Photogrammetry in the State of Baden-Württemberg

In order to understand the background of cadastral photogrammetry, the chronological classification is especially important. The development of cadastral photogrammetry in Baden-Württemberg is shown in Figure 1.
Before 1960: Until 1920, the application of photogrammetry was mostly focused on graphical results, with exceptions. In the period between 1925 and 1960, instrumental developments became the main focus. Photogrammetric tasks such as aerial triangulation or point determination were solved graphically or mechanically where possible (ACKERMANN 1973).
Between 1960 and 1970: The shift to numerical photogrammetry began around 1960. Causes for the shift were particularly strong developments in the area of computer systems, data processing and the corresponding equipment developments for the measurement of model coordinates. In addition, new tasks arose for photogrammetry. For example, cadastral photogrammetry in Baden-Württemberg came into focus, which demanded high accuracies. Nevertheless, the introduction of numerical methods stagnated for a decade. The transition to the technical possibilities progressed only slowly and the factors of hardware and software components were misjudged.
However, aerial triangulation and photogrammetric orientation were extensively tested during this period. Improved hardware (cameras, films, measuring instruments) and programs for computational block adjustment allowed this development to gain momentum (ACKERMANN 1973).
Between 1970 and 1973: At this point, mainly the development of cadastral photogrammetry in Baden-Württemberg is in focus, which was primarily driven by the Institute for Photogrammetry at the University of Stuttgart. In parallel, a similar development took place at other places and in other federal states.
In this phase, the achievable accuracy and the economic efficiency of cadastral photogrammetry compared to conventional methods were discussed. The advantages of cadastral photogrammetry could be exploited especially in the application in land consolidation areas. As control points,

mostly survey points from the already existing official fixed point field could be used. In addition, a large number of new points had to be determined in the land consolidation areas (KRAUS 1973). In the meantime, the availability and the capacities of the computer systems had increased considerably. Thus, especially the program developments were advanced. At the Institute of Photogrammetry, the programs PAT-M-4 (position adjustment) and subsequently PAT-M-43 (spatial adjustment) were developed, which found application especially in cadastral photogrammetry. Both programs were used for block adjustment according to independent models. In parallel, other methods and programs were developed which were intended to increase the accuracy of point determination (ACKERMANN 1973).
In addition to the block adjustment according to independent models, the method of bundle block adjustment was already investigated at that time. For the adjustment according to independent models, however, more evaluation devices were available in practice and the bundle block adjustment proved to be not as accurate as expected for the time being. Thus, adjustment by independent models was preferred and became widespread in practical applications. Bundle block adjustment was not to become relevant again until a decade later (ACKERMANN 1973).
In January 1971, a course on numerical photogrammetry was held at the Technical Academy in Esslingen. Theoretical and practical contents, as well as the developed software system were presented to the public. In further publications, the potential of numerical photogrammetry was recognized and block adjustment and point determination were judged to be accurate and reliable. As a result, cadastral photogrammetry was approved as a method for determining point coordinates in October 1971. This was realized by the administrative regulation VVPhoto and the technical guideline TRPhoto, which came into force on October 14, 1971. Since then, cadastral photogrammetry has been used regularly for land consolidation or road closure surveys.
Between 1970 and 1973, photogrammetric point determination by block adjustment was widely applied and tested. A large proportion of these projects involved practical applications in cadastral photogrammetry for land consolidation procedures. Thus, the responsible State Office for Land Consolidation and Settlement had firmly introduced appropriate evaluation equipment and the photogrammetric block method. At that time, the state of numerical photogrammetry and the block adjustment used according to independent models were considered successful and particularly reliable (ACKERMANN 1985).
For the application in the real estate cadastre, the double survey or a hybrid solution was available for selection. In the hybrid solution, the coordinates are created from photogrammetric and terrestrial observations. The decision was made in favour of the hybrid solution, as this was expected to result in higher neighbourhood fidelity. In this case, span dimensions as well as other geometric conditions were introduced into the adjustment, which were recorded terrestrially between the signalized new points. The so-called "span adjustment" was able to establish the neighbourhood fidelity within the area, which is important in the real estate cadastre. Another advantage was that the provisional coordinates could be checked and gross errors, for example in signalization, could be detected. During the terrestrial recording of the span dimensions, points that were not visible from the air could be recorded at the same time. The terrestrially recorded elements made it possible to determine these points later by calculation. In addition to span

adjustment, least squares interpolation was introduced to increase accuracy. This reduces network stresses and the residual errors at the control points (Ackermann 1973).

The period between 1970 and 1973 can be considered as the development and introduction phase. Between 1970 and 1983, cadastral photogrammetry has been applied in 142 cadastral surveying procedures in Baden-Württemberg. In this operational phase the development of the existing methods was reviewed and advanced (ACKERMANN 1985; WALDBAUER 1985a; WALDBAUER 1985b).

After 1983: At that time, it became known that clear tensions exist in the procedures from the seventies. Accordingly, the block adjustment according to independent models yielded very good internal accuracies, but did not correspond to the theoretical accuracies due to systematic image errors. From 1983 onwards, the introduction of bundle block adjustment and improvements of the evaluation equipment demonstrably improved the accuracy significantly. From then on, model coordinates were no longer measured. Instead, the modern analytical evaluation instrument Planicomp C100 was available for the measurement of image coordinates (ACKERMANN 1985).

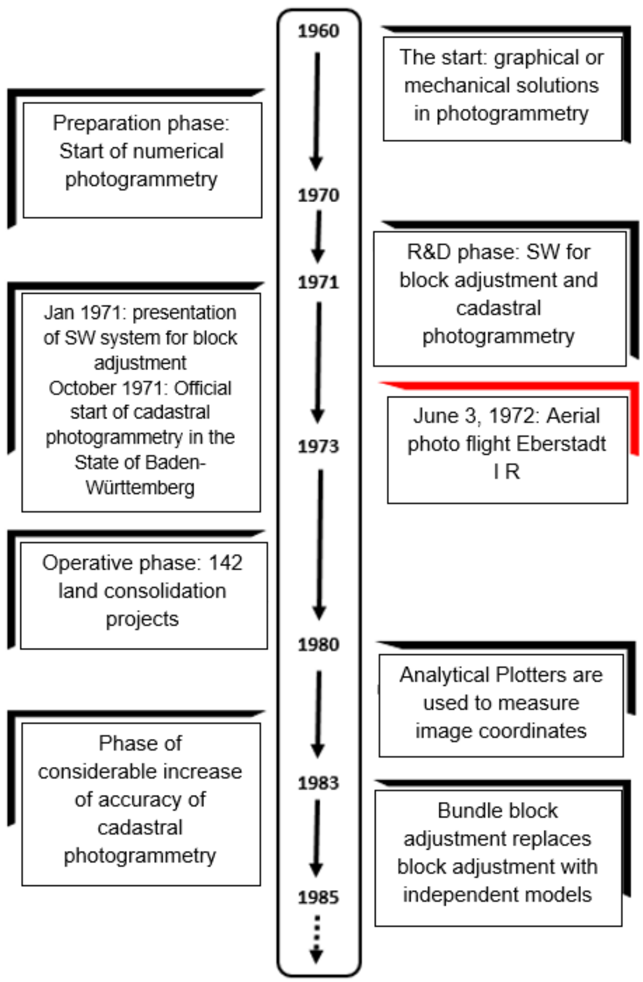

Fig. 1: Timeline of development of Cadastral Photogrammetry in the State of Baden-Württemberg

3 Land consolidation project Eberstadt I R

3.1 Area description

The former vineyard consolidation area Eberstadt I R is located in the district of Heilbronn north of the municipality of Eberstadt. The abbreviation "I R" stands for the first vineyard consolidation procedure in this district.

The Eberstadt I R land consolidation procedure was ordered in 1967. The area of the land consolidation is 181 ha, of which 113 ha are forest and 44 ha are vineyards. In 1977, the final determination of the land consolidation took place.

In order to transfer the coordinates of the new boundaries into the real estate cadastre, the method of cadastral photogrammetry was chosen in this land consolidation procedure and an aerial photo flight was carried out to determine the coordinates. However, no information is available on the aerial photo evaluation, block adjustment and point determination at that time. As described in chapter 2, however, it can be assumed on the basis of the image flight date that the block adjustment was used according to the method of independent models.

3.2 Landslide

Landslides, as they occur at the Eberfirst, are known in the whole Württemberg Keuperbergland, especially east of the Neckar. Responsible for the landslides at the Eberfirst are glacial large-scale landslides which occur in the border area between gypsum keuper and reed sandstone. Thereby, a smooth landslide surface is present between two different geological layers. Glacial large-scale landslides are actually old, closed landslides that can be reactivated by human intervention and/or by special climatic conditions. On the Eberfirst, soil relocation took place as part of the 1970 vineyard consolidation, which included filling and levelling many blades. Due to this intervention and heavy rainfall, the slope began to slide again, (LEO-BW 2022; LGRB 2022a; LGRB 2022b).

Fig. 2: Visible break-off edge (Drone image by Heilbronn Surveying office)

The landslides are limited to the western part of the Eberfirst vineyard. The earth movements are not only known to the surveyor's office, but also take on dimensions that make them noticeable to property owners and residents. These are noticeable by cracks and unevenness in the asphalt of the paths or by visible break-off edges in the terrain and affect the cultivators of the vineyards (Figure 2).

3.3 Historical aerial photo flight

The aerial photo flight in the land consolidation procedure Eberstadt I R was carried out on June 3, 1972. In order to cover the area sufficiently, 16 aerial images were taken in one flight strip. The individual aerial images of the flight strip have a coverage of about 80 percent. The flight altitude of the aerial survey is given as 760 m above ground, resulting in an image scale of 1:5000. The image flight was carried out by the company Geoplana with a film-camera RC8 of the manufacturer Wild Heerbrugg. The lens used has a camera constant of 152.55 mm. The camera calibration protocol of May 31, 1972 is known, so that the calibration values can be used for the new evaluation. Figure 3 shows an aerial image from the Eberstadt I R image flight. At that time, the aerial photos were exposed in the standardized format of 23 × 23 cm on black-and-white film rolls.

However, as an additional difficulty in the evaluation of the land consolidation procedure Eberstadt I R the signalization sketches are no longer available. This means a more difficult assignment of the signalized points in the aerial images, as well as missing span dimensions for the control of the generated coordinates.

Fig. 3: Aerial image from the aerial photo flight Eberstadt I R scanned at Heilbronn Surveying office

4 Workflows for re-evaluation of historical aerial images

Two basic workflows have been used for the re-evaluation: a currently developed workflow for cadastral photogrammetry and a workflow for the detection of landslides. The basic features are presented here and the empirical tests in the Eberstadt I R procedure are evaluated in chapter 5.

4.1 Workflow Cadastral Photogrammetry

In order to re-evaluate the former land consolidation areas using cadastral photogrammetry methods, a uniform workflow is currently developed at the Heilbronn survey office. The processing is divided into several steps. Based on a thorough project preparation and the digitization of the analogue aerial images, suitable control points have to be selected and identified and measured in the field. After an interior orientation of the images using the camera calibration information and an aerial triangulation the basis is prepared for the point determination of ground control-, boundary- and polygon points. These points have to be checked to be finally transferred to the real estate cadastre.

4.2 New aerial triangulation for project Eberstadt I R

As a basis for the landslide detection according to chapter 4.3 the results of the new aerial triangulation for project Eberstadt I R are described below.

4.2.1 Scanning of aerial images

The aerial images have been digitized with an UltraScan5000 of Vexcel with a pixel size of 10 µm × 10 µm.

4.2.2 Measurement of control points

For the necessary control points for the photogrammetric evaluation, boundary and polygon points have been recorded in Eberstadt on three field service days. With the previous UTM-G coordinates the points have been staked out and uncovered. The control points are chosen to be evenly distributed in and around the former land consolidation area. No control points were recorded in the suspected landslide area, since there is no longer any positional identity there. A total of 36 ground control points have been recorded, of which 20 are polygon points and 16 are boundary points (Figure 4).

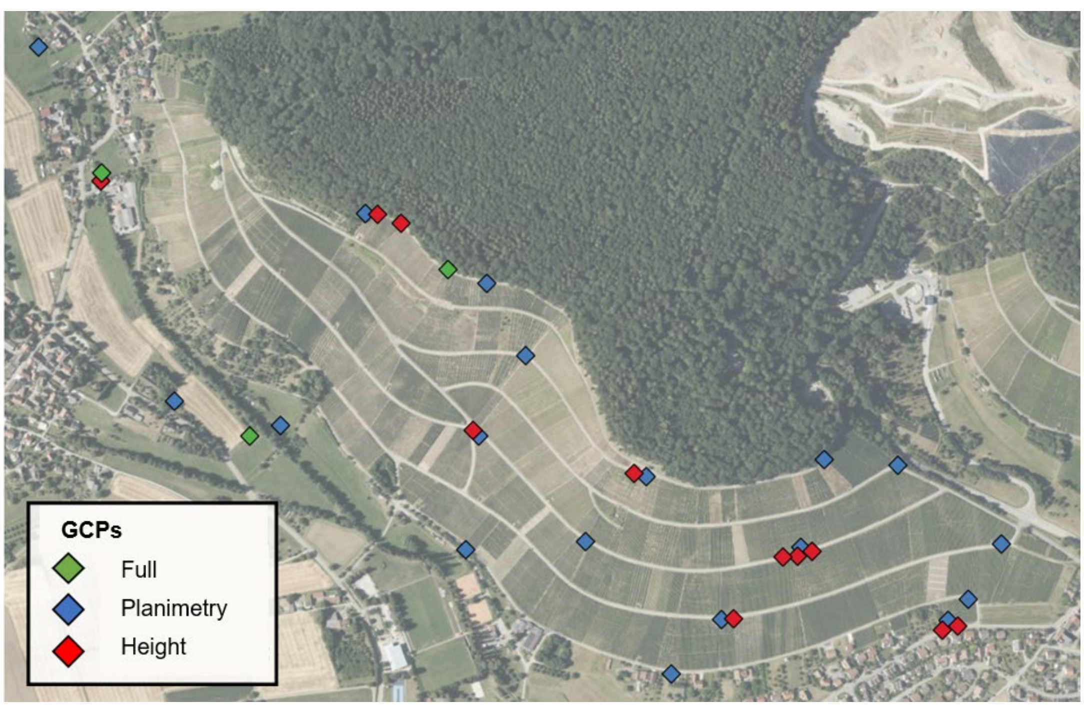

Fig. 4: Distribution of ground control points

4.2.3 Aerial triangulation

The RMSE (Root-mean-square deviation) value for the fiducial measurements was in the range of 0.3 to 0.7 pixel. 476 tie points were used. A total of 33 GCP (Ground Control Points) were used. Of these, 3 can be used as full, 18 as planimetric and 12 as height GCP. The distribution of control points is shown in Figure 4, with the control point types distinguished by color. The RMSE values in X/Y/Z for the ground control points were 0.0344 m / 0.0274m / 0.0282 m respectively. The image measurement accuracy at GCPs was for x/y 0.2956 pixel /0.3297 pixel respectively.
During the photogrammetric point determination, new coordinates were calculated for 1326 boundary and polygon points. On average, a point was determined with five individual measurements.

4.3 Workflow for detecting landslides

The basic idea of detecting landslides is to compare a current and a historical terrain model. If the terrain has changed in the meantime, for example due to landslides, this change will show up when comparing the two terrain models. The current terrain is represented by the digital terrain model DTM1 of the national survey. The historical terrain model is derived from the available aerial images and represents the condition in 1972. For this purpose, the workflow shown in Figure 5 was developed, which consists of seven processing steps. The initial situation is that the historical images are oriented by means of an aerial triangulation. A point cloud is derived from the historical aerial images and is further processed with classifications and filtering. If the processed point cloud contains only the relevant ground points, it can be considered as a historical terrain model. The Erdas Imagine and CloudCompare software is used to perform the developed workflow.

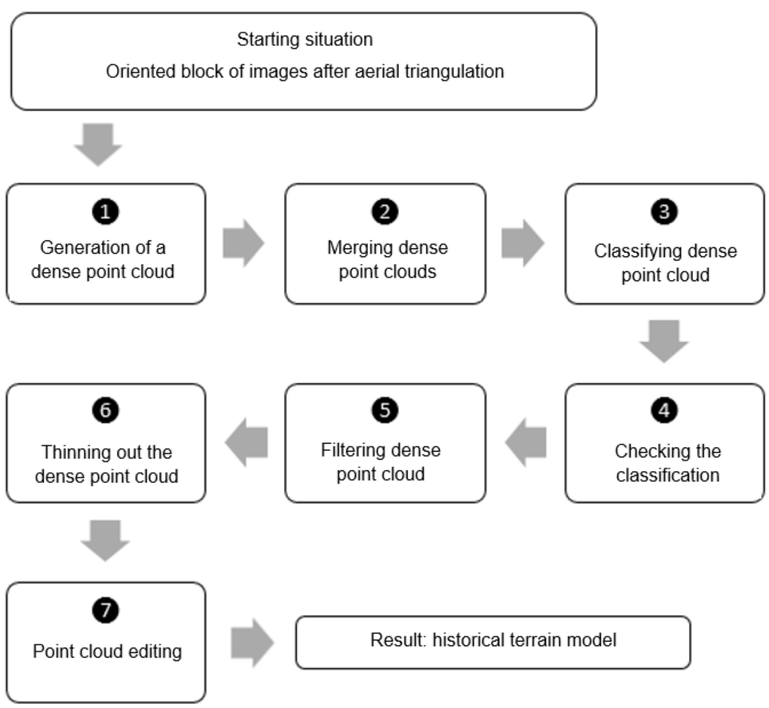

Fig. 5: Workflow for the derivation of the historical terrain model

5 Empirical tests and evaluations in the land consolidation procedure Eberstadt I R

5.1 Accuracy and control

Table 1 compares parameters of the aerial triangulation of four different re-evaluations of former land consolidation procedures. All four test procedures have been evaluated by the surveyor's office Heilbronn with the same workflow from chapter 4. The compared residual errors at the control points are in a similar spectrum. The procedure Eberstadt I R, which is affected by landslides, does not have higher residual errors at the control points too.
It is important to note that there must be a sufficient occupation of planimetric and/or full control points, especially at block edges (RAHN 2021).

Tab. 1: Comparison of aerial triangulation results with 3 other land consolidation projects

Procedure		Beilstein - Etzlenswenden	Flein - Schenkenhalde	Nordheim - IX R	Eberstadt - I R
Residuals [m]	X	0,0214	0,0273	0,0323	0,0344
	Y	0,0201	0,0278	0,0456	0,0274
	Z	0,0195	0,0390	0,0441	0,0282
Total RMSE [Pixel]		0,4771	0,4110	0,4588	0,3859

With a complex adjustment the relative position of the generated coordinates can be controlled. The Soldner coordinates of the former determination and the UTM coordinates of the new determination are compared. As a result of the statistical check a protocol and an overview plan are generated. In the protocol UTM and Soldner coordinates of identical points are compared. Possible gross errors are statistically indicated in the protocol. These possible gross errors are also displayed in the overview plan. If a point vector is conspicuously long and at the same time points in a different direction than the neighboring point vectors, there is a possible gross error. The gross error may have occurred during the determination at that time or during the determination today. In case of a possible gross error, further investigations are therefore necessary. The gross error can be narrowed down by a GNSS control survey or by a span control.
If the vectors point locally (along the agricultural road) in the same direction and have a similar length as shown in Figure 6, a homogeneous determination is present. For the most part, the newly determined points in the Eberstadt I R procedure have been determined with good neighbourhood fidelity. In the area of the landslide no different behaviour is recognizable between neighbouring points. By checking with the complex adjustment, however, no statements can be made about the accuracy of the absolute point position.

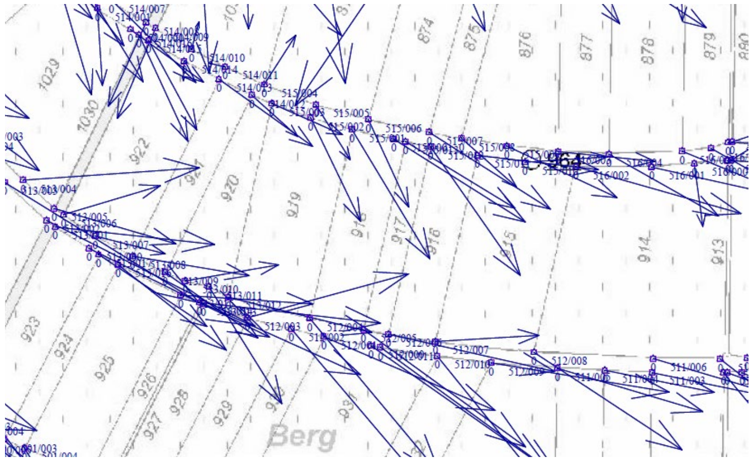

Fig. 6: Part of the result of the complex adjustment result with point vectors

After coordinates for the new points have been generated by photogrammetry, these are to be checked by means of random samples in the field comparison. For this purpose, the generated coordinates are loaded into DAVID-kaRIBik. In the field, a boundary check of the corresponding boundary point is performed with a GNSS survey. With this approach 47 boundary points have been recorded over the area. After evaluation of the measurement data, the positional difference between the coordinates from the redetermination and the coordinates of the actual position can be calculated.

According to the current administrative regulation for the execution of real estate surveys (VwVLV 2022), state coordinates of a boundary point may have a linear deviation of 8 cm when verified. At the time of the survey in 1972, the Administrative Regulations on Error Limits for Cadastral Surveys (VVFEHLERGRENZEN 1971) applied. According to this, a maximum deviation of 8 cm was permissible when checking a boundary point. The extent to which the regulation of that time can also be applied to today's evaluation has not been conclusively clarified.

Of the 47 boundary points checked in a first investigation 30 points possess a deviation of better than 8 cm, which is 64 percent. It should be mentioned here that better values were seen in previous test procedures.

It is noticeable that the Eberstadt I R procedure is larger than the previous procedures and that significantly more new points were determined. It could therefore be possible that in a larger area increased stresses occur, which cannot be completely compensated by the aerial triangulation. Thus, remaining residual errors could possibly also have a negative effect on the coordinates of the redetermination. In addition, it must be noted that the Eberstadt I R procedure was flown and evaluated in 1972. The procedures of Nordheim - IX R and Flein – Schenkenhalde were carried out much later. As described in chapter 2, cadastral photogrammetry was not fully developed at the beginning and the accuracy achieved in practice was not significantly increased until 1980. Thus, it is conceivable that there are systematic errors in the methods and data basis of that time that remain in the coordinates of today's evaluation.

5.2 Landslide area

By using the workflow developed in chapter 4.3, a clear landslide area could be detected. The detected landslide area also coincides with terrain changes visible on site. As assumed, this area is located in the western part of the land consolidation procedure and starts with a clear break-off edge, which is located about 272 m above sea level. This is located along the red colouring in Figure 7, is approximately 280 meters long, and is also clearly visible in the terrain. In the area of the break-off edge, the current terrain has subsided by three to five meters compared to its condition in 1972. Below the break-off edge is a 30 to 40 meter wide strip that has slumped one to two meters due to the landslide. This is followed by a transition area where no elevation change was detected. Below this is the area coloured blue in Figure 7. Here, too, a landslide is present, whereby the current ground level is about one meter higher than the original terrain. The volume of soil that has slipped in the area of the break-off edge thus accumulates again further down the slope. In total, a landslide area of approximately 87,500 m² can be clearly detected with the developed workflow.

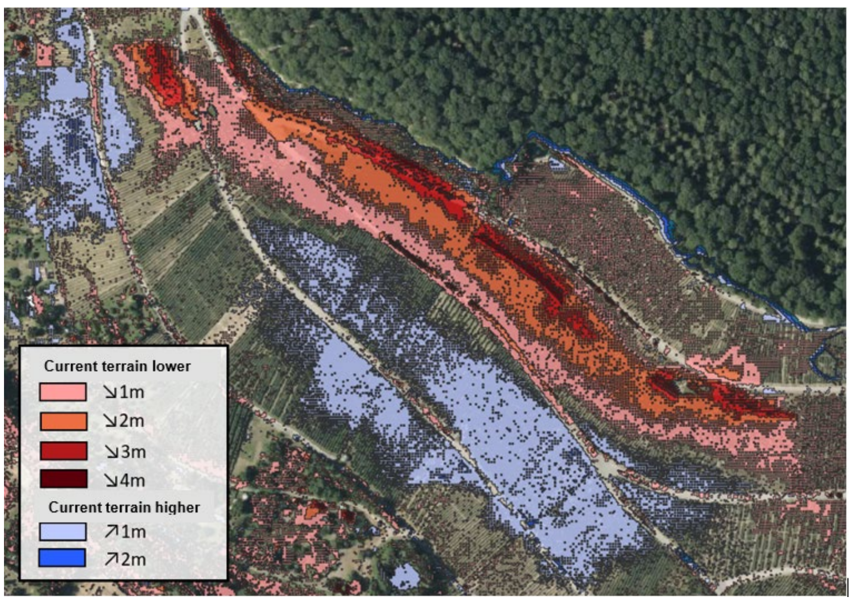

Fig. 7: Detected landslide area and changes in heights compared to 1972

In order to compare the absolute terrain heights of today and back then, it is suitable to compare them in a terrain profile. As an example, a terrain profile is shown in Figure 8. The selected area is particularly suitable for comparison because significant terrain changes are assumed locally there. The terrain changes can therefore also be confirmed by a terrain profile as visible in Figure 8. The original terrain of 1972 (green) has a uniform slope. Between 70 and 80 meters, the slope of the terrain deviates because a path is located there. In comparison, today's terrain (pink) is not so uniform. Within the first 50 meters, the present terrain is clearly indented and is below the original terrain. In this slide area, the terrain has slumped up to three meters in elevation. In the subsequent area, the present terrain is mostly one to two meters above the original terrain. It is also visible that the named road is now located further downslope and must also have been affected by the landslide.

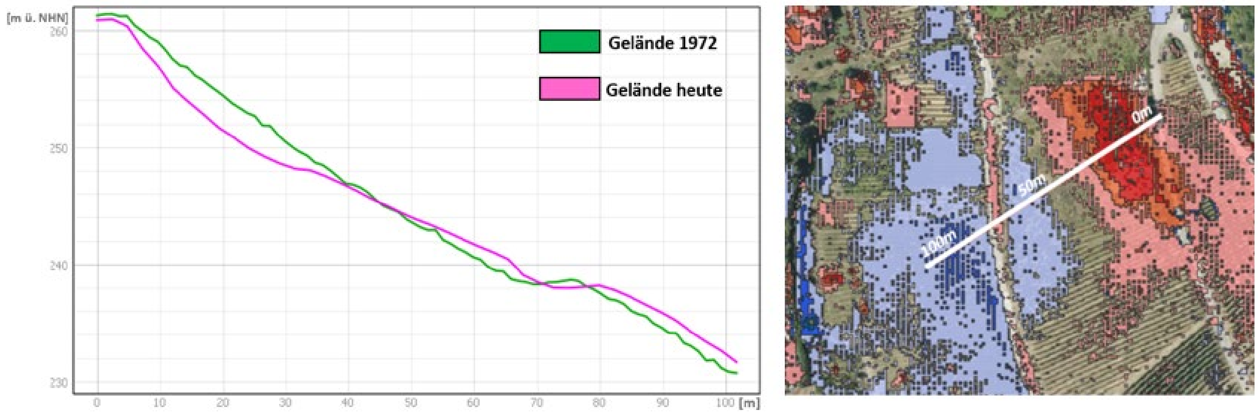

Fig. 8: Cross-section profile of landslide

The developed workflow can only detect landslides that are related to a change in elevation in the terrain. However, landslides can also occur without a change in the elevation of the terrain. For this, the terrain must have a uniform slope and the landslide must not deform the terrain at the surface. If no changes in elevation and terrain deformation occur in the landslide, there will be no changes in the digital terrain model. Therefore, in this case, landslide cannot be detected by the developed workflow. Figure 9 sketches this situation, where the landslide can be detected in use case 1. In use case 2, the landslide cannot be detected by the developed workflow, which was partly the case in the project area. It was possible to precisely delimit an 87,500 m² landslide area with changes in elevation. A maximal height difference of 5 m and a maximal planimetric change of 2.7 m could be found.

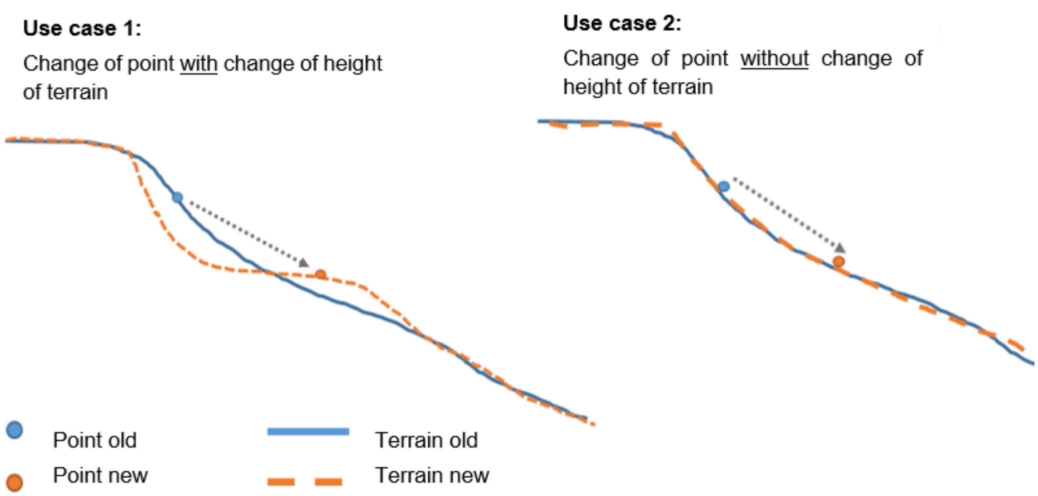

Fig. 9: Two use cases for landslides. Case 1 can be determined by the developed procedure

By comparing the orthophoto with the boundaries of the property map or by comparing site coordinates, the landslide can nevertheless be delineated fairly accurately. The total area of the landslide is approximately 141,000 m², which is approximately 32 percent of the total area.

6 Conclusions

In conclusion, it can be stated that the photogrammetric re-evaluation of the former land consolidation area could be carried out successfully after exactly 50 years. The workflow being developed by the surveyor's office Heilbronn could be applied despite the existing landslide area. The aerial triangulation could be carried out successfully during the re-evaluation. A sufficient number of control points were available, which could also cover the landslide area. The residual errors at the control points used also remained within the expected range. They are comparable with the empirical values from previous test procedures.

In a complex adjustment, the Soldner coordinates of the former determination have been compared with the UTM coordinates of the present determination. This is to check the homogeneity of the photogrammetric determination. During the comparison of the coordinates a neighbourhood-faithful determination was predominantly proven along the ways, whereby outliers were detected only sporadically.

A workflow could be developed that can detect landslides by changes in the terrain. This involves comparing a current terrain model with a historical terrain model. The most current terrain model can be obtained from the State Office for Geoinformation and Land Development. The historical terrain model is generated from the historical aerial images after aerotriangulation has been performed. A point cloud is generated from the historical aerial images, which is then classified and filtered. If the processed point cloud contains only the relevant ground points it can be considered as a historical terrain model. When comparing the two terrain models, elevation differences can be coloured by area and thus the landslide can be visualized. The landslide can also be viewed in a terrain profile. In the Eberstadt I R procedure, it was thus possible to locate a clear break-off edge of the landslide. It was also possible to precisely delimit an 87,500 m² landslide area with changes in elevation. In the Eberstadt I R procedure, however, there are also landslides without significant changes in elevation, which can only be detected by other methods. The comparison of the orthophoto with the boundaries of the real estate cadastre or the comparison of position coordinates can complement the developed workflow in the detection of landslides.

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