D. Fritsch, M. Englich & M. Sester, eds, 'IAPRS', Vol. 32/4, ISPRS Commission IV Symposium on GIS - Between Visions and Applications, Stuttgart, Germany.

HIGH RESOLUTION DIGITAL TERRAIN MODELS OF SHALLOW LAKE BASINS - TOWARDS MODELLING DYNAMICS OF SEDIMENTATION FOR MULTITHEMATIC ECOSYSTEMS RESEARCH

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ABSTRACT

Research on GIS applications in the real world context has to be strengthened besides developing GIS application software itself. An ecologically important field of applications is the integration of GIS technology in wetlands research. Documentation, analysis and modelling of spatial data of wetlands and lakes supports ecological research and planning to the highest extent. High resolution terrain models of lake basins contribute to multithematic investigations especially in the fields of hydrology, limnology and vegetation sciences. Digital terrain models (DTMs) of shallow lakes provide spatial data with high vertical resolution of the slight undulations of the terrain. Spatial dynamics of extensive Research on GIS applications in the real world context has to be strengthened besides developing GIS application sedimentation have to be documented and analysed by establishing two terrain models based on the sediment surface and the surface of quaternary sediments respectively. The DTMs and their difference model are highly efficient data pools for building up time series of topo-chronological change caused by the seasonal and annual dynamics of sedimentation and/or by the water-level-dependent dynamics of the extension of flooded/non-flooded areas. A case study at Lake Fertö (Neusiedler See, Austria, Hungary) proves, that data collection, data analysis and data visualization have to be appropriate and easy to handle on the one hand, but also fully digital with highest precision and utmost multithematic value on the other hand. GIS concepts for monitoring and analysing ecosystems of shallow lakes have to be driven by AT-based research towards the integration of operational digital 4D-models of spatial and thematic topo-chronological data.

1 INTRODUCTION

Not only a hardware-software gap, but also a software-application gap can be stressed when discussing the status quo and the near-future developments in the field of GIS technologies and applications. Thus research on GIS applications in the “real” real world context has to be strengthened besides developing GIS application software itself. A somewhat strange but all the more important field of applications is the integration of GIS technology in wetlands research. Wetlands are the most precious but also the most endangered regions worldwide. International environmental organizations like UNEP and IUCN claim urgent need for harmonizing the documentation, analysis and modelling of spatial data of wetlands and lakes (IUCN, 1994). GIS-based networks of wetland data support ecological research and planning from global to local scale to the highest extent. An important topographic and thematic part of GIS-based wetland monitoring is contributed by the integration of high resolution terrain models of the wetlands and shallow lake basins. Multi-thematic investigations especially in the fields of hydrology, limnology and vegetation sciences highly depend on 2.5D to 3D topographic data. Mapping submersed and littoral vegetation is optimized by the interpretation of high resolution remotely sensed data. CIR-aerial photography and space photography as well as satellite imagery are most important tools for landcover and landuse mapping in wetland regions (Csaplovics, 1995, Csaplovics 1996). Integrating digital imagery with digital terrain models is fundamental for establishing operationalized GISs for ecological monitoring of wetlands and lakes.

Since the early eighties growing needs for creating, maintaining and applying geographical information systems of ecologically unbalanced lakes and their surroundings forced applied research in various fields of remote sensing and GIS.

Limnologists, hydrologists, ecologists and others claimed urgent need for high resolution digital terrain data of lake basins. Especially shallow lakes specifically characterized by dynamics of extensive sedimentation need research on the structure and vitality of littoral vegetation like reed belts, on dynamics of sedimentation in off-shore and vegetation-water-interaction zones and on the variations of water depths and sediment layer thickness respectively (Csaplovics et al., 1996).

2 DTM OF LAKE BASINS

The presented paper stresses research on topographic models of shallow lakes. The term stands for a certain type of lake characterized by very low water depths, alkaline chemistry of water and a more or less dominant influence of dynamics of sediment transport and deposit (Löffler, 1979).

Shallow lakes are often surrounded by extensive belts of aquatic vegetation. The methodology of spatial data collection is thus determined by the heterogeneous structure of the lake floor and its sediment layers both horizontally and vertically. Sonic depth finding may fail because of the lack of homogeneous reflectance horizons. Disturbed reflectance in the regions of aquatic vegetation is caused by dense strata of rhizomes.

Given c for speed of ultrasound in water as $c=(1/(\varkappa \cdot \rho))^{½}$, with for compressibility and for density of water, s for the distance water level-sonar and t for running time of ultrasound, we can derive the water depth z as follows, $z=(c \cdot t)/2 + s$. The RMSE of water depth measurements using conventional sonic depth finders is given by the equation $m_z=\pm(19+0.6z^2)^{1/2}$ (Heyne, 1982). Thus a mean water depth of 2m would give a RMSE of ±4.6cm. The flat terrain of shallow lake basins is often characterized by height differences of as small as 20cm-30cm over a distance in plan of 2km-3km. We therefore need contour line intervals of at least 10cm, claiming a vertical accuracy of height measurement of at least ±2-3cm. It can easily be seen that conventional sonic depth finders do not meet the accuracy requirements for data collection for DTM calculation of shallow lake basins not even in the case of a well-defined reflectance surface.

Vertical sediment profiles are characterized by a non-linear increase of water versus sediment concentration. Thus finding a homogeneous reflectance surface could only be supported by in situ core drilling at representative sites selected by progressive sampling. Furthermore the functioning of sonic depth finding is limited in complex vertical profiles of varying root-water-sediment-ratios in the aquatic vegetation belts.

As digital terrain models of shallow lake basins have to provide data with highest vertical accuracy of the slight undulations of the terrain, not only advanced in situ methods of depth finding, but also carefully specified methods of geodetic point measurements with highest vertical accuracy possible have to be established. Trigonometric height measurement supported by precise ranging from reference stations to remote reflector stations allows both progressive sampling of data as well as elimination of atmospheric effects. Spatial dynamics of extensive sedimentation have to be documented and analysed by establishing two terrain models based on the sediment surface and the surface of the quaternary sediments respectively. Data collection in situ should thus depend on sophisticated methods of sounding based on specially adapted high precision levelling rods. Pilot studies proved, that the RMSE of height measurement m_h was better than ±2.2cm within a range of 3km. Thus the calculation of height contour lines with a distance of 10cm was acceptable to some extent. Nevertheless it was evident, that the accuracy of position will be relatively low depending on the density of contour lines or the flatness of terrain respectively (Csaplovics, 1989).

Given $m_h = \pm 2.2$cm and $\Delta h = 10$cm and a horizontal distance between adjacent contour lines of h_H = (1mm, 5mm, 10mm), the error of position m_p in a scale of 1:25000 will be derived as m_p = (±5.5m, ±27.5m, ±55m), when using the equation $m_p=m_h \cdot h_H / \Delta h$.

The DTMs and their difference model are highly efficient data pools for building time series of topo-chronological change caused by the seasonal and annual dynamics of sedimentation and/or by the water-level-dependent dynamics of the extension of flooded/non-flooded areas. Thus a focal point of DTM interpretation is the calculation and visualization of difference models of the digital terrain data in the form of isolines of thickness of sediment layers and/or tables of sediment volume respectively. Maps based on the intersection of the digital sediment surface data with horizontal planes simulating seasonal and/or annual variations of water levels as well as diagrams of areas and volumes of the water body of the lake in function of varying water levels meet the needs for exact modelling of flooded/non-flooded areas and the water balance of the lake.

Kraus (1987) gives a formula for the RMSE of the difference of two DTMs as follows,

$$m_V\,[m^3] = \sqrt{2} \cdot (n_x \cdot n_y - 3(n_x+n_y)/2 + 9/4)^{1/2} \cdot f_Q \cdot m_h ,$$

with n_x,n_y for the number of grid lines in x- and y-directions, f_Q for the area of one grid element in the horizontal plane and m_h for the RMSE of height of grid points. The finer the grid interval and the higher the accuracy of heights of grid points, the higher the accuracy of the difference model. Building data bases for DTM calculation of wetlands and shallow lakes is thus driven by a strong need for a high density of primary point data and for height measurement of point data with the highest precision possible. Digital sediment models of shallow lakes are thus high resolution spatial and temporal references for future investigations on modelling dynamics of sedimentation. The digital surface model eo ipso and its intersection with simulated water levels represents the status quo of the hydrological volume-water level and area-water level ratios. The integration of results of earlier investigations may provide time series of sedimentation - however to a limited extent due to much lower accuracies of analogue historical data.

3 A CASE STUDY

A case study at Lake Fertö (Neusiedler See) proves, that data collection, data analysis and data visualization have to be appropriate and easy to handle on the one hand, but also fully digital with highest precision and utmost multithematic value on the other hand. Furthermore an impression of the real world value of DTMs of shallow lakes can be given. Lake Fertö, part of the National Park Neusiedler See - Seewinkel, the only national park in Austria meeting the criteria of the International Union for Conservation of the Nature (IUCN), is situated about 50km southeast of Vienna (Austria). USGS level 1 landcover categories are 150 km² open water and about 170 km² wetland vegetation, dominantly reed (*Phragmites australis* L.) (Csaplovics, 1987).

The compilation of the digital terrain models of the Austrian and Hungarian parts of Lake Fertö was terminated in 1996. Sophisticated methods of geodetic point measurements minimized mean height errors to lower than +/-2.5cm. By means of the SCOP-software (Stuttgart Contour Program), (IPF-TUW, 1996), digital terrain models of the recent sediment surface and the surface of quaternary sediments of the lake floor have been calculated covering a region of more than 320km². More than 15000 points per terrain model have been used for grid calculation. These data had been collected following a methodology of progressive sampling in function of the gradient of the slope of the lake basin. Along breaklines and edges, e.g. the sediment edges along the reed-water-boundaries, a high density of point data was provided and additionally enlarged by interpolation. Contour line intervals of 10cm had to be provided to meet the requirements of hydrologists and limnologists. Profiles and perspectives of specific local regions have been calculated and mapped by SCOP-based DTM interpretation (Figure 1).

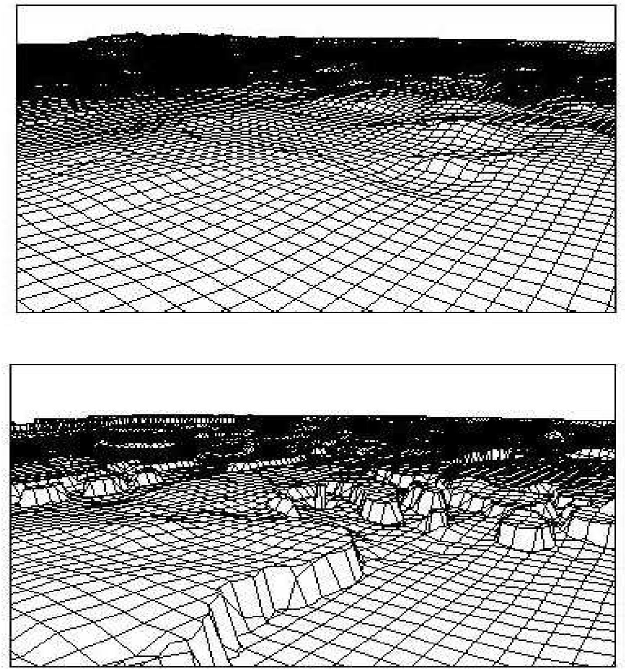

Figure 1. Perspective view of the south-western part of the basin of Lake Fertö; surface of quaternary sediments (upper), actual surface of sediments (lower) (Csaplovics et al., 1997).

The difference model representing the sediment strata was calculated with an accuracy of ±0.01% of the whole volume of sediments deposited in the basin (206.77Mio.m^3). Maps of sediment thickness have been provided in an isoline and raster mode with a contour line interval of 10cm and height intervals of 20cm respectively. These data represent for the first time a high precision, full coverage digital reference for multitemporal modelling of dynamics of sedimentation. Despite much lower accuracies, historical data of 1901 and 1963/1967 have been analysed and integrated with the digital terrain data. Diagrams of time series of volume-water level and area-water level ratios over a period of nearly 100 years have been calculated. Increasing deposition rates of sediments per time interval in the lake basin itself as well as maximum rates of sedimentation along the reed-water-boundaries can be documented (Figure 2).

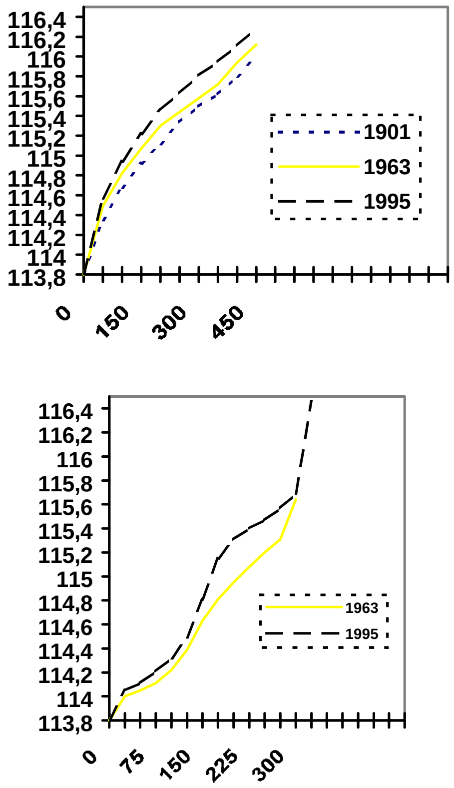

Figure 2. Diagrams of volume-water level ratio (upper) and area-water level ratio (lower) for 1901, 1963/67 and 1995 (Csaplovics et al., 1997).

4 CONCLUSION

Digital terrain models of shallow lakes are basic data pools for building comparative time series of topo-chronological change of sedimentation and/or of the extension of flooded/non-flooded areas. Research has to be stressed on testing the efficiency of integrating new technologies of positioning for collecting high resolution spatial data of wetlands and lake basins. DGPS supported by INS would allow profiling with high geometric accuracy of position and simultaneous depth measurement based on advanced sonar technologies (Hofmann-Wellenhof et al., 1997, Kleinrock, 1992). Nevertheless limits of these high-technology approaches are evident in the real world context, assuming in our case, that the real world is a wetland or a shallow lake basin. Both types of landscape are dominated by heterogeneous patterns of landcover of open water and aquatic vegetation. High costs and sensitiveness of equipment and missions as well as the constraints of the efficiency of sonar depth finding given by the heterogeneity of vertical sediment profiles make it impossible to provide a stand-alone solution for monitoring the morphology of wetlands and lake basins. Integrating indigenous knowledge when collecting primary data for DTM evaluation is often much more efficient than choosing the best technology on the market. On the other hand sophisticated methods of DTM data analysis and interpretation need a certain level of software and hardware technology. It is evident, that real world applications of DTM and GIS technology not necessarily need the solution supported by the highest technology.

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Thus the integration of criteria of intermediate and/or appropriate technologies (IT/AT) has to be strengthened (Yapa, 1990).

Research on the efficiency of methods of spatio-temporal data collection and analysis by remote sensing, DTM and GIS for supporting ecological monitoring is thus driven by a very basic question: what do we want to know and how well do we want to know it (Graetz, 1990). Considering these ambivalences appropriate GIS concepts of monitoring and analysing wetland and shallow lake ecosystems have to be developed further towards the integration of fully operational digital 4D-models of spatial and thematic topo-chronological data.

5 ACKNOWLEDGEMENTS

Research on the Lake Fertö case study was funded by the then Austrian Ministry of Science and Arts and by the Hungarian Academy of Science. Data collection and data correction for the Hungarian part of Lake Fertö was provided by the Department of Geodesy and Remote Sensing at the University of Sopron (Prof.Dr.L.Bácsatyai). DTM calculation and interpretation was done at the Institute of Photogrammetry and Remote Sensing, University of Technology Vienna (Prof.Dr.K.Kraus). Special thanks to Dr.A.Sindhuber, who did the SCOP-based work and was in charge of the project in Vienna.

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