Postgraduate Courses in Geographical Information Systems
to achieve a European Master of Advanced Studies in
Geographical Information Science & Systems

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courses by distance learning

UNIGISMAS2000 - MODUL 15 – U732

Thesis:

”The use of Geographic Information Science (GIS) for extraction of habitat assessment characteristics from governmental aerial images”

Part I: aerial images an GIS- database for environmental analysis

Part II: quantitative river habitat assessment based on ORP

Innsbruck, 31 July 2002

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Chapter 1 Introduction:

Remote sensing technology permits to collect data from a locality by aircraft and for the whole earth via sensors on satellites. Sonar, thermal, optical, radar sensors and a variety of other new types of sensors provide information about weather patterns, land cover, topographic relief, geology, and other phenomena of environmental interest. Commercial and government organizations produce aerial photographs and launch satellites based on newer technologies that offer better resolution of data and error-reduction (Blaschke, 2001). Vector and raster GIS are often integrated with remote sensing data for more comprehensive environmental modelling (Herzog, 2001).

Aerial photography has become an indispensable aid for many administrations and scientists. It is used for the preparation of topographical maps in metrology, geology, archaeology, hydrography, forestry, the utilization of land, scenery ecology (Landschaftsökologie), oceanography, the consolidation of farmland, road construction, flood protection and many more. Furthermore it has become an indispensable means for obtaining updated base information (Kuhn, 1999; Strunz, 1999; Hoffmann, 2001).

The benefit of ortho-rectified images is multifunctional. Software is usually used to extract vector features from the photographs or heads-up digitising is used to trace the feature directly from the photograph on-screen. The ortho-rectified photograph itself often serves as a base layer in GIS to assist in locating features on the landscape. Using photogrammetry, rough topographic maps of vector elevation contours or raster Digital Elevation Models (DEM's) can also be produced from aerial photographs and limited ground control survey data.

Nowadays aerial photographs are taken with digital cameras from small aircrafts. They can be directly processed with software in the process of ortho-rectification e.g. to remove distortion resulting from topographic relief or airplane tilt. Surveyed ground control points saved in the camera are used to equalise immediately the digital photographs to real world coordinates. Surveyed data collected and processed in a digital format are often directly used to generate mapped features for GIS. Many GIS also include Coordinate Geometry (see Open GIS Consortium Inc. OGC, www.opengis.org; GML, Geographic Markup Language, www.opengis.net/gml) procedures for transforming survey data into a uniform graphic format.

Modelling the geographical distributions into geographical reality is a process of discretisation that converts a finite number of database records or objects (Grover, 1999). Environmental processes in the real world become computer based mathematical models. They simulate spatially distributed and time dependent, quantitative assessment of complex environmental issues. GIS enables the necessary predictive and related analytical capabilities to examine complex problems. Spatial representation and its mathematical models are nevertheless critical to solve environmental problems. Most of the research focused on small sites of special interest using intensive sampling techniques and complex modelling procedures. There is also a need for more extensive evaluations of historical knowledge that might help to guide land planning and management at regional scales.

There are main basic issues in water management and environmental protection that are necessary to be modelled in order to understand the problems faced by the environmental system.

Some of these issues are:

<u>Hydrologic</u>

- Water utilization for water supply for municipalities, agriculture and industry
- Flood control and mitigation.

<u>Environmental</u>

- Pollution control and mitigation for both groundwater and surface water
- The competing demands for in stream water use and wildlife habitat.
- Regeneration and protection of wetland, inundation zones and other measures able to support or recover the flora or the fauna of a certain region.

The fundamental question is how to get information on the former environmental condition. Such information is normally stored in old aerial photographs collected during planning and surveying flights in diverse projects in the past. The next questions consequently are:

- What happens to aerial photographs, after they have been taken, processed and analysed?
- Are they stored and conserved?
- Is it possible to extract environmental information?

In the archives from the “Administration des Ponts et Chaussées – Service Photogrammétrie” and the “Administration du Cadastre et de la Topographie” of the Luxembourg government, thousands of aerial images of the last half century are being stored. All these images, not frequently used during the last decades and not only taken for environmental tasks, are full of information about changes. They are non-reproducible documentation about surface water and sometimes even a witness of the historical evolution in Luxembourg. This information, still existing on these aerial images, could and should help as reference information to validate surface water and to guarantee a correct renaturation of strong modified sections along rivers.

Chapter 2 History

Nicéphore Niepce was the French experimenter (1765–1833), who invented the first permanent photograph on a lead plate coated with a layer of bitumen of Judea in 1827. In 1856 G.F. Tournachon alias Nadar, produced the world's first aerial photographs. It was taken from a manned balloon over France (Steiger, 1981). The discovery of the more sensitive gelatine emulsions containing cadmium bromide and silver nitrate in 1871 by R.L. Maddox and the development of a better photographic paper made it possible to obtain photographs from faster aircraft. Not long before the First World War, a chemist from Kronberg even succeeded in producing brilliant shots with small cameras attached to carrier pigeons. Aerial photography techniques improved with the development of civil and military aviation. During the First World War military services took 56000 aerial images in only four days during the Argonne offensive. O. Messter invented the first 'Reihenmesskammer' (RMK) in 1915. The first non-photogrammetric application for geological and agricultural purpose was around 1930. In 1961 J. Gagarin undertook the first manned space flight. Earth images taken from space became more and more frequent. Today satellite images exist for every place on earth. However, aerial photographs are used especially for geographic information science (GIS) vector-data of higher quality.

In the past, most digital spatial data sets were developed from already discrete paper maps that were fastened to a digitising tablet (see Figure 2-2), which was then calibrated to real world coordinates and units. Lines on the aerial images and map were traced with a digitiser to generate a digital duplicate. The digital drawing was then converted into a vector layer in GIS and joined to tabular attributes of the mapped features to create a spatial data set or coverage.

Although at present this procedure is still practiced to some extent, it is now common to scan and vectorise the maps, and then to fix errors using tailored editing tools within GIS. The future of remote sensing and GIS depends on technical advances, public interest and military restrictions. This work shows the possibilities that scientists have.

GIS-work will become a completely facilitated onscreen processing. Better digital cameras, with aerial image saved flight protocols, integrated GPS information, existing DEM with the same resolution as the aerial images and specific specialised programs with remote sensing and open-GIS standards, will improve the ortho-rectification.

Chapter 3 Aims

GIS with its upcoming advanced technology has become a great asset to environmental modelling. The goal of this essay is to prove the applicability of older aerial photographs to today's GIS-techniques for environmental purposes. Especially as far as historical aerial photographs are concerned several flight protocols and camera settings are missing. We tested whether the existing archived photographs can be used to retrieve missing environmental information for an eventual revitalisation or renaturation of running waters as described in Füreder et all. (1999).

A special focus should be put on some future directions of environmental interpretation that was not been possible in the past but that might now be feasible with the application of GIS.

Chapter 4 Study area

Part 4.01 Geographic and demographic telegram of Luxembourg

Luxembourg is the smallest country of the BENELUX economic community situated in the western part of Europe (see Figure 4-1). As one of the five founder members (Belgium, France, Germany, the Netherlands and Luxembourg) it became the seat for European institutions like the European Court of Justice, the secretariat of the European Parliament, and the European Court of Auditors. About 7 000 EU employees work in Luxembourg, which also serves as a finance place for more than 120 banks of the world. This information is important for reason of the rural development of the country.

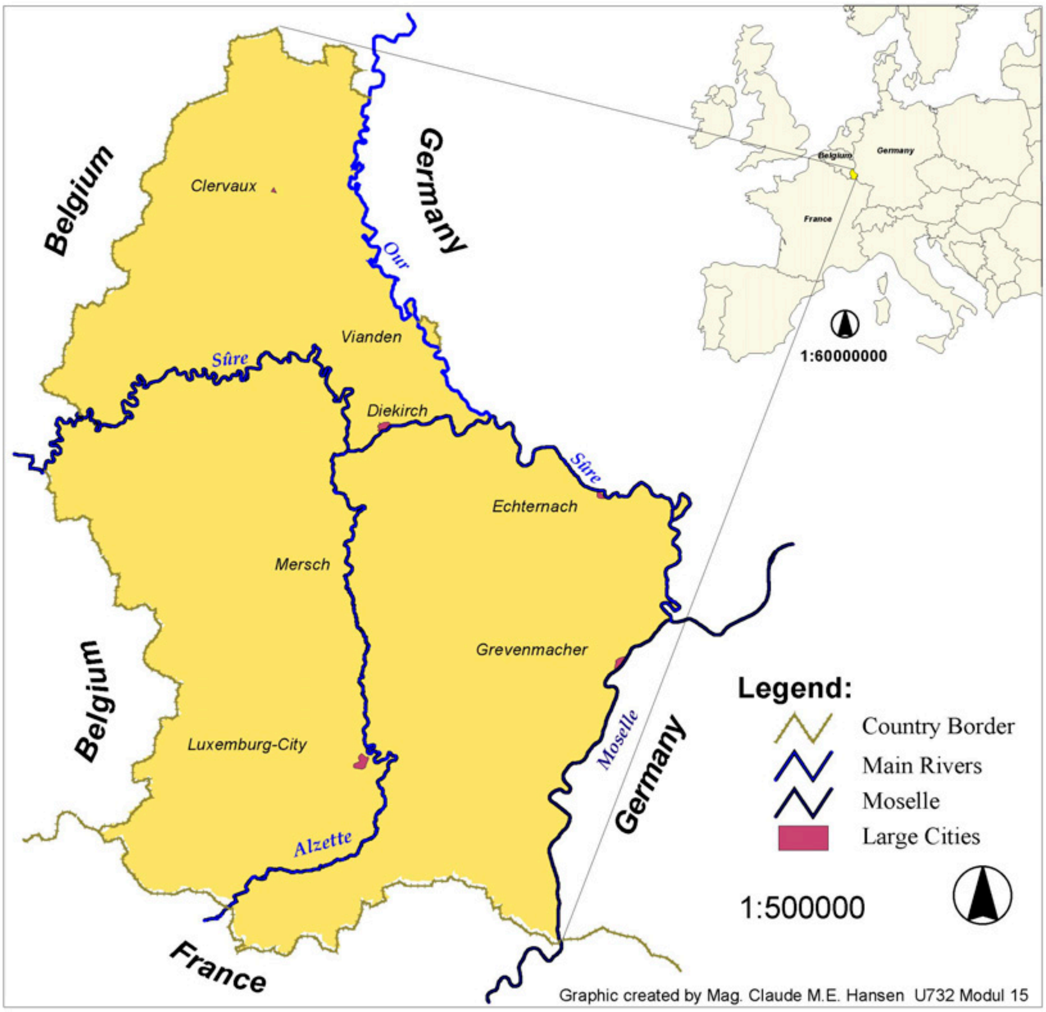

Figure 4-1: Geographic position of Luxembourg and its main rivers Alzette, Sûre, Moselle

Since the late 1950s the country's economy and population have been growing. Especially in the south of Luxembourg the spare space keeps being covered with buildings and infrastructure. The increasing population and infrastructure is putting great pressure on the environment.

The territory of the Grand Duchy of Luxembourg measures 2 586 sq km (999 sq miles). The highest point is Buurgplaatz (559 m/1,834 ft) on the Ardennes Plateau in the north. The southern two-thirds of the country ars a rolling plateau, the Gudland (fr. Bon Pays). Luxembourg has a moderate climate with a mean annual temperature of 10°C (50°F) and a yearly rainfall of about 815 mm.

The population (values of 1999) counts about 429 200 inhabitants with a population density of 166 inhabitants per sq km. The capital is Luxembourg-Ville with a population of 79 844 inhabitants. The Grand Duchy of Luxembourg shares borders (see Figure 4-1) to the north and west with Belgium, to the south with France and to the east with Germany.

The northern part, about one-third of the country, is made up of the hills and forests of the Ardennes, while the rest is wooded farmland. The south-east is the home of the rich wine-growing valley of the Moselle. The capital, Luxembourg-Ville, is built on a rock overlooking the Alzette and Petrusse valleys.

Part 4.02 Catchment characteristics of the Sûre river basin

The Sûre (lx. and dt. Sauer) has its source in Vauy-les-Rosières in the Belgian Ardennes at 439 m.a.s.l. It flows easterly to Luxembourg and drains the Luxembourgish part of the Ardennes, a major part of the plains in the south of Luxembourg (lx. Gudland) and the west of the Eifel (lx. Éislek).

The catchment has an area of 4.240 sq km (Figure 4-2). The most important tributaries of the Sûre are the Wiltz (L), Alzette (L), Our (L/D) and Prüm (D) and two smaller tributaries like the White Ernz (L) and Black Ernz (L). The Sûre meets the Moselle at 130 metres a.s.l. in Wasserbillig (L) and Oberbillig (D) The Moselle is here at its 205,.9 river kilometre. The lower part of the Sûre constitutes about 30 kilometres of the border between Luxembourg and Germany. The river is mostly natural with no waterway and no significant industry.

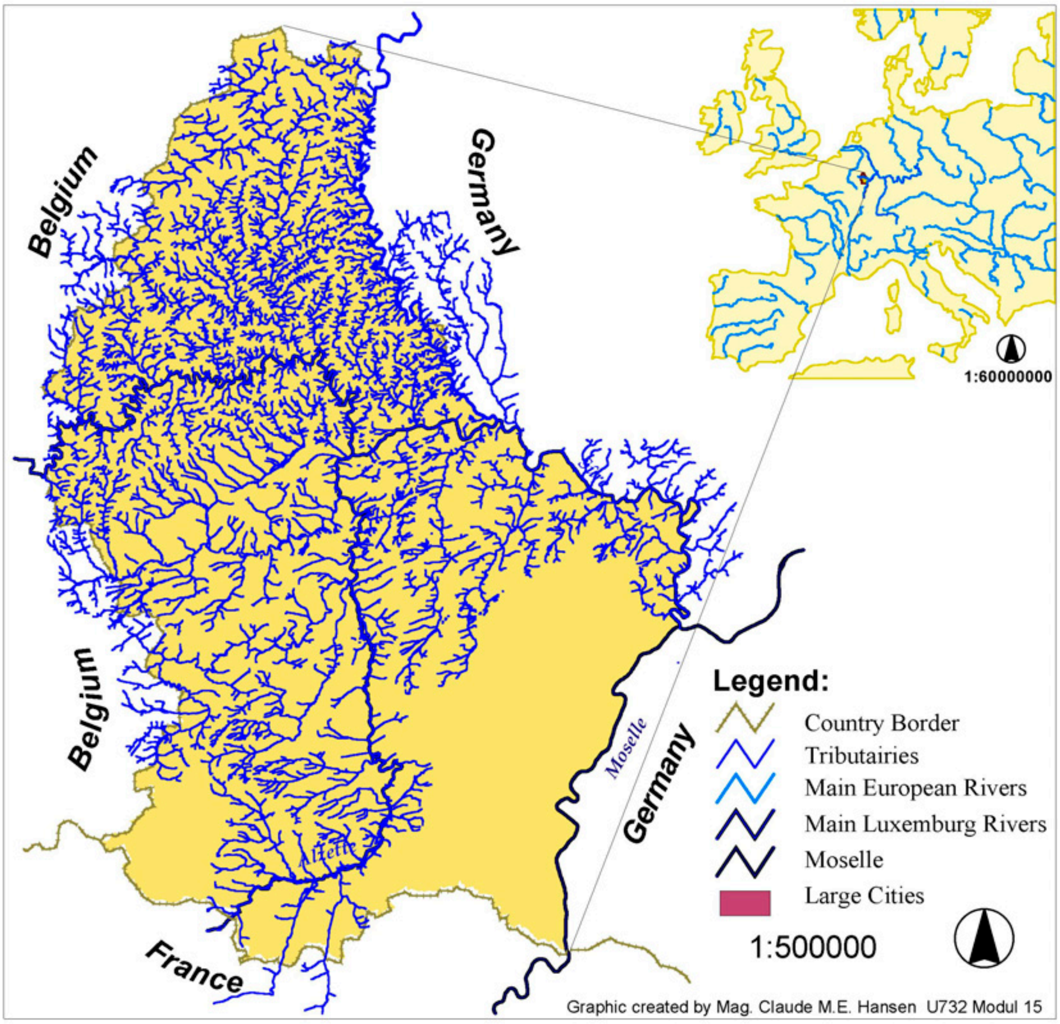

Figure 4-2: Study areas with the main rivers Alzette, Sûre, Moselle and their tributaries

Chapter 5 Material and methods

Part 5.01 Aerial images: criteria of assortment

The chosen aerial photographs were pre-selected fulfilling following conditions:

- The selected rivers in the analysed section should not be smaller than 12 metres for the studied section.
- The selected study area had to be large enough so that relevant water characteristics could be detected.
- The available aerial image-set had to be as homogeneous as possible. Excessive differences in resolution, brightness, contrast, and colours would reduce the quality of the results.
- A historical subset of aerial images of the selected section had to be available.

Because of the borderline to Germany additional information had to be elaborated from the German topographic maps 1:25 000 of the Rhineland-Palatinate (CD-ROM: Nr.2. Mosel - Eifel- Hunsrück and the CD-ROM: Über die Grenzen SAAR-LOR-LUX).

We selected the Sûre/Sauer, the second widest river in Luxembourg, for the later habitat assessment analyses. A series of 14 aerial images from the "Administration du Cadastre et de la Topographie" were available. As far as the Sûre river is concerned the selected sector lies between Wasserbillig and Ettelbruck over a length of ca. 55 km. The planed analysed zone, necessary to guarantee a further habitat assessment valorisation, was defined to a buffering zone of 150 metres on the left and right borders of the selected river. The buffering zone was created by the river theme of the BD Topo/Carto luxembourgeoise (BD-L-TC) vector database. A supplementary buffer zone based on a 10 metre elevation difference to the water body was calculated based on the generated digital elevation model (DEM).

In order to be able to evaluate the historical aspect we needed a set of aerial images in which long time series were available. In the archives of the "Administration des Ponts et Chaussées" we could assort a collection of 30 years of images of the Alzette between Schieren and Colmar. The section had a length of more or less 2 kilometres. The aerial images are described in Table 5-2.

Part 5.02 Availability of Data

(a) Cartes topographiques numériques

All digital data used for this assay were available in form of map-sheets from the "Administration du Cadastre et de la Topographie" (ACT). Table 5-1 shows the common scales, the year of creation and the number of map-sheets covering the whole country.

Table 5-1: Available and used digital maps from the "Administration du Cadastre et de la Topographie"

Scale	Map-sheets	Edition
1/5 000	261	1996-2000
1/10 000 - 1/20 000	96/30	1987
1/20 000 TC	21	1998-2001

The topographic maps 1/5 000 resulted from the BD-L-TC and were created from aerial images covering the whole country with 261 sheets. These maps replaced the 96 old topographic map sheets 1/10 000 from 1987.

(b) Ortho-rectified aerial images

No ortho-rectified aerial images were available for the study area. It was planned to create new ortho-rectified aerial images in colour for the year 2002 (not yet available for this assay) with a ground resolution of 0.5 metres.

For these reasons, no set of ortho-rectified aerial images, covering the whole country of Luxembourg, existed either in the "Administration du Cadastre et de la Topographie" or in the "Administration des Ponts et Chaussées". Most historical aerial images were taken as small zones near roads and buildings as a consequence of territorial planning and building surveys.

Countrywide series of aerial images were only available from the "Ministère de L'Environnement" for surveying and mapping reasons of the vegetation cover (fr. Occupation Biophysique du Sol, OBS).

The quality of historical aerial images was sometimes very low. The oldest aerial images were in black and white and dated from 1972. For several locations along the Sûre it was impossible to get pictures where the river was in the middle of the image, so that small parts were lost after the rectification processes. Metadata, like the calibration protocol or coordinates are not available for every data.

> *Remark: Hard copies of analogue aerial images are very expensive. As a consequence it would be helpful to store aerial images as digital files in the future. This may help to reduce the preparative work, guarantee a fast search and avoid a loss of image quality and resolution.*

(c) Arial photographs of the ACT

Since 1954 the "Administration du Cadastre et de la Topographie" has regularly taken aerial images of the territory of Luxembourg with the aim of mapping and surveying it. Since 1994 the aerial images have been in colour. Ortho-rectified images don't exist for public use yet. The scale and price of the old and new aerial images of the ACT are shown in Table 5-2.

Table 5-2: Price of aerial photographs of the ACT

Scale	Price	
	Black and White	Colour
1/ 5 000	/	150.00 €
1/10 000	24.79 €	75.00 €
1/10 000	12.39 €	37.50 €
1/25 000	7.44 €	

Part 5.03 Projection

(a) Georeferencing systems

One of the greatest problems of sharing spatial data sets was that thematic layers from different sources may lie in different locations in the coordinate space. This can occur because of the use of different geodetic data, units, map projection, or reference ellipsoid, transforming data from the earth's curved surface into 2-D space during the process of geo-referencing. Although the earth looks relatively round from space, it is actually an imperfect ellipsoid. Therefore, mathematical models of the surface called reference ellipsoids are used to describe placement of features on the earth's surface. Over the past 150 years, a number of manual, automatical and GPS surveys have been conducted to establish geodetic datum or dates in order to model these reference ellipsoids. Satellite snapshots taken of the earth from a variety of angles have improved the accuracy of the models in recent years.

(b) Geo-referencing systems for aerial images

There is no way to take a curved surface and make it flat without introducing some distortion. Therefore, all aerial images distort in area, shape, angles, distance, or direction their map properties. Small areas of the earth are less curved than large areas, so projection errors in local area maps are usually smaller. A projection method tailored to a particular area was used to increase accuracy for our study area. Understanding errors that arise from different types of projections helps to minimize distortions that would degrade the rectification and analyse of the data.

Figure 5-1: Cylindrical projection - Transverse Mercator used in Luxembourg

(c) Geo-referencing system of Luxembourg

The national datum of Luxembourg is called LUREF, a Transverse Mercator projection (Table 5-3) which due to the small size of the country has only one zone. LUREF is used as standard projection for all datasets.

National Datum Ellipsoid Parameters	
Semi-Major Axis a (m):	6378388m
Flattening 1/f:	1/297
Semi-Minor Axis b (m):	6356911.946m
Eccentricity e^2:	0.006768170197
Ellipsoid:	HAYFORD INTERNATIONAL 1924
Fundamental point (Laplace-point):	Habay-la-Neuve (Belgium)
Details of the Luxembourg Projection System	
Name:	Projection Gauss Luxembourg
Generic Projection Type:	Transverse Mercator Projection
Parameters:	
Longitude of Central Meridian:	6° 10’ East of Greenwich
Central Meridian Scale Factor:	1
Longitude of Origin:	6° 10’ East of Greenwich
Latitude of Origin:	49° 50’ North of Equator
False Origin:	
Position of False Easting:	80 000 m
Position of false Northing:	100 000 m
National Luxembourg Height Datum	
Name:	NIVELLEMENT GENERAL DU LUXEMBOURG (NG-L)
Reference Point:	Wemperhardt
Altitude:	528.030m
Reference Tide Gauge:	Pegel Amsterdam

The NG-L is based on geometric levelling only, it counts 3800 points which corresponds to a density of 1.8 points/km^2.

Further information about the transformations to other projections can be found on the official homepage of the Grand Duchy of Luxembourg http://www.etat.lu/ACT.

Part 5.04 Vector-data

Vector data are discrete geographical features consisting of points (coded as vectors) and lines (coded as groups of points), forming chains, arcs, or polygons. The used vector-database «BD Topo/Carto luxembourgeoise (BD-L-TC)» from the "Administration du Cadastre et de la Topographie" is produced in the topographic scale of 1:5 000 and exists for the whole territory of the Grand Duchy de Luxembourg (Figure 5-2). The used sheets were TC 9, TC 10, TC 11, and TC 15 as ESRI-shape files with attributes. Table 5-4 shows some of the classes of the BD-L-TC.

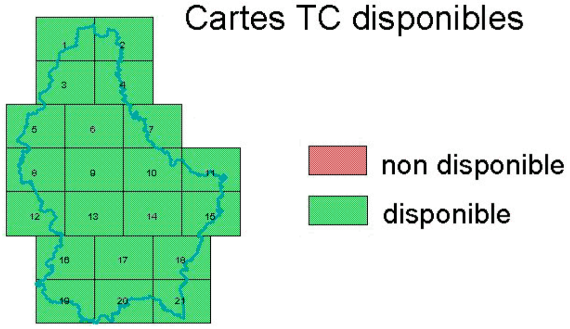

Figure 5-2: Overview of the availability and position of the BD-L-TC of the ACT.

The BD-L-TC were based on aerial photographs on a scale of 1:20 000 (done by the French firm l'IGN France) and had been created for the following reasons:

- ❖ The creation of a new topographic map on a scale of 1:20 000
- ❖ The creation of a topographic database on a scale of 1:5 000

Figure 5-3 shows two examples of the new vector based topographic maps on a scale of 1:5 000 (left) and 1:20 000 (right) from the "Administration du Cadastre et de la Topographie".

Figure 5-3: Map example created with the classes of the BD-L-TC. On the left a map of Garnich on a scale of 1:5 000 and on the right a map of the same town on a scale of 1:20 000. (picture source: http://www.etat.lu/ACT)

Part 5.05 Digital Elevation Model’s

Different types of surface models were tested for representation and rectification. A Triangulated Irregular Network (TIN) was used as a 2 ½ dimensional representation of the data. For the image rectification we had to calculate a Digital Elevation Model (DEM).

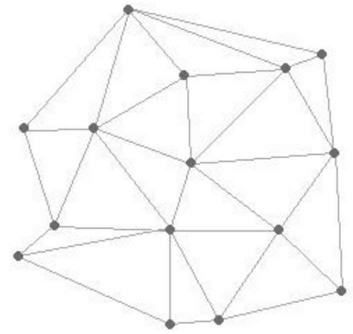

Figure 5-4: TIN - Triangular Irregular Network in which lines triangulate points, usually at different elevations, to appear three dimensional upon shading.

(a) Description of a Triangulated Irregular Network (TIN)

A method for representing geographical features is athe Triangulated Irregular Network (TIN), which connects all points in an area with lines to form a system of triangles

Figure 5-4). The traditional use of TIN’s was to develop contour maps from point elevation data. In GIS, TIN’s are often used as the basis for 2 ½-D renderings of topography upon which other layers of data can be draped.

(b) Digital Elevation Model (DEM)

A digital elevation model (DEM) is a representation of the earth’s surface over some area. It is a digital file consisting of terrain elevations for ground positions at regularly spaced horizontal intervals and is stored as a raster file (ASCII or binary) that contains spatial elevation values in a regular grid pattern in the raster format. A DEM becomes more accurate as the distance between grid points decreases.

DEM’s can be interpolated with Ground Control Points (GCP) of private and governmental offices. As the points have to be measured in field for large areas, the point density is mostly low and therefore only raster files of 50 to 150 metres cell size are useable. A middle resolution can be reached with DEM’s created during ortho-rectification of stereo-images from special firms. At present the highest resolution is available by scanning the earth's surface from airplane, space shuttle or satellite. Special aerial raster scanning techniques allow DEM's with a raster cell size on a scale of centimetres.

Figure 5-5: Point density grid of the official ground control points (GCP) of the vector-database «BD Topo/Carto luxembourgeoise (BD-L-TC)» from the "Administration du Cadastre et de la Topographie"

An important part of the assay was the creation of a DEM for the study-region. This allowed to create three-dimensional representations of the area, and to drape aerial imagery and satellite imagery of the terrain.

Remark: As no existing DEM's on a reasonable scale were available for the present project, we had to create our own.

In order to create a digital elevation model it is necessary to have ground control points (GCP) with elevation information. The accuracy of the interpolated DEM is strongly dependent on the density of the points.

The density of the pointcot-theme (GCP) is high in populated areas and low on the tops of the hills and in the valleys near the German border. (Figure 5-5). The point density is high enough to create a DEM for ortho-rectification but will bring low results in the those valleys where the rivers flow.

In order to obtain a higher resolution and accuracy in the valleys, which were the focus of our interest, we had to create a denser point theme. Therefore we used the high information of the elevation isolines theme from the vector database BD-L-TC.

(c) Spans Isolines to Point algorithm

(i) Algorithm description

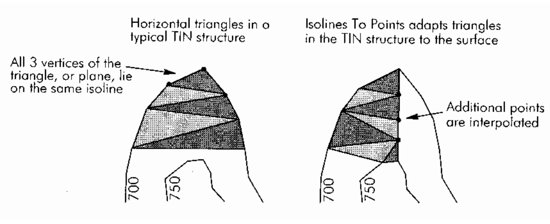

Figure 5-6: Generating additional point-information with SPANS Isolines to Point algorithm

The isolines to point function converts line or area data containing Isolines to Point data (Figure 5-6). Isolines are lines or areas on a map, which indicate a constant value such as temperature, rainfall or elevation. The function is particularly appropriate for converting isolines representing elevation to point data that is suitable for generating a DEM (see also Map 1-1 DEM - Modelling).

The algorithm interpolates additional points to define critical features such as valley bottom and ridges in the following situations:

- Two points on one isoline are further apart from each other than compared to the average distance between points
- Upwards of an outstanding point on a ridge line
- Downwards of an outstanding point on a ridge line.

More details about the Isoline to Point algorithm can be read in the SPANS Topographer Guide.

(ii) SPAN isolines and GCP combination

The accuracy of the GCP shape file was higher but the density was lower than the spans isolines point (SIP) shape file. Therefore we deleted all SIP in a buffering zone of 25 metres around the GCP's (= half cell size of the DEM).

Figure 5-7: Point-density grid of all elevation points (AEP) used for the digital elevation model

Merging both grids to one single elevation grid we obtained a new elevation point shape file (all elevation points, AEP) with a higher point-density. This is shown in Figure 5-7.

This can be seen between Grundhof and Bollendorf where the point-density is between 800 and 1100 points per square kilometre.

(d) Additional Data and Information

Because of the borderline between Luxembourg and the Federal Republic of Germany -Rhineland-Palatinate- it was necessary to use supplementary information for the DEM, ortho-rectification and data interpretation. That information, mostly GCP's, consisted of generated data from the following CD-CD-Rom products:

- CD - Rheinland Pfalz 1:25 000
- CD - Carte topographique 1:25 000 “Au-delà des Frontières”

These points are already integrated in the analyses of the point density.

Part 5.06 Raster-data

The aerial photographs of the Sûre river were provided (hardcopy) by the "Administration du Cadastre et de la Topographie (ACT)" and the "Administration des Ponts & Chaussées (P&C)". A number of 14 aerial pictures for the predefined section of the Sûre and Alzette rivers and 6 aerial pictures of the upper Sûre were selected (Table 5-5).

Table 5-5: Relevant parameters of the selected habitat assessment aerial photographs of the ACT and P&C **(italic values were calculated by scale and image size)**

picture-ID	scale	flight date	aircraft altitude	flight time	sensor	calibration protocol
		yyyy-mm-dd	m a.s.l.	hh:mm:ss		
10-0634	1/10 000	1994-05-31	3314	13:26:15	RMK TOP 15	0271
10-0632	1/10 000	1994-05-31	3309	13:25:44	RMK TOP 15	0271
10-0630	1/10 000	1994-05-31	3302	13:25:12	RMK TOP 15	0271
10-0628	1/10 000	1994-05-31	3300	13:24:40	RMK TOP 15	0271
10-0674	1/10 000	1994-05-31	3349	13:54:50	RMK TOP 15	0271
10-0668	1/10 000	1994-05-31	3337	13:48:26	RMK TOP 15	0271
10-0669	1/10 000	1994-05-31	3343	13:48:41	RMK TOP 15	0271
10-0625	1/10 000	1994-05-31	3369	13:17:18	RMK TOP 15	0271
10-0570	1/10 000	1994-05-31	3347	12:57:33	RMK TOP 15	0271
10-0563	1/10 000	1994-05-31	3355	12:51:43	RMK TOP 15	0271
10-0510	1/10 000	1994-05-31	3377	12:32:29	RMK TOP 15	0271
10-0494	1/10 000	1994-05-31	3403	12:24:01	RMK TOP 15	0271
10-0441	1/10 000	1994-05-31	3274	12:05:42	RMK TOP 15	0271
10-0370	1/10 000	1994-05-31	3305	11:25:21	RMK TOP 15	0271
06-0779	1/6 000	1995-07-24	*910*	no	UAg 1036	no
06-0780	1/6 000	1995-07-24	*910*	no	UAg 1036	no
06-0781	1/6 000	1995-07-24	*910*	no	UAg 1036	no
06-0782	1/6 000	1995-07-24	*910*	no	UAg 1036	no
06-0783	1/6 000	1995-07-24	*910*	no	UAg 1036	no
06-0784	1/6 000	1995-07-24	*910*	no	UAg 1036	no

The image-ID was composed of the scale and the photograph registration identification number. All other image relevant parameters of the aerial photographs can be read in Table 5-5. Not all photograph information was available. Estimated and calculated values as the aircraft altitude during the photograph were in italic numbers.

The RMK TOP15 images were flown on 31st May, 1994 at about 1 p.m. at a height of 3 300 till 3 400 metres above sea level. The ground approximate resolution was about 1:10 000. The calibration protocol has the registration number 0271. The UAg1036 aerial photographs were taken on 24th July, 1995 with an approximate resolution of about 1:6 000.

All historical aerial photographs were provided by the “Administration des Ponts et Chaussées (P&C)”. The picture series date from the years 1972 to 1998. Not all the relevant parameters of the aerial photographs are known. All known parameters of the images can be read in Table 5-6.

Table 5-6: Relevant parameters of the selected historical aerial photographs from 1972 - 1998 of the P&C (**italic values are calculated by scale and image size)**

picture-ID	**scale**	**flight date**	**aircraft altitude**	**flight time**	**sensor**	**calibration protokol**
		yyyy:mm-dd	m a.s.l.	hh:mm :ss		
03-3449	1/3 000	1972-03-13	no	no	no	no
03-3450	1/3 000	1972-03-13	no	no	no	no
03-3451	1/3 000	1972-03-13	no	no	no	no
03-3452	1/3 000	1972-03-13	no	no	no	no
03-3453	1/3 000	1972-03-13	no	no	no	no
03-3454	1/3 000	1972-03-13	no	no	no	no
06-4588	1/6 000	1982-04-15	no	no	no	no
06-4589	1/6 000	1982-04-15	no	no	no	no
06-4590	1/6 000	1982-04-15	no	no	no	no
06-4591	1/6 000	1982-04-15	no	no	no	no
06-4592	1/6 000	1982-04-15	no	no	no	no
06-4593	1/6001	1982-04-16	no	no	no	no
06-1032	1/6 000	1992-07-10	*916*	no	Wild 15/4 UAGA-F	no
06-1033	1/6 000	1992-07-10	*916*	no	Wild 15/4 UAGA-F	no

The geographic position of the historical aerial photographs in the east of Luxembourg along the Sûre and Alzette rivers can be seen in Map 1-2 Overview.

Part 5.07 Scanning parameters

(a) Scanning with TOPAZ image-scanner

All aerial photo-graphs existed only as hard copy and had to be scanned on a special image scanner. Such a scanner for aerial photographs is very expensive. The Institute of Geography of the Leopold Franzens University, owner of such an image scanner, provided permission to use it.

(b) Scanner-Type

The scanner is an aerial image scanner Line-Color® May, 1999 by the firm Heidelberger Druckmaschinen Aktiengesellschaft Business Unit Prepress Siemenswall (http://heidelberg.com).

(c) Scanner settings

We used mostly the standard settings of the Topaz–scanner. All scanner settings are listed in Table 5-7 grouped by the photograph date, scale and colour.

Table 5-7: Topaz-Image Scanner settings for the different types of aerial photographs

date	**1995**	**1998**	**1995**
image type	**colour**	**colour**	**colour**
scale	**1:10 000**	**1:6 000**	**1:6 000**
calibration	Kodak Reflective Topaz	Kodak Reflective Topaz	Kodak Reflective Topaz
contrast	brighter	standard	standard
colorflsist	landscape	standard	standard
light corr.	corrected	not corrected	not corrected
CMYK corr.	not corrected	not corrected	
filter	standard	standard	standard

date	**1992**	**1998**	**1982/1972**
image type	**colour**	**colour**	**black & white**
scale	**1:6 000**	**1:3 000**	**1:3 000**
calibration	Kodak Reflective Topaz	Kodak Reflective Topaz	Gray Scanner General
contrast	overexposure	standard	shaded
colorflsist	landscape	standard	standard
light corr.	not corrected	not corrected	corrected
CMYK corr.	not corrected	not corrected	
gray- Korr			not corrected
filter	standard	standard	standard

(d) Scanner parameters

The following Table 5-8 shows the scanning parameters used for the aerial photographs. Every aerial photograph dataset was scanned in different settings for quality and scale reasons and the estimated ground resolution necessary to analyse and interpret the digital images for habitat assessment purposes.

Table 5-8: Scan parameters of all aerial photographs with the estimated ground resolution

image-ID	image size	scan resolution	focal length	covering surface	ground resolution
	[mm]	[dpi]	[mm]	[km²]	[m]
10-0634	230*230	1180	153.462	24.67	0.43
10-0632	230*230	1180	153.462	24.60	0.43
10-0630	230*230	1180	153.462	24.49	0.43
10-0628	230*230	1180	153.462	24.46	0.43
10-0674	230*230	1180	153.462	25.19	0.43
10-0668	230*230	1180	153.462	25.01	0.43
10-0669	230*230	1180	153.462	25.10	0.43
10-0625	230*230	1180	153.462	25.50	0.43
10-0570	230*230	1180	153.462	25.16	0.43
10-0563	230*230	1180	153.462	25.28	0.43
10-0510	230*230	1180	153.462	25.62	0.43
10-0494	230*230	1180	153.462	26.01	0.43
10-0441	230*230	1180	153.462	24.08	0.43
10-0370	230*230	1180	153.462	24.54	0.43
06-0779	230*230	950	151.69	1.90	0.23
06-0780	230*230	950	151.69	1.90	0.23
06-0781	230*230	950	151.69	1.90	0.23
06-0782	230*230	950	151.69	1.90	0.23
06-0783	230*230	950	151.69	1.90	0.23
06-0784	230*230	950	151.69	1.90	0.23
03-3449	235*235	1100	no	0.50	0.17
03-3450	235*235	1100	no	0.50	0.17
03-3451	235*235	1100	no	0.50	0.17
03-3452	235*235	1100	no	0.50	0.17
03-3453	235*235	1100	no	0.50	0.17
03-3454	235*235	1100	no	0.50	0.17
06-4588	235*235	900	no	1.99	0.20
06-4589	235*235	900	no	1.99	0.20
06-4590	235*235	900	no	1.99	0.20
06-4591	235*235	900	no	1.99	0.20
06-4592	235*235	900	no	1.99	0.20
06-4593	230*230	900	no	1.90	0.20
06-1032	230*230	950	152.73	1.90	0.22
06-1033	230*230	950	152.73	1.90	0.22
06-0792	230*230	950	151.69	1.90	0.22
03-4210	230*230	600	153.37	0.48	0.18
03-4277	230*230	600	153.37	0.48	0.15

03-4278	230*230	600	153.37	0.48	0.17
03-4279	230*230	600	153.37	0.48	0.17
03-4280	230*230	600	153.37	0.48	0.15
03-4282	230*230	600	153.37	0.48	0.15

The image size corresponded to the complete image space with the image fiducial for the scanned part of the aerial photographs. The scan resolution was chosen to get a realistic ground resolution and to guarantee a proper ground resolution after the ortho-rectification and mosaicing, where a common pixel size for an image set had to be set. The real ground covering surface of an aerial photograph depended on the camera type and the scale (aircraft altitude during the photograph). In the Table 5-8 the covered surface is indicated in square kilometres.

Part 5.08 Picture Ortho-Rectification

(a) Overview

Ortho-rectification is simply the process of removing scale variations from a remotely sensed image, such as an aerial photograph, SPOT satellite image, radar image, etc. The actual causes of scale variations in images differ for each type of sensor, and therefore the procedure used to ortho-rectify an image depended directly on the type of sensor used to collect the image. In the case of aerial photography, scale variations are caused by small tilts in the camera at the instant of exposure, as well as by the natural point-to-point variations in the elevation of the terrain being imaged. Scale variations are also caused by the distance variation of objects out from the principle point of the camera, as it is a perspective projection. Once these variations in scale have been removed from a photo, it becomes a true image map of the ground, where “map” is defined as a constant scale representation of a portion of the earth’s surface.

Normally, the ortho-rectification process produces an image, which is also geo-referenced. Moreover, the scale variations of the image are not only removed, but the x and y axes of the image are aligned with the east and north axes of the used map projection, and each pixel in the image is geo-coded with its associated coordinate in the map projection.

(b) Projection settings in ERDAS IMAGINE 8.5

The Figure 5-9 shows the projection settings used for all aerial photographs in ERDAS Imagine 8.5 OrthoBase. The projection is necessary for the geo-referentiation of the ortho-rectified images.

(c) Camera Calibration Report

(i) Overview

It is useful to have access to the camera calibration report being used to take the aerial photograph. The camera calibration report contains pertinent information such as the focal length of the camera, the calibrated positions of fiducial reference points found on the corners and mid-edges of most aerial photographs, and precise maps of the optical distortions caused by irregularities in the camera's lens. The camera calibration report allows maximum accuracy in the ortho-rectification process, but it is not absolutely necessary. In some cases of this aerial photograph set the camera calibration report was not available, thus allowing the use of approximate values instead of the unknown camera parameters.

(ii) Existing calibration certificate

Only for the aerial photographs 1:10 000 from the "Administration du Cadastre et de la Topographie (ACT)" one calibration protocol of the "Deutscher Kalibrierungsdienst (DKD)" was available. The camera was an aerial survey camera of the Carl Zeiss manufactory, Oberkochen (Germany). The camera type is RMK TOP 15 with the serial number 142 830. The focal length was 153.4610 mm, further information was collected in the Table 5-7.

(iii) Additional organised information

Basic information about the other aerial photographs from the "Administration des Ponts et Chaussées (P&C)" had to be organized by internet search. Nevertheless, due to the missing camera calibration protocols (Table 5-7) only the four image corner fiducials could be set to guarantee an acceptable RMSE. Figure 5-2 shows an example of measured image fiducials in the ERDAS 8.1 Frame Editor. Every aerial image got four corner fiducials with maximal 24 pixel RMSE for a 0.5 metre ground resolution.

Chapter 6 Results and discussion

Part 6.01 DEM

Digital Elevation Models or DEM's are increasingly becoming the focus of attention within the larger realm of digital topographic data. The process to create our DEM is described on Map 1-1 DEM - Modelling and the result is shown on Map 1-2 DEM - Overview.

Ground control points (GCP) are very accurately measured in the field, but their density is too low to create a DEM for river-related analyses (see also Part 5.05(b)).

Figure 6-1: Contour map of the DEM interpolation of the GCP for the region 1, red circles indicating the false interpolations.

Several valley areas are so high that not really existing lakes are interpolated in the DEM (see Figure 6-1 red circles).

Therefore we generated the elevation information of the isolines as elevation points (ILP). But the DEM generated only with isolines vertex points ILP is too inaccurate especially for the top and the bottom (hollow) of the slope areas (see Figure 6-2 red square doted line).

The 3D-Surface of the ILP shows extreme steep slopes with non-existing cuts (valley). The spans isolines points (SIP)-DEM will respect this fact and interpolate realistic modelled hill shapes (see Figure 6-2). But as far as the river valley is concerned the elevation point information is insufficient.

Figure 6-2: Contour map of the DEM interpolation of the SIP for the region 1, red square doted line indicating the false interpolations.

Therefore, the SIP-DEM has to be combined with the GCP-DEM for to interpolate a definitive AEP-DEM (Figure 6-3).

The minimal reasonable cell size for the AEP-grid is defined by Golden Software INC. program Surfer®8 as a grid line geometry report for a optimal cell size of 30.28 metres.

Figure 6-3: Contour map of the DEM interpolation of the AEP for the region 1

For this cell size the grid shows over-interpolations for various elevation points in some areas due to irregular point density.

The definitively used cell size for the grid interpolation was set to 50 x 50 metres.

This AEP-DEM was used as elevation information during the ortho-rectification processing for all aerial photographs.

Figure 6-4 shows the result of the grid calculation SIP minus GCP. It shows that the GCP-grid would produce large non-existing lake areas in the valleys and over-inter-polated hills (blue) tops.

Figure 6-4: Grid analysis (SIP minus GCP) for the region 1. The green parts show a strong difference for the over-interpolated elevation values especially for the valleys and the blue parts on the tops of the surrounding hills.

Remark: It seems to be impossible to create an accurate DEM respecting the valley bottom and river typology with this dataset.

Nevertheless we had to create a DEM for the ortho-rectification of the aerial photographs. We used as interpolation method the kriging technique with the variogram settings indicated in Figure 6-5. Figure 6-6 shows the results of the generated AEP-DEM for the whole study area. The accuracy, shown exemplary for the region 1 in Figure 6-1, Figure 6-2 and Figure 6-3, is different because of

Figure 6-5: Variogram calibrations for AIP different elevation information based on several data sources.

Figure 6-6: 3D surface of the generated digital elevation model of the whole study area in the eastern part of Luxembourg with important villages of the region. For 1 and 2 elevation information of the Luxembourg government, 3 additional elevation in a distance of approximately 300 metres had to be taken from topographic maps , 4 is the river basin of the Mosel/Moselle.

The regions of Figure 6-6 indicated with 1 and 2 show good results. Number 1 indicates the region where the historical aerial photographs belong to.

The region 3 describes the borderline to Germany. The elevation information of the German part had to be taken from 1:50 000 topographic maps. The point density was about 300 metres. The DEM was not usable for our purpose on the German site. The number 4 is the region of the estuary of the Sauer/Sûre river and did not directly take part in the study. For a higher resolution see Map 1-2 DEM Overview.

Especially for the bottom of the river valley, the AEP interpolation was better. All information of the GCP can be integrated in the projection.

Remark: Nevertheless, this DEM is only a makeshift. It would be better to generate a DEM only from GCP's or by raster scanning techniques from airplane.

Part 6.02 Image ortho-rectification

The benefit of ortho-rectified photographs (ORP) for GIS applications is the constant scale of the ortho-rectified photograph which means that the distance measured between any two points in the image can be converted to its corresponding distance on the ground by multiplying it by a single scale factor. As a result, the ORP are used in a Geographic Information System (GIS) as a base map layer over which vector layers, such as vegetation cover, river and road networks, can be laid (see map 3). Depending on the scale, the accuracy varies.

On map 3 we see the ORP mosaic of six aerial photographs from the year 1996 on a scale of 1:6 000 with an appropriate pixel size of 0.25 m. The mapped scene is shown for the Sûre river over a length of about 3.5 kilometres between the estuary of the Alzette (coord. 75.978; 101.540) and about 1.5 kilometres above Erpeldange (coord. 75.423; 104.865), as an example for all rectified aerial photograph sets. The left image shows the ORP overlaid with the coordinate network for the Luxembourg projection LuRef. The right ORP mosaic shows the same extent overlaid with the GIS vector dataset from the "Administration du Cadastre et de la Topographie" of the Luxembourg government.

Figure 6-7and Table 6-1 show that the mean accuracy is higher for the theme river Sûre and tree/shrubs. The variance shows that the measurements differ for the measured position in the ORP. The measured accuracy is more constant for the themes buildings, vegetation, railroad and roads (variance 0.41-0.50). It seems that the accuracy of the themes within the GIS-vector dataset varies.

Remark: Even when the accuracy varies in the ORP scene, it is very difficult to achieve a true location effect with other image rectification methods, such as e.g. image warping. Therefore ortho-rectification is the method of choice when preparing an image set for use in a GIS.

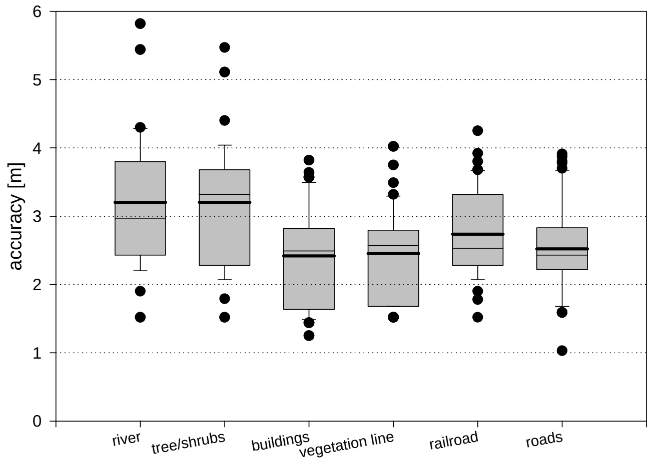

Figure 6-7: Box plots for the measured accuracy (N=48) of the categories river, buildings (polygon themes) and threes/shrubs, vegetation lines, railroad and roads (polyline themes). The plot shows the mean (solid dash) median (thin dash), 10th and 90th percentiles as vertical boxes with error bars and outliers (dots). Error bar values are column means.

Table 6-1: Statistics of the measured accuracy (N=48) of the categories river, buildings (polygon themes) and threes/shrubs, vegetation lines, railroad and roads (polyline themes)

	river Sûre	**trees / shrubs**	**buildings**
N	48	48	48
mean	3.10	3.21	2.42
max	5.82	5.47	3.82
min	1.46	1.52	1.25
stdev.	1.08	0.93	0.68
variance	1.14	0.85	0.45
	vegetation line	**railroad**	**roads**
N	48	48	48
mean	2.45	2.74	2.52
max	4.02	4.25	3.91
min	1.39	1.51	1.03
stdev.	0.66	0.63	0.71
variance	0.42	0.41	0.50

Part 6.03 Historical Images

(a) Image Mosaicing

If it is necessary to form a seamless image map covering large areas ORP can be put together. Image rectification algorithms, such as image warping, generally have problems with achieving seamless mosaics, and thus roads and other features generally do not line up across mosaic boundaries. In order to achieve a seamless match across images, simple image warping requires a very time-consuming collection of many tie points between adjacent images.

Remark: Even then results are not always perfect, and the correct geometric representation of the ground is distored.

The following figures show some of the problems related to image mosaicing. All mosaicings were made with ERDAS Imagine 8.5

Example

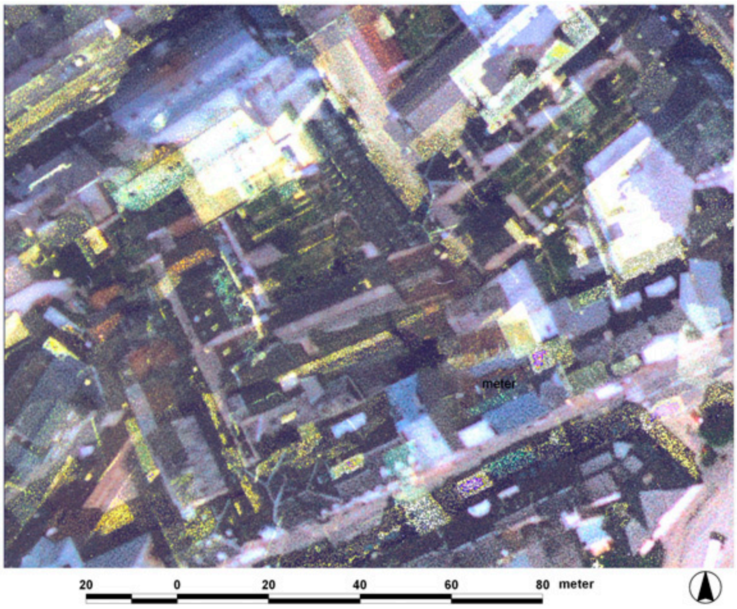

Figure 6-8: Selection of the ORP mosaic of the aerial photographs of 1995, scale 1:6 000 with a pixel size of 0.25 metres. The scene shows buildings of the town of Ettelbruck

Commentary

The overlay of two ortho-rectified aerial photographs is nearly impossible in the border area of the images. The perspective changes changing during the flight of the aeroplane and high buildings change their relative location to other buildings.

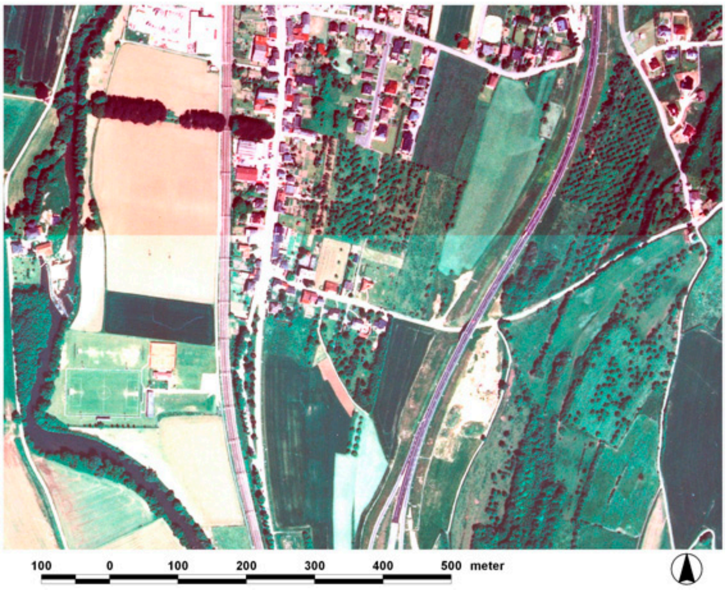

Figure 6-9: Selection of the ORP mosaic of the aerial photographs of 1994, scale 1:10 000 with a pixel size of 0.5 metres. The scene shows the linear intersection of two images.

While making mosaicing of two ORP of different colour, the intersection zone can be linear, smooth or interpolated for the whole zone. The used method depends on the motive the images are produced for. In our case we tried to keep our ORP as original as possible to guarantee an optimal habitat assessment evaluation.

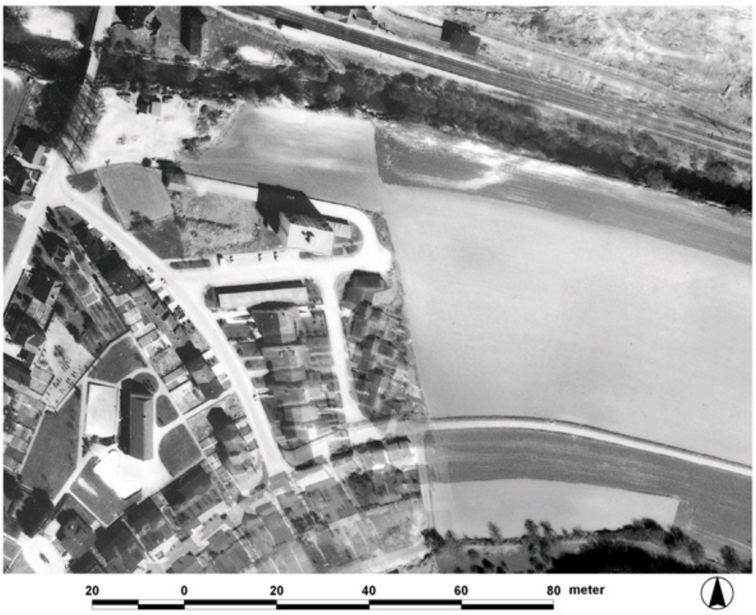

Figure 6-10: Selection of the ORP mosaic of the aerial photographs of 1982 in black and white, scale 1:6 000 with a pixel size of 0.3 metres. The scene shows the mosaic zone of two images.

Older ORP in black and white show the same problem for mosaicing as the ORP in colour. Buildings and trees make the ORP mosaic lose their sharpness especially as far as these regions are concerned. Finally, it is important to decide individually which method used to mosaic ORP will bring the best results or in some cases even subset the ORP without mosaicing.

(b) Historical ortho-rectified photographs

Map 4 shows time series of ORP of the years 1972, 1982, 1992 and 1998. The ORP of the years 1972 (1:3 000) and 1982 (1:6 000) are still in black and white. The ORP of 1992 (1:6 000) and 1998 (1:6 000) are in colour. The aerial photographs were being taken by the “Administration des Ponts et Chaussées (P&C)” for reasons of road planning, construction and surveying over a period of 25 years. The location of the historical ortho-rectified photographs is shown on Map 2 – Study Cites- Overview.

Remark: Historical aerial photographs have to be ortho-rectified before they can be brought together with a GIS-database.

Figure 6-11: Image processing to create GIS-usable ORP

The ORP production process is shortly illustrated in Figure 6-11 and the results are shown on map 4 - History. It was possible to create an image set for about 25 years of the river (Alzette) over a length of about 2 000 metres. These aerial photographs possess more than only anthropogenic road related information. Environmental changes were registered as well. In this case for instance, the temporal changing of the bank vegetation can be observed.

As a consequence historical data may help as a guide for conservation measures, revitalisation and renaturalisation preparations.

Chapter 7 Conclusion

We state that the ortho-rectification of the aerial photographs depends on various factors:

- image scale and quality
- the age of the aerial photograph
- scan quality
- the overlapping area of the image set
- the existence of an flight protocol

Part 7.01 Dataset and Fractals

It is important to note that geographic features and the symbology used to represent them, e.g. point, line, or polygon, are dependant on the graphic scale (map scale) of the data. Some features are represented by point symbology in a small scale, e.g. villages on a 1:10 000 map, and by spacial symbology on a larger scale, e.g. villages on 1:6 000 or 1:3 000 maps. Accordingly, the accuracy of the feature's location is fuzzier on a smaller scale than on a larger one. The generalization of features is an inherent characteristic of data presented on a smaller scale.

Part 7.02 Picture information

Generalizing data to a smaller scale, means loss of detail which cannot be recreated! Therefore, it is important to guarantee the highest resolution possible at the beginning, but oversizing an image makes no sense either. When the scale of a map increases, e.g. 1:3 000 to 1:10 000, the relative size of the features decreases. The creation of the GIS dataset from the “Administration du Cadastre et de la Topographie” of the Luxembourg government is based on aerial photographs on a scale of 1.10 000. Therefore, the interpretation, accuracy and details of the GIS-vector dataset cannot be as complex as the elements in the used ORP. Features change in shape, e.g. boundaries become less detailed and more generalized. Accordingly, the use of data from vastly different scales will result in many inconsistencies between the number and type of features. This can be a problem especially for historical ORP because of their reduced availability and diversity in available scales.

> *Remark: The use and comparison of geographic data from vastly different source scales is very inappropriate and can lead to significant errors in geographic data processing.*

Part 7.03 Data Accuracy and Quality

The quality of data sources for GIS processing has become an ever-increasing concern among GIS application specialists. With influx of GIS software on the commercial market and the accelerating application of GIS technology to problem solving and decision making roles, the quality and reliability of GIS products has become under close scrutiny. Much concern has raised as to the relative error that may be inherent in GIS processing methodologies. While research was ongoing, and no finite standards had been adopted in the commercial GIS marketplace yet, first steps were taken by the Open-GIS consortium. Several practical recommendations have been identified which help to locate possible error sources, and define the quality of data.

Basically two types of accuracy exist. These are positional and attribute accuracy. Positional accuracy is the expected deviance in the geographic location of an object from its true ground position. There are two components to positional accuracy: relative and absolute accuracy. Absolute accuracy concerns the accuracy of data elements with respect to a coordinate scheme, e.g. UTM. Relative accuracy concerns the positioning of map features relative to one another like measured in chapter Part 6.02 Image ortho-rectification. In our case, relative accuracy is of greater concern than absolute accuracy. For environmental purpose, we can live with the fact that survey area coordinates do not coincide exactly with the survey objects. Attribute accuracy is as important as positional accuracy. It also reflects estimates of the truth. Interpreting and depicting boundaries and characteristics for river bank vegetation or river polygons can be exceedingly difficult and subjective.

Quality defines the fitness for use for a specific data set. Data that is appropriate for one application may not be fit for another one. It is fully dependant on the scale, accuracy, and extent of the data set, as well as on the quality of other data sets of use. The recent U.S. Spatial Data Transfer Standard (SDTS) identifies five components to data quality definitions.

These are:

- ❖ Lineage
- ❖ Attribute Accuracy
- ❖ Completeness
- ❖ Positional Accuracy
- ❖ Logical Consistency

The identification of positional accuracy is important. This includes consideration of inherent errors (source errors) and operational errors (introduced errors). The attribute accuracy helps to define the quality of the data. This quality component concerns the identification of reliability, or the level of purity (homogeneity) in a data set. The Logical Consistency is concerned with determining the faithfulness of the data structure for a data set. This typically involves spatial data inconsistencies such as incorrect line intersections, duplicate lines or boundaries, or gaps in lines. These are referred to as spatial or topological errors. The final quality component, completeness, includes consideration of holes in the data, of unclassified areas, and any compilation procedures that may have caused data to be eliminated.

While error will always exist in any scientific process, the aim of GIS processing should be to identify existing errors in data sources and to minimize the amount of errors added during processing. An awareness of the error status of different data sets will allow the user to make a subjective statement on the quality and reliability of a product derived from GIS processing.

Several comments and guidelines on the recognition and assessment of errors in GIS processing are produced in papers on the subject. The most important are summarized as follows (Childs, 1002):

- There is a need for developing error statements for data contained within geographic information systems.
- The integration of data from different sources and in different original formats (e.g. points, lines, and areas), at different original scales, and possessing inherent errors can yield a product of questionable accuracy.
- The accuracy of a GIS-derived product is dependent on characteristics inherent in the source products, and on user requirements, such as the scale of the desired output products and the method and resolution of data encoding.
- The highest accuracy of any GIS output product can be only as accurate as the least accurate data theme of information involved in the analysis.
- Accuracy of the data decreases as spatial resolution becomes more coarse.
- As the number of layers in an analysis increases, the number of possible opportunities for errors increases.

Part 7.04 Recommendations and perspectives

(a) Recommendations for cost and ease of use

Today the hardware components are today no more the limiting factors for good ortho-rectification. On the other hand there is no real “best” ortho-rectification software package. The ortho-rectification software for any particular individual or organization is completely dependent on general considerations such as costs, ease of use, accuracy, flexibility, and support. Low costs and easy-to-use solutions do not necessary compromise on accuracy or photogrammetric rigor. Several products are available today. They can be grouped in several groups depending on cost, learn effort and field of use.

We used several software packages. For environmental purposes the best compromise between software costs and software handling, accuracy, data transport and formats has to be arrived at. Nevertheless, it seems impossible to find one software package for all manipulation.

Table 7-1: Used software, costs and usability

Software	Costs	Learn effort	Field of use	% of work
Arc-View 3.2	middle	middle	GIS and mapping	25
several ESRI extensions	freeware	low	data transformation	10
ERDAS Imagine 8.5	very high	very high	ortho-rectification, mosaicing and image subset	45
Surfer 8	middle	middle	Statistics and interpolations	10

The goal should be to provide the scientist and end user with the power, rigor, benefits, simplicity and ease of use of simple rectification packages. GIS-software should not require extensive training in photogrammetric theory or principles. It should be an easy-to-use package to guarantee the wide dispersion of this future directive technique.

(b) Perspective

The GIS techniques have the potential for widespread application to resource evaluation, planning and management (Andresen, 1002). Modelling provides the opportunity for realistic represention of the three-dimensional nature of natural landscapes. Looking into the future of information technology is a high-risk activity for the possible evaluation of GIS priorities (Maidment, 1993). Technologically, the effective acquisition and manipulation of high-resolution spatial data will become commonplace to every individual for assessing the development factors in an area (Weiers, 1999).

Further increase in efficiency and limitless access to information may lead to real detriment. The huge amount of data may cause problems while analysing and interpreting data (Blaschke, 1002). New techniques like object oriented image segmentation and context based analyses may facilitate data classifications and interpretations.

Important critical points of Knauer were presented in Ulm (Germany) 1992 (published in Zölitz, 1999):

- It will be impossible to bring the complexity of the nature in a GIS.
- Environmental GIS is often not protected by the law.
- Data protection and GIS are contra-productive.
- Environmental GIS is a never-ending story.
- Who will pay for GIS?
- Software implementations is mostly missing.
- Not everything is possible with a GIS.

GIS will invigorate and progressively subsume to modelling management and operational control systems. But until then a lot of work has to be done.

Chapter 8 Acknowledgements

I want to thank the UNIGIS-Team of the Institute of Geography and Applied Geoinformatics of the University of Salzburg for their two years guidance and diverse helps. My friends Peter ACS, Renate Ettinger, Monica Tolotti and Ronald Schmitt, and Danièle Di Cato for constructive comments.

The GIS-data and aerial imagery were provided by the “Administration du Cadastre et de la Topographie” and “Administration des Ponts & Chaussées (P&C)” whom I would like to thank not only for the data but for the cooperation in special.

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