Digital Landscape Documentation: A Case Study on How to Create Useful Geographic Information

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Key words: GPS, GIS, Digital Terrain Model, Animation, Internet/Web.

SUMMARY

Digital landscape documentation is always needed as a base for the management of spatial data of all kind. Thus, the processes which lead to a reliable spatial data base have to be analysed and to be designed carefully. The paper addresses some of the most important issues in that field.

The first section discusses the establishment of a spatial reference system and deals with GPS measurements of local reference points, with the connection to the global reference system WGS 84 and with aspects of usability for non-specialists.

The second section explains procedures needed to merge spatial data which are obtained from different sources, namely from field survey, from high resolution satellite data, from digital data recorded from analogue maps, from geophysical field measurements and others. Special credit is given to the role of digital terrain models (DTM): properties of DTM's obtained from different sources are analysed, the integration of DTM's created with different techniques (field survey, maps) is discussed, applications of DTM functions (perspectives, animated virtual flights, texture mapping, cross sections, slope and visibility analysis, etc.) are described in the case study.

The design and the implementation of an Internet presentation to support and promote information exchange between the specialists involved in a project and all other interested persons is another point of interest. Some important aspects of web design are discussed.

The case study explains the processes on the basis of a spatial data base originally created to serve as a groundwork for prospected archaeological excavations. Readers will get an idea how to combine data from various sources with divergent spatial properties in one spatial information system and how to integrate this information in a web-based overall project information system.

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1. INTRODUCTION

One of many civilisations lodging in Anatolia was the Hittite Empire which ruled nearly 600 years in the 2nd millennium BC in the area. Their military, political, social and commercial relations with the neighbouring countries were recorded in a large number of tablets, which recently were nominated and recommended for inclusion in the UNESCO Memory of the World Register (UNESCO, 2001). Tavium, or Tavia, was the capital of the Galatian tribe of Trocmi, and at the same time, was the centre of meeting for roads leading to all parts of Asia Minor. Nowadays, we find there only the remains of ruins, notably of a theatre, which survived the use of historical material in building the neighbouring village of Yozgat. Figure 1 shows the location of the ancient city in Central Anatolia, around 200 kilometres east of Ankara, the capital of modern Turkey. Since 1997 archaeological research has taken place in the area of Yozgat. The Department of Ancient History and Antiquities of University of Klagenfurt, Austria, the Department of Prehistory and Near Eastern Archaeology of University of Heidelberg, Germany, the Department of Geoinformatics and Surveying of University of Applied Sciences, Mainz, Germany, and others have worked together in the Tavium Research Project to explore this ancient city in close co-operation with

Figure 1. Archaeological research area of Tavium, Central Anatolia, Turkey (Jefferson, 2003)

the local heritage conservation authorities (Strobel and Gerber, 2000). This article focuses on the preparatory work for future excavations, mainly by developing a spatial information system, which was designed to contain all kind of geospatial data. The paper intends to describe the spatial properties of the content data which were acquired until now. Additionally, some issues concerning the webbased presentation of the content data will be addressed.

2. LOCAL REFERENCE SYSTEM

2.1 General Strategy

According to the agreed standards of the geodetic community surveyors do their best to bring all measurements of a project into a common geodetic reference frame. The normal way to achieve this is to connect the results of the local survey to the official state system. This, however, was not possible in our project due to the fact that no official co-ordinates of any points in the project area have been available until today. That is why is was decided to define one physically identified point, which is known to be part of the official Turkish reference system (point no. 1000, see Figure 2) to be the fundamental point of a local reference system.

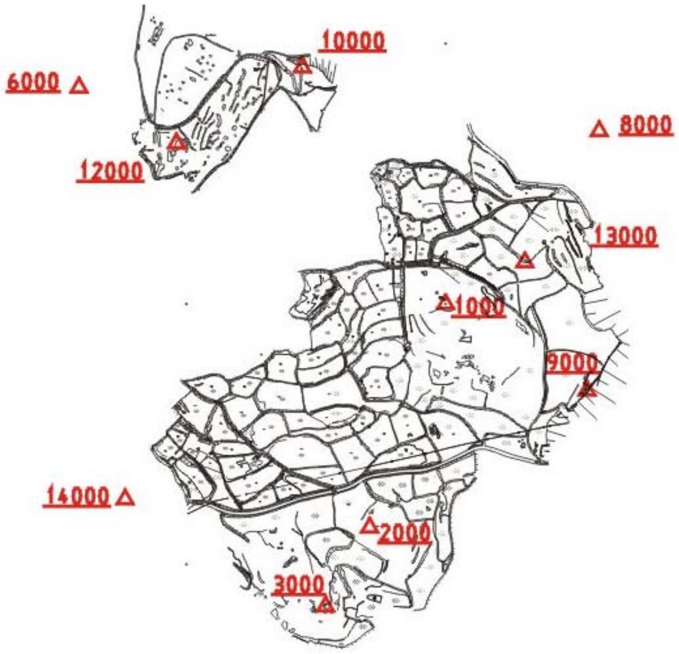


Figure 2. Points of local reference network

To avoid negative co-ordinates in the project area this point was given local co-ordinate values in East direction E = 10000,000 m and in North direction N = 10000,000 m in the same way. A Turkish 1/5000 scale map was available on which the fundamental point was identified. To make the new local system fit as well as possible to the height system of that map, the fundamental point was given the rounded up height value H = 1130,000 m above sea level which was very close to the annotated point height value of 1129,987 m in the map.

By that way of establishing the reference system it was made sure that the height system fits with the official system and that no confusion between the currently used local co-ordinate values for Eastings and Northings and any other co-ordinate system which will eventually be used in future can occur.

2.2 GPS Measurements

A set of points was established to serve as the geospatial base for all subsequent measurements. The co-ordinates of these points were determined by GPS baseline measurements with two Trimble 4700 system receivers in static mode and by calculation of co-ordinate values in postprocessing mode. The results of the baseline measurements were processed with Terrasat's software package GeoGenius® which delivered a set of geocentric co-ordinates in the WGS 84 reference frame and, on the basis of the Earth Model JGM3/OSU91, which is a composite of the JGM3 and OSU91A models (Merry, 2003) a set of geographic co-ordinates and orthometric heights for all measured points. Table 1 shows the list of plane and height co-ordinates after shifting it to the predefined co-ordinates of point no 1000. As can be seen, the standard deviation (sE, sN, sH) of the point co-ordinates resulting from a free network adjustment are all in the 1 centimetre range thus establishing a highly accurate base reference frame. This set of co-ordinates serves as the georeferential base for all subsequent work.

Pt. No.	Easting	Northing	Height	sE	sN	sH
1000	10000,000	10000,000	1130,00	0,0	0,0	0,0
2000	9853,615	9570,622	1092,82	3,2	2,8	7,8
3000	9768,449	9419,180	1080,17	3,2	2,8	8,1
4000	8790,385	8922,818	1108,18	2,8	3,1	7,2
6000	9292,813	10415,763	1221,69	2,5	1,9	4,9
7000	9441,799	11058,075	1278,81	2,1	1,7	4,5
8000	10296,378	10332,056	1096,51	1,9	1,7	4,6
9000	10272,821	9833,549	1095,35	1,5	1,2	3,1
10000	9723,471	10454,293	1162,28	2,2	2,3	4,7
11000	11221,836	9928,892	1046,45	6,9	5,3	14,3
12000	9480,751	10308,714	1193,73	2,0	1,5	3,4
13000	10153,024	10080,383	1104,21	1,6	1,2	2,9

Table 1: Reference point co-ordinates with their relative standard deviation values (all metric values given in unit metre)

Above that, the geographical co-ordinates as obtained from the GPS measurements established an absolute geodetic reference frame within the accuracy which can be obtained from absolute GPS measurements.

2.3 Quality Checks

The quality of the local area network was checked in several ways. Firstly, the height of the local fundamental point no. 1000 which was obtained from the world wide Earth model JGM3/OSU91 was compared with the height which was taken from the map. The difference was in the 4 metre range, which seems to be within a reasonable scale. Secondly, a set of distances was measured by electronic distance measurements between some of the reference points. The comparison of the independently measured distances and the distances as calculated from co-ordinates showed that the difference in all cases was below 2 centimetres (see Haas, 2002).

3. LARGE SCALE MAPS

In-depth archaeological field work often needs detailed large scale maps for the georeferenced documentation of findings, etc. In several campaigns parts of the landscape of the research area were captured by extensive tacheometric surveys. A sample of highly detailed 1/500 scale maps was generated (see Figure 4) within a predefined map sheet framework (Figure 3). Up to now, around 17.000 ground points were captured to produce the 1/500 scale map sheets.

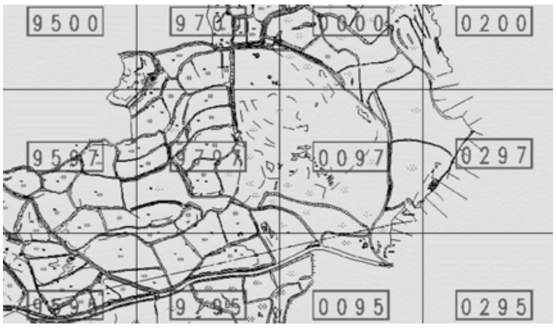


Figure 3. Framework of map sheets (Görgen, 2002)

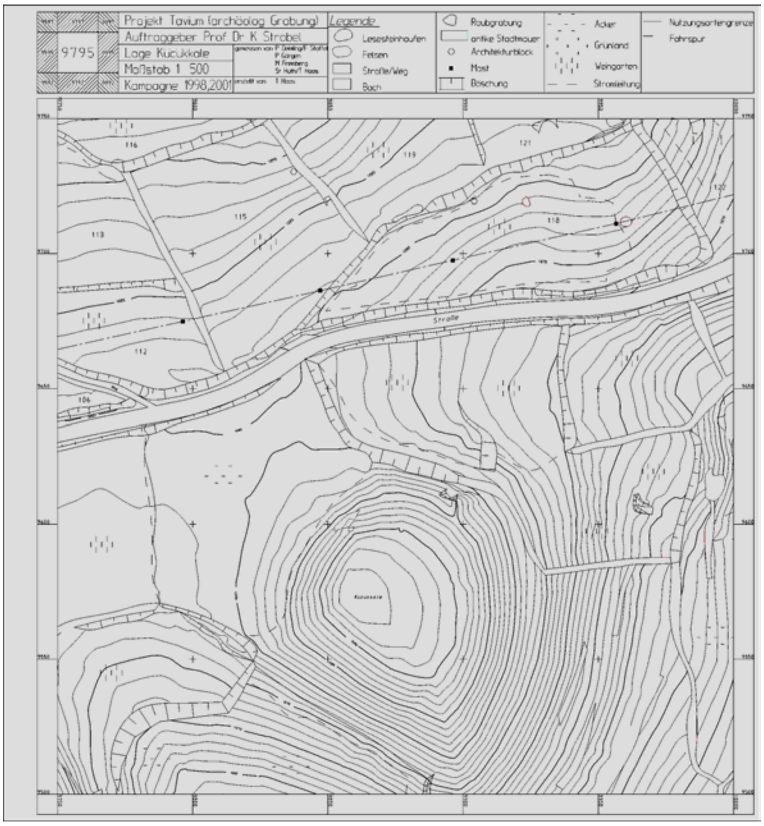


Figure 4. Map sheet, scale 1/500

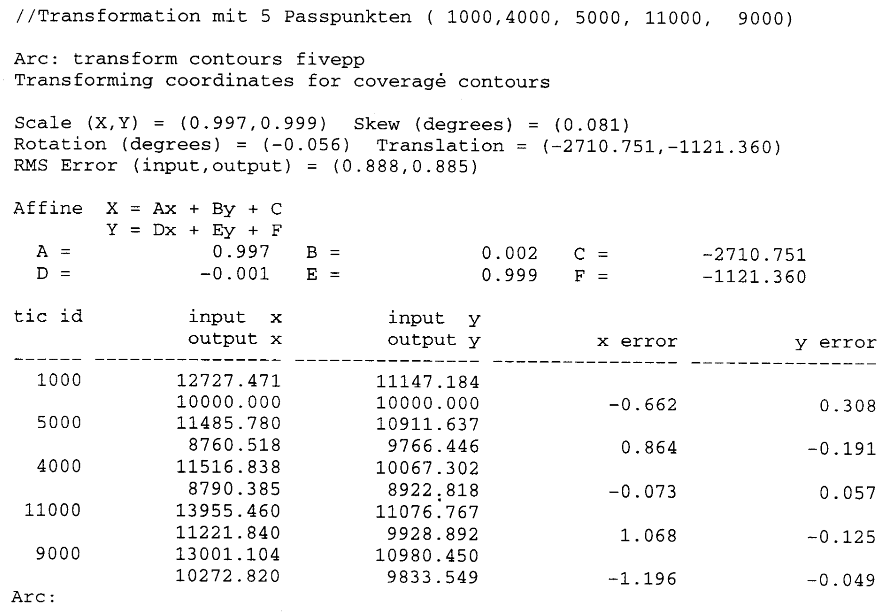
4. DIGITAL ELEVATION MODELS (DEM)

Once a digital elevation model of a landscape is available, such a model can serve as a base for many applications, like contour line generation, volume calculation, visibility analysis, calculation of cross sections and all other applications which need a digital representation of the terrain as an input, like virtual flights and walk throughs, for instance.

In our area there are mainly two sources of digital heights available, namely the results of the tacheometric field surveys and a set of 1/5000 scale paper maps (Siebold, 1998). Both sources were used to create a Triangular Irregular Network (TIN). Three-dimensional point co-ordinates were taken from the tacheometrically measured ground points and from digitised contour lines of the paper maps, respectively. When performing the fusion between these two data sets several items have to be addressed.

4.1 Common Spatial Reference Frame

The local reference frame (see section 2) was to be used as the one common base system for all data sets. That is why, in a first step, all data sets available in other reference systems had to be transformed into that target system. For the results of the tacheometric surveys this task could be easily performed by using a set of common reference points which were used in all field campaigns in the same way. The TIN's which had been generated from the paper maps were transformed by using a set of points on the maps which could be identified in the field. Table 2 shows the residuals of a redundant affine transformation with 5 control points. As can be seen the root mean square error is in the range of 1 metre, which equals 0,2 millimetres in 1/5000 map scale, a satisfying measure which proofs the quality of the whole data conversion process starting from the paper map and ending in the data fusion with data sets obtained from independent field surveys.



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//Transformation mit 5 Passpunkten ( 1000,4000, 5000, 11000,  9000)

Arc: transform contours fivepp
Transforming coordinates for coverage contours

Scale (X,Y) = (0.997,0.999)  Skew (degrees) = (0.081)
Rotation (degrees) = (-0.056)  Translation = (-2710.751,-1121.360)
RMS Error (input,output) = (0.888,0.885)

Affine  X = Ax + By + C
        Y = Dx + Ey + F
  A =           0.997   B =            0.002   C =         -2710.751
  D =          -0.001   E =            0.999   F =         -1121.360

tic id          input  x         input  y
                output x         output y          x error           y error
------ ---------------- ---------------- ---------------- ----------------
  1000       12727.471        11147.184
             10000.000        10000.000           -0.662             0.308
  5000       11485.780        10911.637
              8760.518         9766.446            0.864            -0.191
  4000       11516.838        10067.302
              8790.385         8922.818           -0.073             0.057
 11000       13955.460        11076.767
             11221.840         9928.892            1.068            -0.125
  9000       13001.104        10980.450
             10272.820         9833.549           -1.196            -0.049
Arc:
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Table 2. Results of an affine data set transformation

4.2 Handling of Concurrent Information

The 1/5000 scale paper maps cover a much larger area than the 1/500 scale maps do. The smaller scale maps enclose the actual research area. Following the progress of the archaeological research digital elevation information for more and more parts of the research area will be captured in future by tacheometric high quality measurements. This procedure of continuously extending the ground survey unavoidably will result in concurrent and possibly in contradictory elevation information as compared with the already available digital elevation information obtained from the paper maps. In our case we assume the accuracy of the ground survey results to be substantially higher than the paper map results. Thus, we decided to supersede paper map results by ground survey results whenever a ground survey was available.

4.3 Quality Checks

The concurrent elevation information available in all areas covered by ground survey results so far was used for an in depth quality check by analysing the differences of heights calculated from the concurrent TIN's: Heights for the complete set of around 17.000 tacheometrically measured 3D points were calculated from the paper map TIN. If one compares these calculated heights with the tacheometrically measured point heights one gets a sound insight into the properties of both data sets. Figure 5 shows the spatial pattern resulting from a classified plot of height differences. As one can see a striking fact is that the hillocks (Büyükkale, Kücükkale, Zegreg Tepe and others) in general show positive height differences against the pseudo true values of the ground survey TIN. This means that the heights calculated from the paper map TIN are lower than the heights obtained from ground surveys in that areas. In other areas we have to do with the opposite facts: the heights obtained from the paper map TIN are larger than the ground surveyed heights. Both facts can be explained: in the paper maps sometimes there were no spot heights available at the top of a hillock, which means, that the contour lines with the highest locally available height numbers define the top. The remaining height difference up to the real top of the local hillock is missing, whilst it is present in the ground survey data. The fact that there are areas where the surface of the paper map TIN is located systematically above the real ground surface may be caused by the map production process: data automation from aerial photographs, the standard method for medium scale map production, often focuses the problem that the physical earth surface is not visible because it is covered by vegetation. That is why digital elevation models sometimes reflect the vegetation surface instead of the physical ground surface. Having all these shortcuts, either proved or suspected, in mind the coincidence of the different TIN's within a 1 to 2 metres range on average is very well in coincidence with the quality of the available data sets.

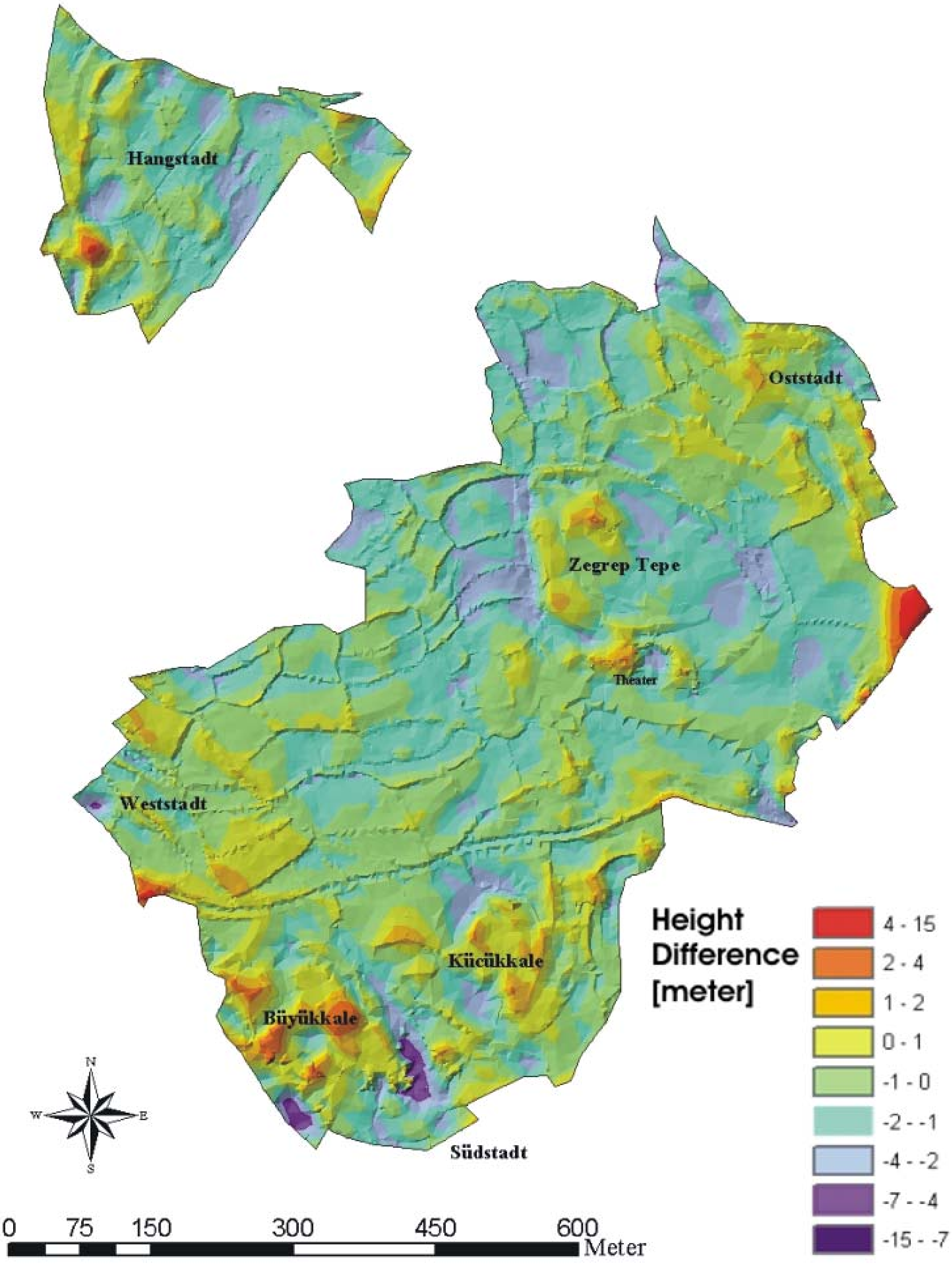

Figure 5. Spatial distribution of height difference TIN 1/500 – TIN 1/5000

Figure 6 shows an overlay of contour lines in the area around the two major hillocks Büyükkale and Kücükkale in a zoomed view. The smooth dashed lines are generated from the paper map TIN, the more jittery solid lines are the result of the highly detailed TIN generated from ground survey.

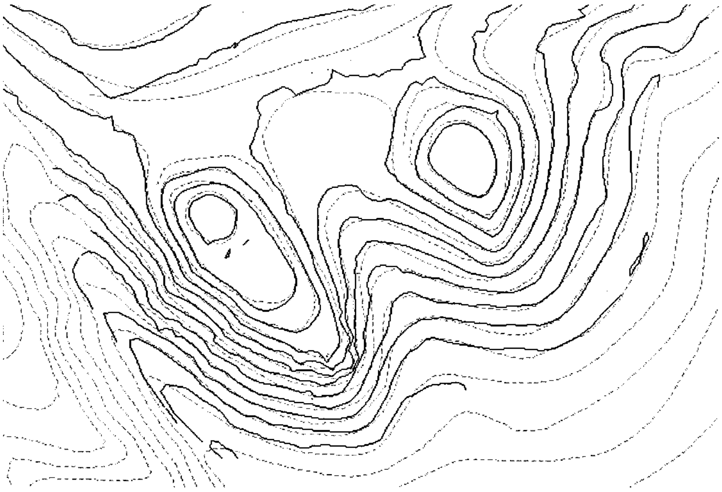

Figure 6. Overlay of contour lines generated from 1/5000 scale TIN (dashed lines) and from 1/500 scale TIN (solid lines).

Digital terrain models can also be used to generate cross sections. Figure 7 shows the presentation of such a cross section, again from both digital elevation models. As can be seen the top of the local elevation appears to be cut in the paper map DEM, but otherwise both curves fit well.

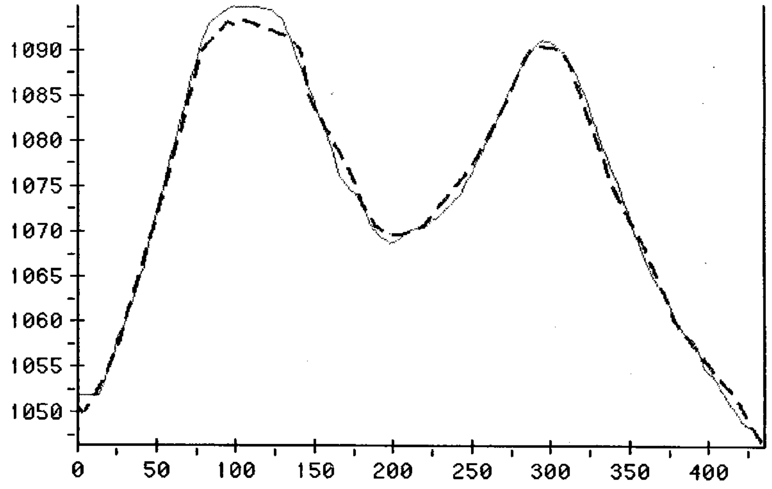

Figure 7. Overlay of cross sections generated from 1/5000 scale TIN (solid line) and from 1/500 scale TIN (dashed line)

4.4 Applications in Archaeological Field Research

As an extract of the wide range of DEM applications, this section describes some examples of how digital elevation models can support archaeological research activities.

4.4.1 Volume Calculations

The historical theatre which was discovered in the research area is one of the most important archaeological remains which are currently known in the Tavium archaeological site. The volume of the earth mass which had to be moved during the excavation of the theatre could be easily calculated from the DEM. All points actually located in the theatre area were removed from the DEM. Another DEM was calculated from the reduced data set. In that way, the present surface of the theatre area was replaced by another surface which was calculated from the surrounding points located in the slope surface (see Figure 7).

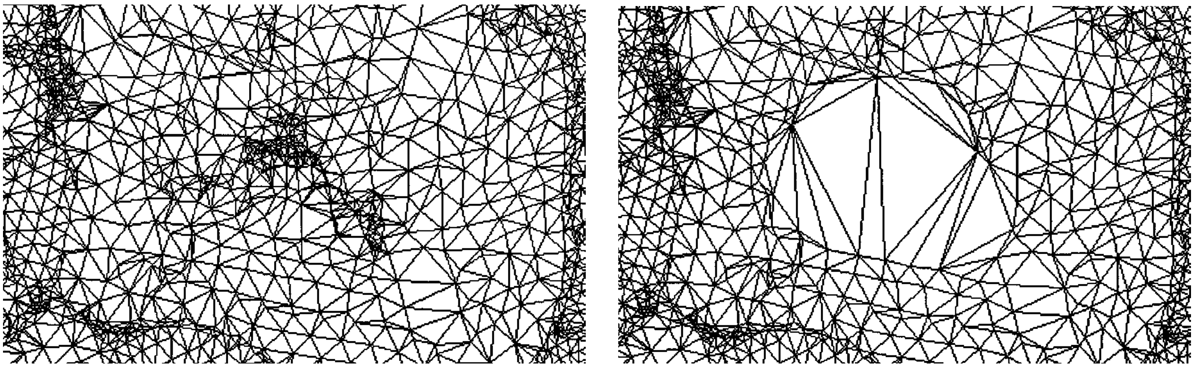

Figure 7. Detailed TIN of terrain surface in the theatre area: current terrain surface with cavity (left), simulated surface without cavity (right)

By performing a so-called cut fill operation between both DEM's, namely the DEM not containing and the DEM containing the theatre cavity, the earth volume which had to be removed to construct the theatre was estimated to be about 2.000 cubic metres.

4.4.2 Visibility Analysis

Visibility analysis is another DEM application which can support the archaeological research in many ways. Figure 8 shows how one can detect from a DEM if a terrain point is visible for an observer or not once both points, the terrain point and the observers point of view are known. With the hypothesis of a former temple located at the top of the hillock Küyükkale (see also Figure 9) one can calculate the maximum height of the former theatre platform if one assumes that the platform should not be an obstacle for the theatre visitors. The result of this calculation is, that the visitors had the temple in their view field while joining a theatrical performance if the platform was not higher than 9 metres.

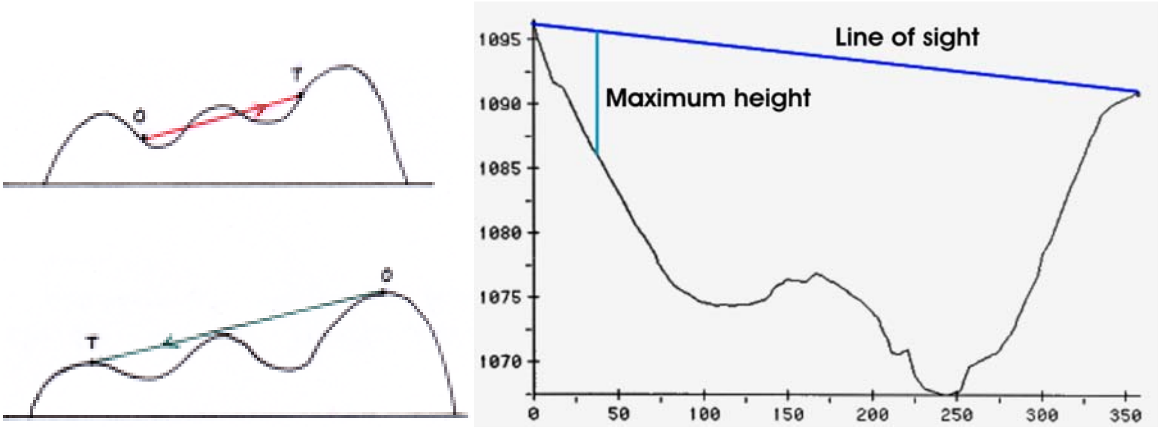

Figure 8. Principle of line of sight analysis (left),line of sight analysis at the Tavium theatre (right)

Figure 9 shows the complete landscape area which could be overlooked by the theatre visitors.

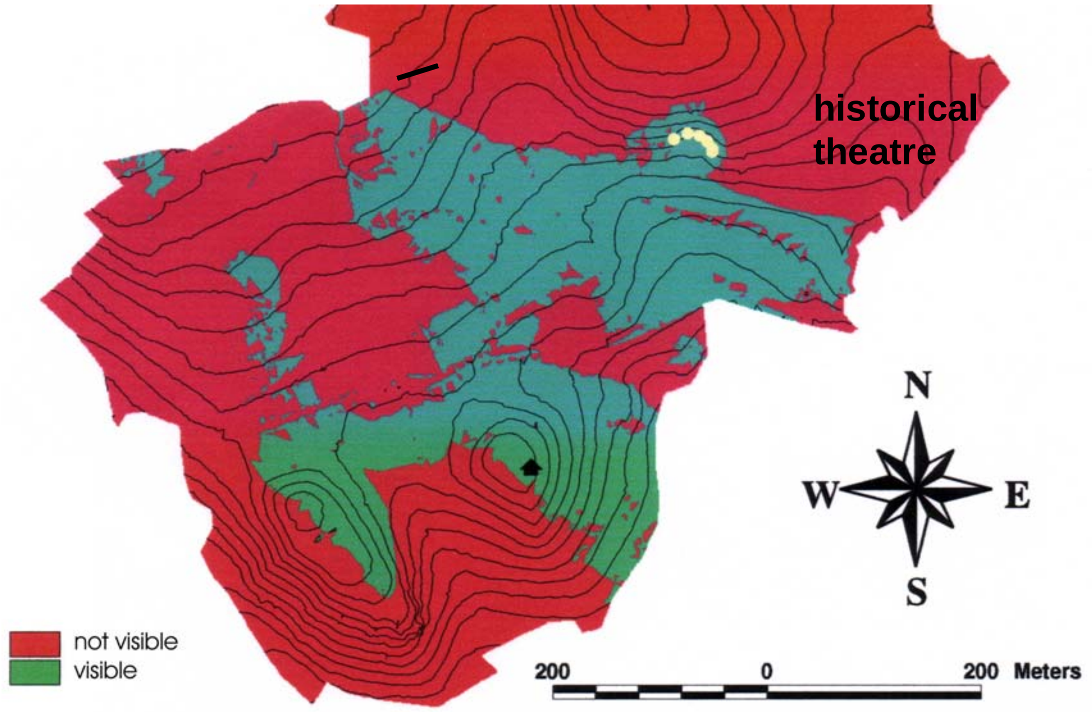

Figure 9. Visible terrain for historical theatre visitors

Visibility analysis can be used for many other purposes, like for the detection of suspected watchtower locations which were needed to control a certain area, for an analysis to answer questions like ‘from which points of the ancient trade roads was it possible to see the city?’, ‘from where could a certain religious building be seen?’ or, in turn, ‘where is the most probable location of a religious building which is assumed to be seen from a certain area?’.

4.4.3 Other DEM Applications

Slope is an important terrain measure and is strongly linked with many archaeological research items, like landuse considerations, for instance, because agriculture or building construction may be restricted to a maximum terrain slope. Natural erosion processes strongly correlate with slope measures, artificial slopes may have been created to improve the defence capabilities against attackers, steepest path calculations can help to discover remains of irrigation systems. All slope calculations needed in such cases can be performed very easily once a DEM is available. Automatic cross section calculations can be used for the validation of suspected courses of paths, roads, rivers, etc. Visualisation is another wide DEM application field which will be discussed shortly in the context of the Internet presentation of the Tavium Research Project (see next section).

5. TAVIUM RESEARCH PROJECT WEBSITE

Meanwhile, the Internet became a standard medium for information exchange. The advantages of this new medium are obvious: information can be accessed all around the clock from everywhere in the world, the contents of websites can be updated easily within a very short time span, all information is provided at a relatively low cost level as compared to classical print media, but still at a considerable size, etc. In some way a certain standard of how to structure and to present information on the Internet is already available. A website for the Tavium Research Project was created which meets the requirements of all the de facto agreements with regard to the arrangement of information on the screen, to the navigation through all pages, to the use of commonly used icons and other components of a widely accepted Internet look and feel.

5.1 Website Design

A flat hierarchy of categories was established to facilitate the navigation on the website (see Table 3). At the moment of publication the website contains more than 150 Internet pages. Actually, the pages are only available in German language, but the intention is to provide the presentation in English language, too, and, possibly, even in Turkish language. Figure 10 shows the front page of the Internet presentation.

TAVIUM RESEARCH PROJECT

WILLKOMMEN! WELCOME! MERHABA!

Willkommen auf der Website des
TAVIUM RESERACH PROJECT.

Wir bieten Ihnen untenstehende Einstiegsmöglichkeiten in unsere Seiten.

Sie können sich aber auch direkt über die einzelnen
Punkte zu den Seiten hier schnell informieren!

Figure 10. Front page of the Internet presentation

Category	Subcategory	Category	Subcategory
Front page		Research	• Field campaigns • Surveying and Geoinformatics • Field research • Excavations • Findings • Results
Home	• General • Site map • Information	Images	• Region • Büyükknefes • Tavium • Findings • Measurements • Models • Maps
News	• Field campaign 2002 • Credits	Literature	• Tavium • The Galats • Full texts
Project	• Aims • Management • Co-workers • Co-operation • Sponsors	Links	• Related websites • Tips
Region	• Natural environment • Traffic networks • Research area	Contact	• e-mail
Tavium	• Walk around • Location • Research history • Topography • General history • Cults	Logout	

Table 3. Design of the Tavium Research Project website

5.2 Applications in Archaeological Field Research

In addition to much purely textual information (see Table 3), the website contains a number of images and some animated image sequences. The DEM information (see section 4) was put together with texture information obtained from the 1/5000 scale paper maps to create a number of virtual flights over the research area. Figure 11 shows a single image which was extracted from one of the films. On the right side of the Figure a conventional photograph of the same scene is given. The scene shows the major hillocks Büyükkale and Küyükkale, in the film snapshot with an excess factor of 2 in elevation to improve the 3D impression.

Figure 11. Virtual scene (left) as generated from paper maps vs. conventional photograph (right)

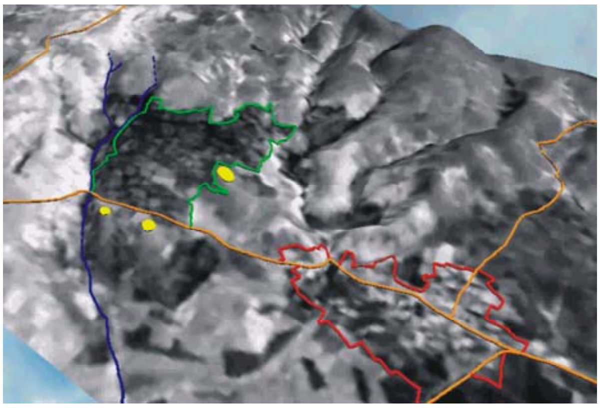

Figure 12. Virtual scene as generated from a SPOT panchromatic scene with marked topographic features

The use of highly detailed paper map information is adequate for close range flights showing the terrain in a highly zoomed in view. Above that, a SPOT scene was used to create overview flights for the Tavium Research Project which at the moment covers an area of about 3 x 4 kilometres. Panchromatic SPOT scenes are available at a 10 metres resolution in ground scale. This measure determines the scale of usability. Figure 12 presents a single image shot from the digital film. To facilitate user orientation the film shows some specially marked topographic features like main roads, borders of actually built-up areas, etc. The point markers in yellow color delineate the major hillocks Büyukkale, Küyükkale, Zegreg Tepe.

6. CONCLUSIONS

A digital archaeological research information system has to contain spatial information of various kind. This information has to be managed in a well organised way to enable the users to generate feasible information from it. The described way of how to create a comprehensive digital landscape data base may serve as a guide for similar tasks in other application areas of geographic data processing.

REFERENCES

Freisberg, M., 2002. Aufbau einer Internet-Präsentation Tavium/Türkei. Diploma thesis, Mainz University of Applied Sciences, Germany, unpublished.

Görgen, P., 2002. Projektaufbau und Auswertung Tavium/Türkei. Diploma thesis, Mainz University of Applied Sciences, Germany, unpublished.

Haas, Th., 2002. Aufbau eines Festpunktnetzes Tavium/Türkei und Referenzieren vorhandener Messungen. Diploma thesis, Mainz University of Applied Sciences, Germany, unpublished.

Huth, S., 2002. Analyse und Vergleich digitaler Gelände-modelle am Projektbeispiel Tavium/Türkei. Diploma thesis, Mainz University of Applied Sciences, Germany, unpublished.

Jefferson, 2003. http://jefferson.village.virginia.edu/~umw8f/Barbarians/Maps/ map_galatia.jpg (accessed 28 Apr. 2003)

Merry, C.L., 2003. Comparison of geoid models for the southwestern cape province, south africa. Department of Surveying & Geodetic Engineering, University of Cape Town, http://www.ucalgary.ca/~sideris/SWG/merry.htm (accessed 17 Jun 2003)

Siebold, M., 1998. Berechnung eines digitalen Geländemodells für das Gebiet Yozgat/Türkei. Diploma thesis, Mainz University of Applied Sciences, Germany, unpublished.

Strobel, K. and C. Gerber, 2000. TAVIUM (Büyükknefes, Provinz Yozgat) – ein regionales Zentrum Anatoliens. Bericht über den Stand der Forschungen nach den ersten drei Kampagnen (1997–1999*). Istanbuler Mitteilungen 50*, pp. 215–265.

UNESCO, 2001. Memory of the World - Register - Nomination Form, Turkey - The Hittite cuneiform tablets from Bogazköy. http://www.unesco.org/webworld/mdm/2001/eng/turkey/ cuneiform/cuneiform_form.html (accessed 17 Jun. 2003)

BIOGRAPHICAL NOTES

Hartmut Müller got his diploma and doctoral degree at Karlsruhe University. After 8 years of research he turned into the marketing and software development departments of international enterprises for 6 years. Since 1991 he has been working as a professor at Mainz University of Applied sciences. Since 1998 he has been a member of the board of i3mainz, Institute for Spatial Information and Surveying Technology. In the DVW – German Association of Geodesy, Geoinformation and Land Management he is the chair of working group 2 -Geoinformation and Geodata Management.

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