Bathymetry generation using sonar and satellite imagery

Generation of lake bathymetry using geo-referenced sonar sounding and satellite imagery

Introduction

Bathymetric information on lakes and reservoirs has important value in hydrology. Besides water level – volume - lake area or stage curve relationships, multi temporal comparison between bathymetries is an indicator for environmental changes like lake or reservoir sedimentation. From this information, lake ecosystem functioning, life times of reservoirs or erosion - sedimentation rates of catchments can be derived. Monitoring lake bathymetry has become attractive using recent advances in Global Positioning Systems, portable sonar sounders and remote sensing data. A methodology for rapid bathymetric survey and map generation, developed by the International Institute for Geo-information Sciences and Earth Observation (ITC) is described.

Methodology

Generation of a bathymetric surface or map basically consists of 3 parts: geo referenced depth data acquisition, generation of a bathymetric surface using interpolation methods and verification of mapping accuracy.

Data acquisition

Water depths are registered using a portable sounder connected to a Global Positioning System (GPS) installed on a small boat. The sounder uses a single frequency transductor of 200 kHz to measure the distance from sensor to lake bottom with an accuracy of 10 cm. The GPS records both the location coordinates and the depth measurement of the sounder. Depending on the type of GPS used (DGPS, WAAS-enabled GPS, and handheld GPS); the location can be measured with an accuracy varying from 15 meters to a few centimeters. Also pending the type and cost of the sonar instrument, higher depth accuracies can be obtained. The depth observation density or measurement grid distance is a function of the variation of the lake bathymetry. As a rule, high variations in depth require high observation densities. The grid distance is obtained by navigating at a constant boat speed in combination with an appropriate GPS data track recording interval (e.g. boat speed 35 km/h and recording interval 5 seconds translates into 1 measurement every 48 meters). Using this setup, a 30 Mm3 reservoir lake with 6 km2 water surface in Portugal could be surveyed in only 2 days using a 250-meter grid (acquiring +/- 3.300 measurements). A detailed study of a 60 Mm3 reservoir with a water surface of 16 km2 in Poland was done in 8 days using a 50-meter grid (acquiring +/- 20.000 measurements).

In order to increase the accuracy at shallow depths and near the lake shorelines, elevation information extracted from satellite imagery was used in complement. The shoreline can be extracted digitally from imagery and used as measured known elevation points if the water level at the time of image acquisition is known. Various images can be used, but a high-resolution image (i.e., IKONOS, Quick Bird, and SPOT5) or ASTER is preferred. In our various bathymetric surveys, ASTER (Advanced Space born Thermal Emission and Reflection Radiometer) imagery has been used. Advantages of this sensor are its high resolution (15 meter pixel size) and low image cost. After georeferencing the image using GPS points, a False Color Composite is created using the VNIR band combinations to be able to distinguish between water vegetation and weeds, water and land. The shoreline is digitized, and after adding its elevation, converted into a dense point map that can be incorporated in the sonar sounding dataset.

Data interpolation

Various interpolation techniques can be used to interpolate point data: e.g. inverse distance interpolation, spline and kriging. For the interpolation of bathymetric point data, we preferred kriging, because the method gives more control over the interpolation due to the use of a semivariogram model. To be able to check the accuracy of the interpolation, the split data approach was used. The full sonar data set is randomly split into 2 sets; 1 set containing the data for interpolation (e.g. 80% of the total number of points), and 1 control set (e.g. 20% of the total number of points).

Data verification

The accuracy of the interpolation was then assessed by correlating the interpolated surface with the independent control point data set. A regression evaluation line is fitted and the root mean square error and rotational error is determined. All bathymetric studies by ITC show a correlation of 98 – 99% and little rotational error. A comparison between 2 bathymetric maps made 7 months apart in Poland at different water levels show a very good reproducibility of the measurements. This indicates the high accuracy of the methodology and equipment used and the usefulness of this application for comparative studies.

Conclusion

Rapid generation of lake or reservoir bathymetric maps using a GPS connected portable sounder and satellite imagery creates highly accurate maps if the equipment is well operated. Lakes that are difficult to access can now be surveyed using little time and with no need for complicated equipment or a specialized boat. Using the ITC methodology, hydrologists can now update their knowledge on lakes using little time and financial resources.

Figure 1: Overview of equipment used: sounder, sounder connected GPS, transductor, navigation GPS and wiring.

Figure 2: Sounding in progress in Turawa, Poland (Fig. A) and Angostura, Bolivia (Fig. B).

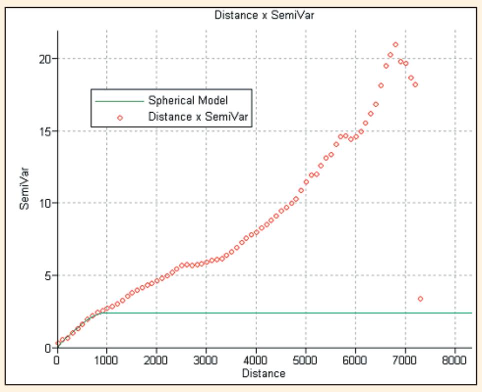


Figure 4 Turawa 2004 Variogram model used for kriging; the spatial correlation uses a lag spacing of 100 meter.

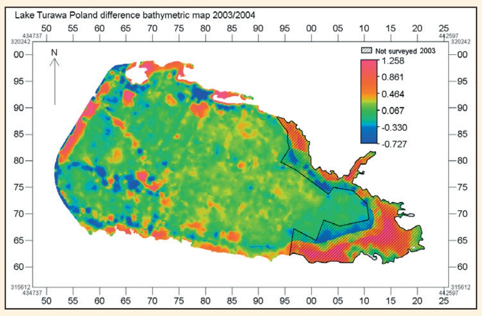


Figure 6 Difference of the 2003 (250 meter grid) and 2004 (50 meter grid) bathymetric map of Lake Turawa (Poland), showing little variation and thus high reproducibility except in areas that where not measured in 2003 due to low water levels and areas that indicate sand movement.

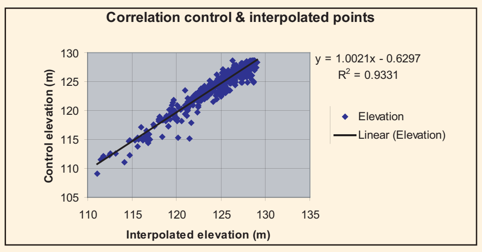
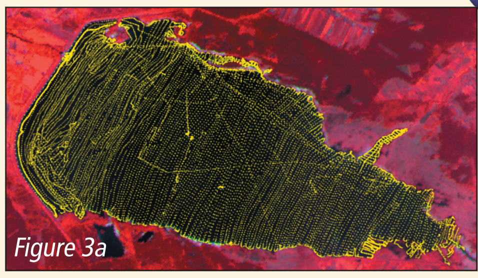


Figure 7: Correlation between interpolated map and control points of the Roxo, Portugal bathymetric map.



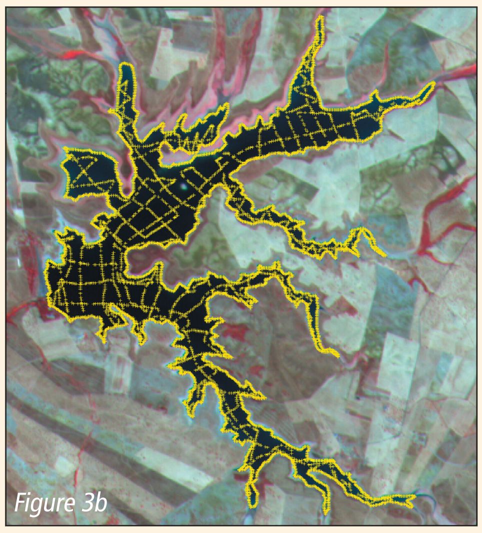
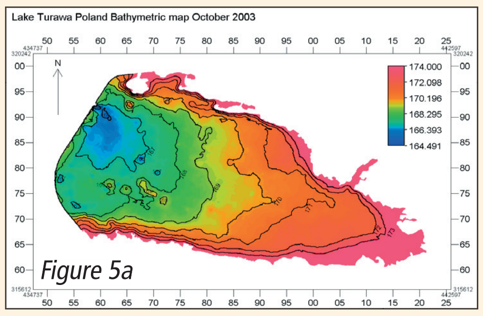
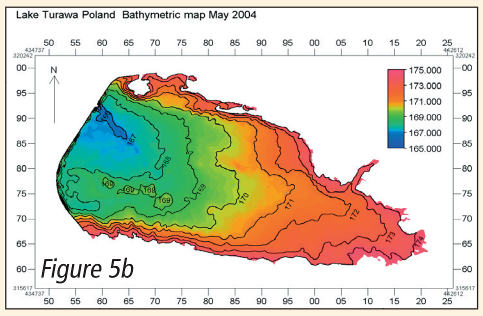


Figure 3 ASTER False Color Composite (RGB321) of Lake Turawa, Poland (Fig. A) and Lake Roxo, Portugal (Fig. B). The yellow crosses show the measured points and the lake outline digitized from the ASTER image; note the different grids used, 50 meter for Turawa and 250 meter for Roxo.





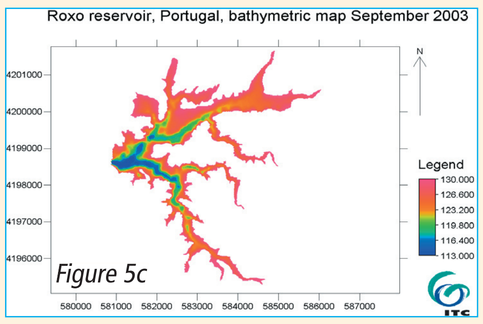


Figure 5 Bathymetric maps of Lake Turawa, Poland made in 2003 (Fig. A) using kriging and a 250 meter measure grid and in 2004 using a 50 meter grid (Fig. B) and of Lake Roxo, Portugal made in 2003 (Fig. C) using kriging and a 250-meter measure grid

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