Hydrographical Surveying of the Subaqueous Delta Plain of the River Rhine at Lake Constance

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Key words: Hydrography, inland lakes and waterways

SUMMARY

This paper describes the surveying of the delta plain of the River Rhine at Lake Constance using multi-frequency as well as multi-beam sounding systems. The total area of about 100 km2 was surveyed at the beginning of 2008. The Rhine originates high in the Swiss Alps and enters Lake Constance on Austrian territory. The resulting subaqueous delta is constantly growing due to the enormous load of suspended sediments resulting from erosion processes along its course of more than 100 kilometres. Since 1911, hydrographical surveying is undertaken every ten years to determine the distribution and thickness of sediments in the Lake Constance basin. Within the last 50 years, dams had to be built to displace the mouth of the river by about five kilometres from the original lakeshore to deeper zones of the lake. It was possible to calculate the change in the distribution and amount of sediments based on data from previous bathymetric campaigns calibrated using sediment probes from different places within the project area. Data from a network of gauging stations at major tributaries were used to verify the sediment displacements determined at the delta.

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1. INTRODUCTION

Following the displacement of the mouth of the Rhine at Lake Constance from Rheineck, Switzerland by approximately 12 kilometres to the east to Hard/Fussacher Bay, Austria in 1900, the riverbed in the eastern part of Lake Constance have been surveyed approximately every ten years since 1911. The purpose of the surveys is to document changes in the mouth of the Rhine and the sediments deposited by the Rhine as well as the Bregenzerach and Dornbirnerach in Lake Constance. (Figure 1).

Figure 1: Sedimentation process and the subsequently undertaken embankment dam constructions at the Rhine delta ()

Due to topographical changes in the lakebed as a consequence of sediments deposited by the Rhine as well as the Bregenzerach and Dornbirnerach and the subsequently undertaken lengthening of the Rhine dam towards the lake center, it has been necessary to extend the survey area repeatedly over the decades (Figure 2). The aim of the extension of the Rhine is to alleviate the siltation of the bays on which Fussach, Hard and Bregenz are located.

2. PROJECT DEFINITION AND OBJECTIVES

In spring 2008, the *Gemeinsame Rheinkommission* (Swiss-Austrian Rhine Commission) commissioned the hydrographical surveying of the subaqueous delta plain of the Rhine at Lake Constance and the subsequent analysis of changes in the riverbed since 1999.

This was to be determined from differences in volumes of the digital terrain models between current surveys of the lakebed and those undertaken in 1999 and verified using the sediment data concerning the tributaries (Rhine, Bregenzerach and Dornbirnerach) of the Swiss National Hydrological Service.

Moreover, the survey area for 2008 was to be extended beyond that for 1999 in order to ascertain whether sediments were transported to more distant areas further west of Nonnenhorn by comparing the data with those of the comprehensive survey of Lake Constance by the *Internationale Gewässerschutzkommission für den Bodensee (International Commission for the Protection of the Lake Constance)* from 1990 (Braun, 1990).

3. METHODOLOGY AND MEASURING SYSTEM OF THE LAKEBED SURVEY IN 2008

3.1 Single-beam survey and survey area

Surveying of the entire area was undertaken using single-beam sounding along predefined survey lines identical to those in 1999, which provided for comparability of the depth measurements taken in 2008 and 1999. Depending on the survey area, the distances between the survey lines were 25, 50 or 100 metres (Figure 3). The survey area from 1999 was extended towards the west (Figure 2). The survey conducted in 2008 therefore covered an overall area of 92 km2 with approximately 1,000 kilometres of measured depth profiles.

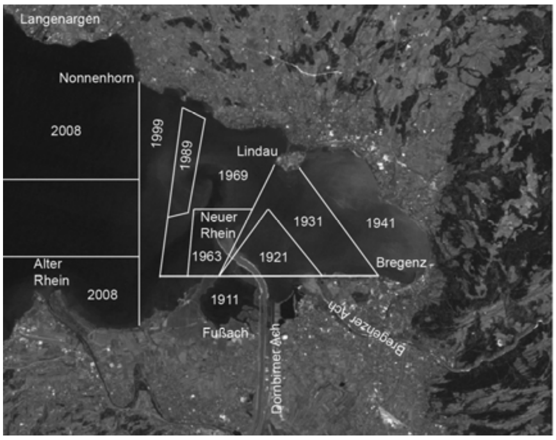

Figure 2: Continual extension of the survey areas at Lake Constance since 1911

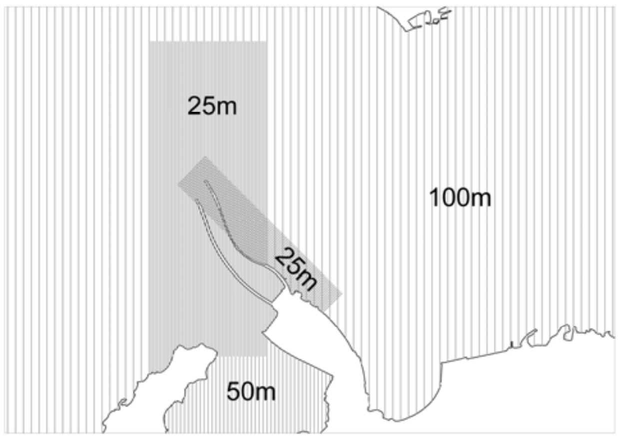

Figure 3: Survey line layout in the area of the mouth of the river Rhine

3.2 Multi-beam echosounding in the subaqueous delta plain of the Rhine

Immediately following completion of the single-beam surveys, the subaqueous delta plain of the Rhine was surveyed comprehensively using multi-beam echosounding (Figure 4). In doing so, the topography of the lakebed was measured using a multi-beam with an aperture angle of 150° made up of 101 beams with a frequency of 240 kHz and 1.5° x 1.5° aperture angle. With a maximum water depth of ten metres in the area of the subaqueous delta plain, footprints with a diameter of less than 26 cm arise.

The entire survey area of 2 km by 2.5 km was measured using double overlapping for the purpose of ensuring quality (SIEGEL 2005). With a maximal travelling speed of ten km/h and a water depth of ten metres, this corresponds to a theoretical measuring point density of approximately one hundred points per square metre .

Owing to the double overlapping of the individual swath of 50 %, the swath to water depth ratio is round 1:4. In light of water depths between 1.5 and 5 metres, this implies a distance between the survey lines of the multi-beam sounding of 6 to 20 metres. In addition, strong currents mean continual course corrections and lead to a mean cruising velocity of 5 km/h. This led to an output of measured area of only 0.2 to 1 km2 per survey day.

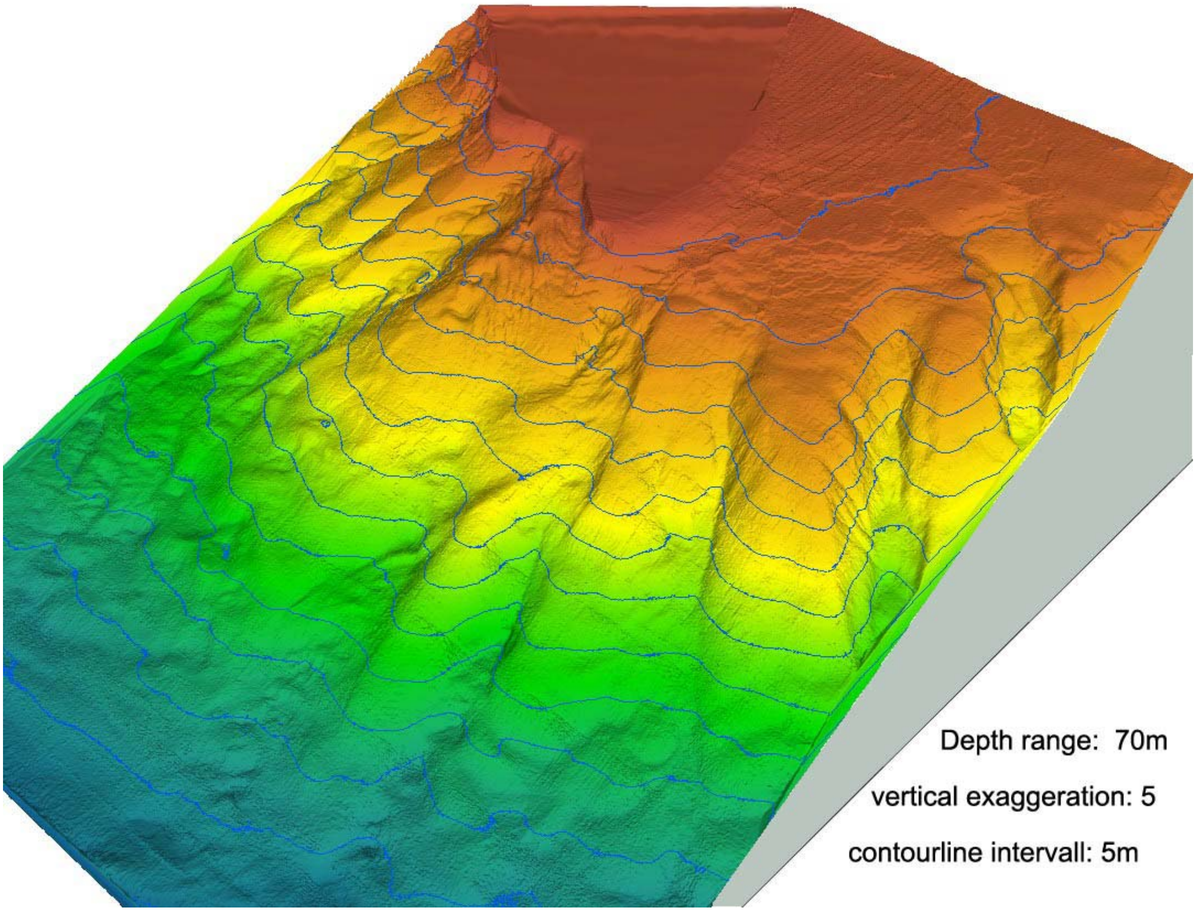

Figure 4: True-to-detail digital terrain model of the subaqueous delta plain of the Rhine created from multi-beam echosoundings

3.3 Measuring system

The measuring system was essentially made up of the following components:

Boat:	Lorsby boats; length: 8.0 m, width: 2.5 m, draught: 0.35 m
Echo sounder system:	Multi-frequency single-beam echo sounding system Kongsberg EA 400 with 15 kHz, 200 kHz and 38 kHz transducer and a 200 kHz side-scan transducer Multi-beam echo sounder system Reson Seabat 8101

Motion sensors:	XSEA OCTANS 3, IMU, motion sensor / gyrocompass; roll / pitch / hub / heading accuracy: 0.01°
Sound velocity probe:	Valeport Monitor SVP with temperature and pressure sensor
Positioning system:	RTK-DGPS equipment

The measurements of all sensors were synchronised as a common temporal reference using GPS.

4. POST-PROCESSING OF THE MEASUREMENT DATA

4.1 Terrain model creation

The terrain model in this case was created using TIN (triangulated irregular network). In the steep coastal areas in particular, the very inhomogeneous distribution of the measured points required the additional definition of breaklines.

For the cubature calculations (Ch. 4.2) by means of comparing the models from 1999 and 2008, it had to be ensured that the two datasets were consistent with one another regarding their creation. Thus, the digital terrain model from 1999 using the original measuring points from 1999 was also generated anew in line with the method of TIN. Moreover, the Institute for Lake Research in Langenargen undertook sediment thickness measurements in Lake Constance using sediment core samples in summer 2008 due to uncertainty concerning the vertical datum used in the data from 1999. The sediment thickness was determinate by matching the sediment stratum of the core sample with the respective year of its immission. Thus it was possible to adapt the digital terrain model of the 1999 survey with regard to its vertical datum (Figure 5).

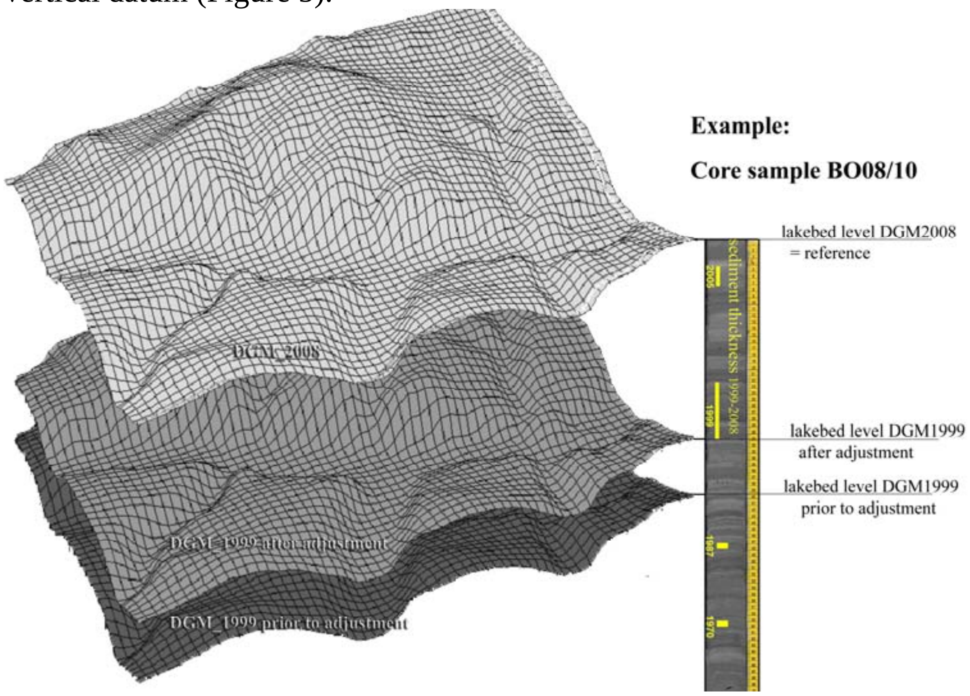

Figure 5: Schematic representation of the height adjustment of the digital terrain model from 1999 using sediment core sample data from core sample BO08/106

4.2 Cubature calculation

To calculate deposition or erosion of sediments, the digital terrain models available as TIN were converted to high-resolution raster datasets. By calculating the differences in the cell values of the respective digital terrain models in the individual raster cells, the cubature of deposition or erosion of sediments of each cell was calculated.

To verify the results of the calculation of difference volumes, the immission of the tributaries was calculated using suspended substance measurements and compared with the difference volumes of the lakebed surveys (Fig.6). The base data was provided by the suspended substance measurements of the Swiss National Hydrological Service taken at the gauging station Diepoldsau am Rhein.

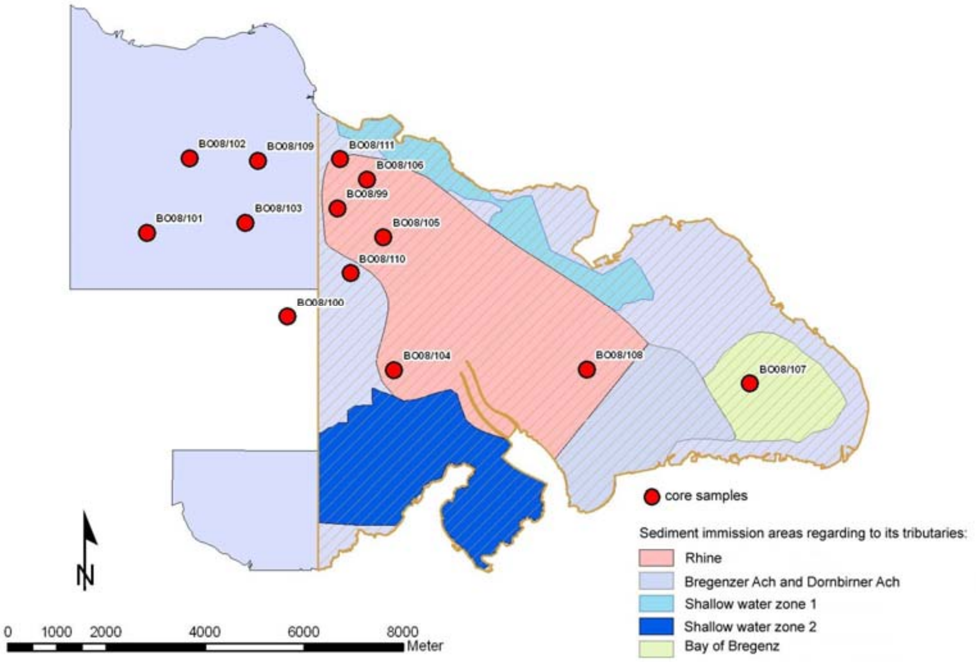

Figure 6: Location of the core sample collections (red dots) and sediment immission areas regarding to its tributary

5. RESULTS AND DISCUSSION

By using two independent measuring systems (single-beam and multi-beam sounding systems), it was possible to ensure a high quality depth measurements at the Subaqueous Delta Plain of the River Rhine at Lake Constance in 2008.
The resulting terrain model of the lakebed presents a very good basis for time series analyses as well as future comparison measurements (Figure 7).

The difference calculation between the terrain models from 1999 and 2008 shows how the sediment deposits are distributed over the lake. The majority of the sediments are deposited directly in the area of the Rhine delta towards the north and northwest – approximately 15.24 million m^3 for the area at the mouth of the Rhine (MAYR, HEINE & BOLTER 2008).

The sediments of the Bregenzerach and Dornbirnerach are distributed uniformly over the lakebeds at their respective mouths and intermix with the immission area of the Rhine to the northwest.

For the Fussacher Bay and the shallow water areas off the Rohrspitz and Hard, no depositions for the last ten years could be quantified.

The measurement data do not clearly demonstrate whether the siltation trend is taking place further to the west in Lake Constance. Based on sediment studies (Institute for Lake Research in Langenargen), sedimentation of a few centimetres was ascertained in this area. These slight changes cannot be proved using echosounding.

On principle, a volume difference calculation from interpolated single-beam sounding with survey line distances of several tens of metres are erroneous, since deviations arise especially here on account of different measuring systems and evaluation methods or due to interpolation. This has an especially high impact in steep areas of the lakebed. A comprehensive multi-beam echosounding for the entire survey area would provide the desired increase in accuracy.

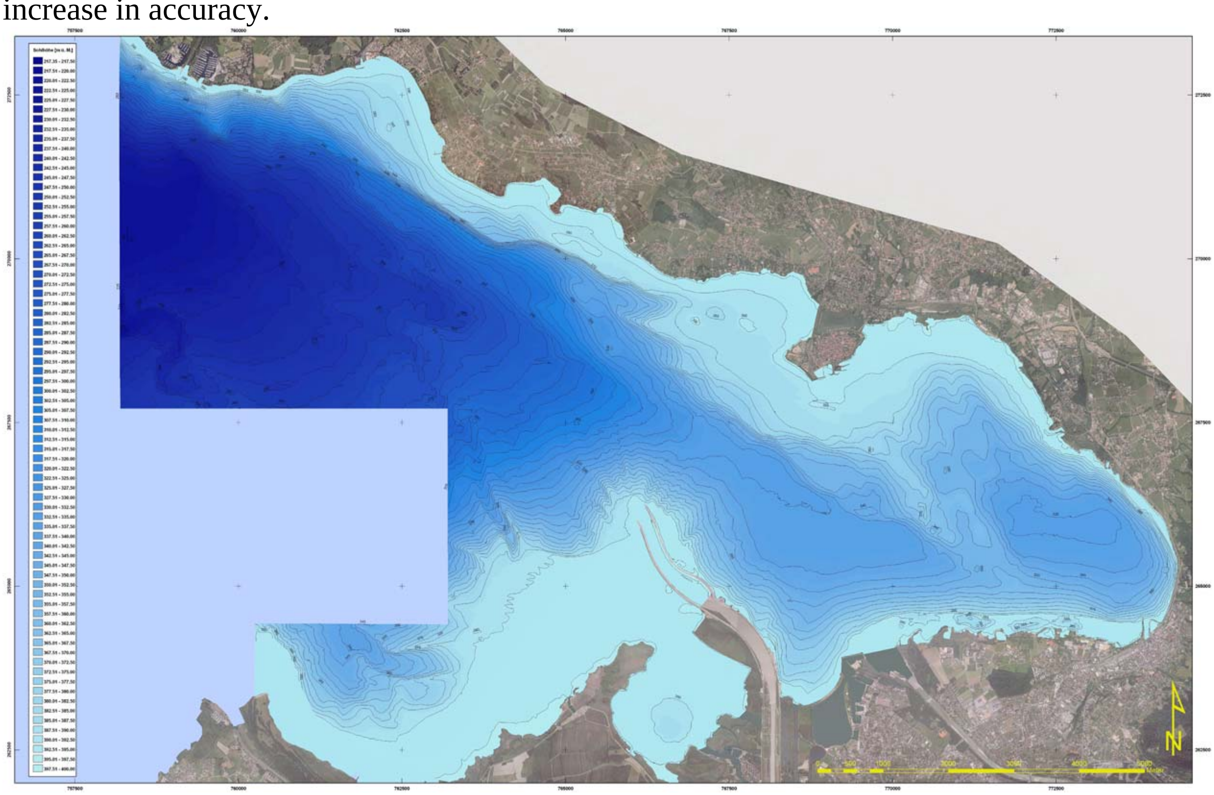

Figure 7: Map of the lakebed resulting from of the survey in spring 2008

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BIOGRAPHICAL NOTES

Erwin HEINE currently works as an Assistant Professor at the Institute of Surveying, Remote Sensing and Land Information at the BOKU - University of Natural Resources and Applied Life Sciences, Vienna (BOKU Wien). In 1992 he obtained his Master's degree in surveying and in 1997 his PhD degree at the University of Technology in Graz. Between 1993 and 1998 he worked as a researcher at different international sites (Mexico, Nepal, Germany, and Spain). His research work is focusing on Hydrographic surveying and GPS based positioning and navigation, which is also lecture topic of the BOKU master's program "water management".

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