

NATURAL DAM LAKES FROM CUEJDIU WATERSHED (STÂNIȘOAREI MOUNTAINS) – NON-INVASIVE METHODS USED FOR BATHYMETRIC MAPS

¹ Alin Mișu-Pintilie, ¹ Gheorghe Romanescu, ¹ Cristian Stoleriu, ² Ionuț Cristi Nicu,
² Andrei Asăndulesei, ³ Elmar Schmaltz

¹ University “Alexandru Ioan Cuza” of Iasi, Faculty of Geography and Geology, Department of Geography,
Romania Email: mișu.pintilie.alin@gmail.com

² University “Alexandru Ioan Cuza” of Iasi, Romania Interdisciplinary Research Department – Field Science,
ARHEOINVEST Platform

³ Institute of Geography, Eberhard Karls University Tübingen, Germany

Abstract

Cuejdi river watershed (area: 97.41 km²; max. altitude: 1213 m; min. altitude: 306; length: 29.11 km) left tributary of Bistrița river, drains the south-eastern part of the Central Group of Stânișoarei mountains, from the Central Group of Eastern Carpathians, Romania. The geographical position indicates a specific geological feature individualized by a very high morpho-dynamic induced by the presence of external flisch deposits. This fact was the premise of early Quaternary landslides triggering, and so far, the landslide bodies leading to the emergence of several natural dam lakes. Three of them are the subject of the present study: lake Cuejdel, which is the largest natural dam lake in Romania, at this moment (area: 13.95 ha, maximum depth 16.45 m), lake Cuejdel II (area: 0.5 ha, maximum depth 4.5 m) and lake Bolătău-Ponoarele, the oldest within the basin. So far, their investigation has been hampered by reduced accessibility and high forestation degree. Starting from 2011 until now our research team conducted several campaigns of bathymetrical surveys of these lakes, using a series of non-invasive techniques. The first method is based on using Midas Valeport Surveyor sonar (Bathy-500DF Dual Frequency Hydrographic Echo Sounder) and Leica System1200, consisting of Leica TCR 1201 total station and Leica GPS1200, which helped us making the topographic corrections. Through this technique were made detailed DEMs with the bottom of the lakes Cuejdel (2011) and Bolătău-Ponoarele (2013). The second non-invasive method used was the GPR (Ground Penetrating Radar). Using 100 MHz shielded antenna (Malå RAMAC X3M), we were able to scan the entire surface of Lake Cuejdel (2013), succeeding in addition to bathymetric maps a model of the initial river bed valley, before the landslide occurrence. The use of these high-precision techniques made possible the gathering of a good cartographic database which can be successfully used in determining the current dynamics of lake basins.

Keywords: bathymetry, ecosounder, Ground Penetrating Radar, natural dam lake, Carpathian Mountains

1. INTRODUCTION

Most of the natural dam lakes are formed in the foothills and mountain area where the relief favorability and predisposition toward unleashing slope processes is high. Very often lakes are formed in volcanic areas due to leakage caused by lava flows or pyroclastic materials, but also as a consequence of the seismic activity. Lakes formed behind ice dams are identified largely with the subarctic areas or with the upper parts of the great mountain chains (Alden, 1928; Glazzyrin & Reyzvikh, 1968; Marsh & Neumann, 2003; Huss et al., 2007; Romanescu et al., 2013). Of all the current geomorphological processes, landslides are responsible for the emergence of most of natural dam lakes in the world. In the international literature are mentioned a series of lakes which had considerable size, but have not resisted in time due to the fragility of the earth dams (Marsh & Neumann, 2003; Huss et al., 2007; Romanescu et al., 2013).

In Romanian literature, natural dam lakes are in the classification of lake units in a simplified form when compared with the diversity from the international literature. From these, the best represented category is that of natural dam lakes formed as a result of landfall and gravitational processes of the land (Ichim et. al., 1996; Gâștescu, 1998; Rădoane, 2003; Romanescu et al., 2013). The most favorable conditions for the formation of natural dam lakes in Romania are found in Oriental Carpathians, Curvature and Moldavian Subcarpathians, and in some remote areas from Moldavian Plateau. The highest susceptibility is in flisch area from Oriental Carpathians, where permeable and impermeable layers, lithological alternation with different hardness and relief steep slopes combine, induce the violent manifestation of slope processes (Mișu-Pintilie & Romanescu, 2011; Mișu-Pintilie et. al., 2012).

The majorities of natural dam lakes from Romania are found in remote areas in the mountains and usually have small dimensions and a short lifespan. Our research team has succeeded to make the bathymetrical

survey of three natural dam lakes formed in the upper part of Cvejdiului catchment (Stânișoarei Mts.): Cvejdel Lake and Cvejdel II Lake (Constelației) from Cvejdel brook, and Bălătau-Ponoare from the same catchment. Non-invasive methods used in bathymetric survey were carried out with the aid of high accuracy equipment. The present study aims to describe these methods used in modern limnological research and to complete the existing database on natural dam lakes. Also, we are trying to eliminate a couple of errors related to the morpho-bathymetrical parameters of Cvejdel Lake, the largest natural dam lake from the Carpathian Mts.

2. REGIONAL SETTING

Cvejdi river is a left tributary of Bistrița river, which drains the South-eastern part of Stânișoarei Mts. from the Central Group of Oriental Carpathians. The total area of the catchment is 97.41 km², maximum altitude is 1213 m, lowest altitude is 306 m and the length of water course is 29.11 km. The three lakes are positioned in the upper part of the catchment, Cvejdel (47°02'08" N - 26°12'59" E) and Cvejdel II Lakes (47°01'52" N - 26°13'17" E) were formed on the left bank in 1991, and Bolătau Lake (47°02'08" N - 26°12'59" E), much older, formed on the right side of the catchment in the place known as Ponoarele Hill (Figure 1).

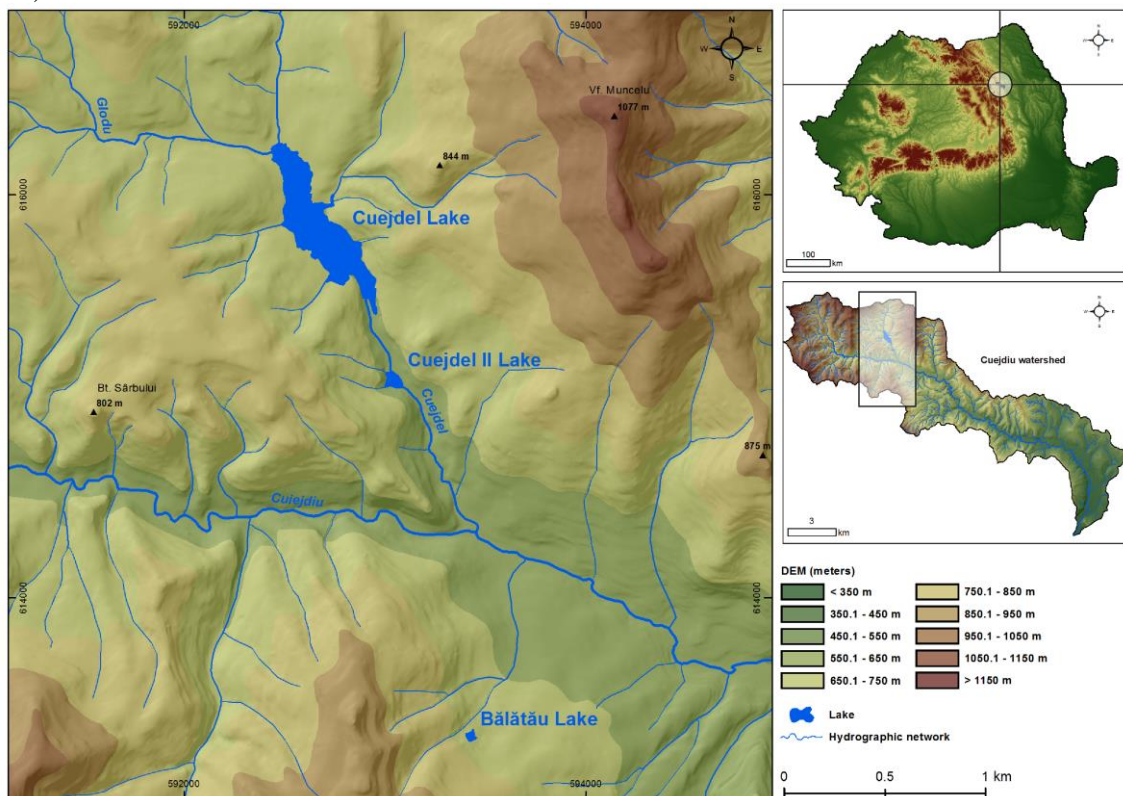


Figure 1. Geographic location of the lakes în Romania and Cvejdi watershed

3. METHODS AND TECHNIQUES

Methods of mapping the lake basins were based on a series of non-invasive techniques used successfully in international limnology studies. The equipment is from Geoarchaeology Laboratory within the Faculty of Geography – University “Al.I.Cuza” of Iasi. For this reason, we would like to describe the principles of function and the manner in which they have been used.

3.1. Bathymetrical mapping using Valeport Midas Ecosounder

The method is commonly used in the underwater morphology maps from coastal areas, lake basins or riverbeds (Mihu-Pintilie et. al., 2012, 2014; Romanescu & Stoleriu, 2010; Romanescu et. al., 2013). In

this case we had a very precise ecosound (model - Valeport Midas Ecosounder; type - Bathy-500DF Dual Frequency Hydrographic Echo Sounder) with dual frequency acoustic signal (210/33 kHz) and equipped with a GPS system. In this way, the frequency of readings of depth points was made with a density of 0.25 cm for each lake (Cuejdel and Bălătau-Ponoarele Lakes).

As a result of surveys of the lakes has resulted a database with a high volume of information (Cuejdel Lake - 45.000 depth points, Bălătau-Ponoarele Lake 25.000 depth points). After removing the errors caused by the presence of trees fallen in the water, we manage to realize detailed bathymetric maps (resolution 0.1 m/pixel). In the case of Cuejdel II Lake, due to the difficult access, the mapping was realized with a GPS carried out on the lake surface by a diver. In this case, the bathymetric map has a low resolution, but due to the small area of the lake, the final map has a good resolution (0.43 m/pixel) (Figure 2a).

2.2. GPR method (Ground Penetrating Radar)

GPR is a geophysical tool accepted by the scientific communities all around the world, but unfortunately is less used in Romania. So far it has had the most applications in archaeological research and fewer applications in hydro geological and geomorphological research. However, international literature is rich with studies in which the bathymetrical scanning and determination of sediment thickness was made with GPR technology GPR (Sass et. al., 2007; William et. al., 2007; Denziman et. al., 2010; Plado et. al., 2011; Proulx-McInnis et. al., 2013).



Figure 2. Methods of mapping lake basins

a. Survey with GPS and a diver for Lake Cuejdel II. b. Survey with GPR (Ground Penetrating Radar) for Cuejdel Lake

The operation principle of a GPR is based on the propagation of electromagnetic waves in the substrate (soil, sediment, rock) and scanning of these crossed structures (Reynolds, 1998). The best results are obtained in terms of a smooth and dry topographic surface, while the investigation depth must be adapted to the relative permittivity of the material (ϵ_r), void permittivity (ϵ_0), which is calculated from the formula 8.8542×10^{-12} F/m, and the frequency of the antenna selected for scanning (in this case 100 MHz antenna). In order to highlight the sediments deposition and lithological structures of Lake Cuejdel we had to take into account a series of values of relative permittivity of the lacustrine materials.

GPR – Malå Ramac X3M model used for survey the underwater morphology of Cuejdel Lake can operate continuously for several hours, depending on the environment temperature, the structures visualized in real time, allowing to establish its quality directly in the field. Subsequently, the images are processes through a series of filters to improve the reflection of electromagnetic pulses, tracked structures (present riverbed, initial riverbed, sediment thickness) can be easily transferred in GIS where the data can be interpolated and processed (Figure 2b).

3. RESULTS AND DISCUSSION

The first bathymetric surveys were carried out in the summer of 2011 for Cujejel Lake. Depth points were determined with ecosound equipped with a GPS, attached to a boat fitted with an electric engine. After the removal of errors and making the corrections, the data was processed in GIS software (ArcGIS, TNT Mips) resulting a high quality DEM of the lake bottom. The main parameters were derived: 2D area – 13.95 ha, 3D area – 14.31 ha, average depth – 6.67 m, max. depth – 16.45 m, volume – 925346.6 m³. Hypsometric integral indicates a depression with a concave shape (f 1.5) (Kalff, 2003) with a relatively steady hydro morphological equilibrium (Miha-Pintilie et. al., 2012) (Figure 3).

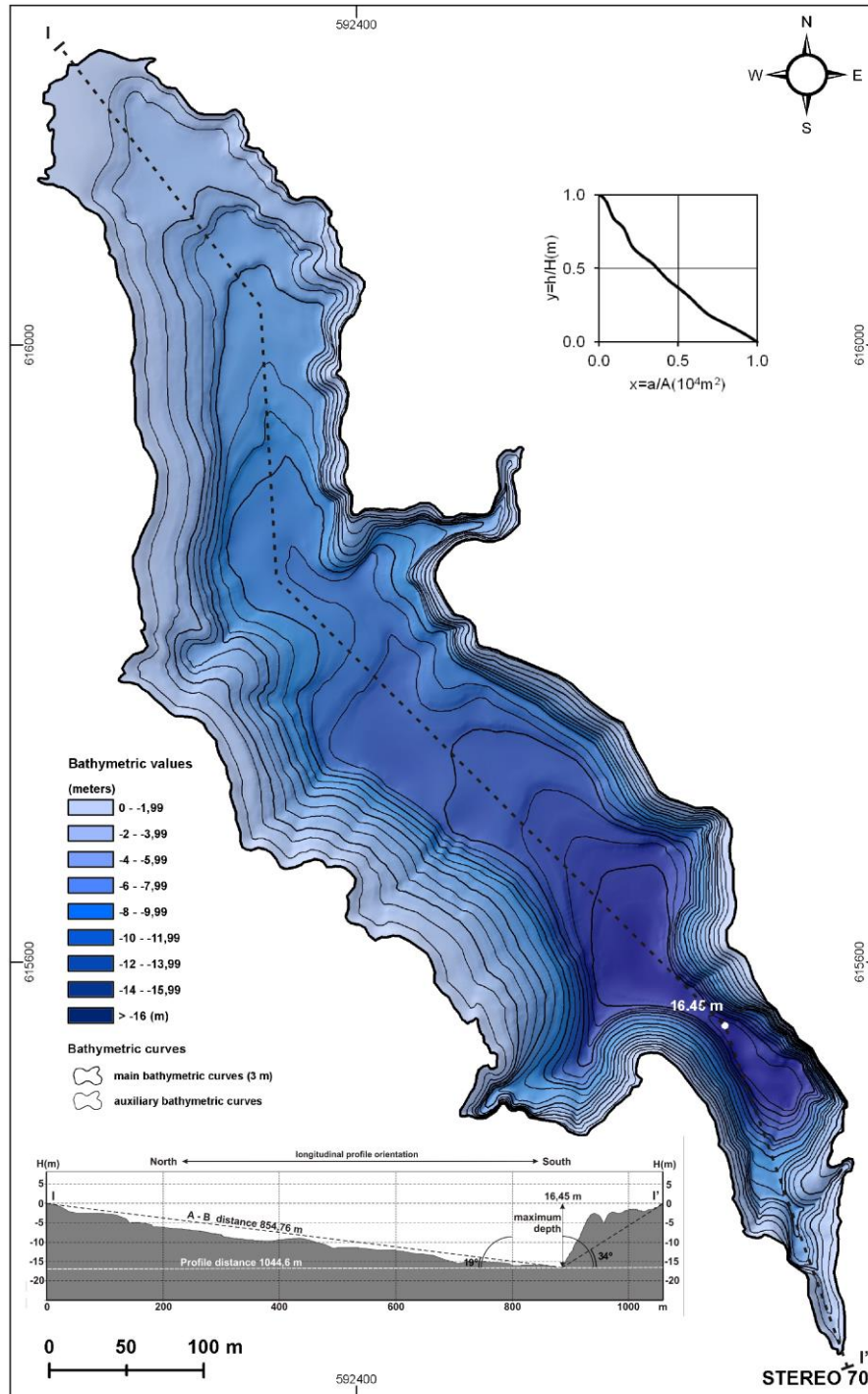


Figure 3. Bathymetric map of Cujejel Lake realized in 2011 with Valeport Midas Ecosounder

The second bathymetric survey of Cujejdol Lake was conducted in winter of 2013, on a ice bridge with a thickness between 30 – 45 cm, using a GPR Malå Ramac X3M control unit and 100 MHz antenna, capable to collect information from different porous media (water, lacustrine sediments, rocks) up to 25 m. A number of 12 cross sections and 1 longitudinal profile were made, which show with a high fidelity the lake bottom, the structures and the thickness of alluvia deposits. After processing the data, the lake basin had the following parameters: 2D area – 13.88 ha, 3D area – 14.09 ha, average depth – 5.88 m, max. depth – 14.9 m, volume – 815986.2 m³.

Comparison of the two DEMs has highlighted a number of minor changes which have occurred between 2011 and 2013, the majority due to high quantity of rains and the torrential activity which has deepened the drainage channel formed on the soil dam surface. Thus, the lake surface (2D) decreased with 735 m², the real surface (3D) with 2247 m², maximum depth with 1 – 1.5 m and the total volume of water with 109316 m³. Also it is found a significant change in the bottom morphology between 12 – 13 m depth, corresponding with the last lacustrine micro-terrace. These changes have occurred as a result of the accumulation of sediments carried during the torrential rains (Table 1).

Table 1. Vertical variation (1/1 m) of bathymetric curves and partial volumes characteristic for Cujejdol Lake between 2011 and 2013

Depth (m)	Bathymetric curves surfaces – area 2D (10 ⁴ m ²)			Bathymetric surfaces – area 3D (10 ⁴ m ²)			Partial volume (10 ⁴ m ³)		
	2011	2013	Losses	2011	2013	Losses	2011	2013	Losses
0	13.95	13.88	-0.07	14.32	14.09	-0.22	13.22	12.79	-0.43
-1	12.66	11.95	-0.71	13.08	12.16	-0.92	11.89	11.24	-0.65
-2	11.23	10.58	-0.64	11.61	10.77	-0.83	10.57	9.98	-0.59
-3	9.74	9.40	-0.34	10.07	9.57	-0.51	9.27	8.88	-0.39
-4	8.81	8.38	-0.43	9.10	8.52	-0.57	8.42	7.94	-0.48
-5	8.05	7.51	-0.54	8.29	7.63	-0.66	7.56	7.08	-0.48
-6	7.15	6.66	-0.49	7.35	6.75	-0.59	6.67	6.21	-0.46
-7	6.15	5.77	-0.38	6.30	5.84	-0.46	5.76	5.32	-0.43
-8	5.40	4.87	-0.53	5.53	4.92	-0.60	5.06	4.36	-0.70
-9	4.66	3.86	-0.80	4.77	3.90	-0.86	4.15	3.39	-0.76
-10	3.63	2.95	-0.68	3.71	2.97	-0.74	3.20	2.48	-0.71
-11	2.88	1.99	-0.89	2.94	2.01	-0.93	2.53	1.30	-1.23
-12	2.18	0.62	-1.56	2.22	0.63	-1.59	1.67	0.41	-1.26
-13	1.36	0.27	-1.09	1.39	0.27	-1.11	1.16	0.18	-0.99
-14	0.99	0.09	-0.89	1.00	0.09	-0.91	0.84	0.02	-0.82
-15	0.67	0.01	-0.66	0.68	0.02	-0.66	0.46	0.00	-0.46
-16	0.27	-	-	0.27	-	-	0.10	-	-

In 2012 was conducted the bathymetric map of Lake Cujejdol II (Constelației) using a differential GPS and a gradually bathymetric cable for lake depth correction. Due to the difficult accessibility, for mapping the lake bottom autonomous diving equipment much easier to carry was used. After interpolation of depth points, first bathymetric map of this lake was realized. The main parameters resulted as follows: 2D area – 3493.5 m², 3D – 3583.6 m², average depth – 1.8 m, max. depth – 4.3 m, volume – 6540.7 m³. From the morphologic point of view, the lake corresponds with an old junction of Cujejdol Lake with a right side tributary. Nowadays, due to torrential flow that focuses on the flooded riverbed, the erosion maintains the maximum depth of the lake around 4 m value. The triangular shape of the lake indicates a barring on the west bank of the watercourse where, redirected by a landslide lithological erosion remnant, has transported landslide body in the blocked riverbed. Currently, due to relatively small size, the lake is experiencing a significant variation of morphometric parameters due to changes induced by erosion activity of Cujejdol river during high waters (Figure 4a).

In the case of Bălătau – Ponoare Lake, bathymetric map was realized with the help of ecosound, the same as in Cujejdol Lake case. The difficulty here was the high density of trees from the bottom of the lake. For this reason, out of 25.000 depth points, about 10% were errors who have been removed. After the data processing, the DEM resulted was indicating in 2013 the following parameters: 2D area – 2512.3 m², 3D – 2786.5 m², average depth – 2.3 m, max. depth – 7.9 m, volume – 5898.6 m³. The age of lake, according to some authors still dating from the late Quaternary period, contrasts with unusually large depth, in the context

in which it has only underground water supply and a drainage channel active only when torrential rains occur (Ichim, 1979). The funnel shape is given by the accumulation behind a landslide body formed at the half of the slope affected in the past by intense gravitational processes. Another hypothesis of this shape can be explained by the fact that the discharge of water from the lake is made through suffosion which continuously eliminates fine sediments. Underground leakage is proven by many underground springs which are emerging at the base of marl-clay dam (Figure 4b).

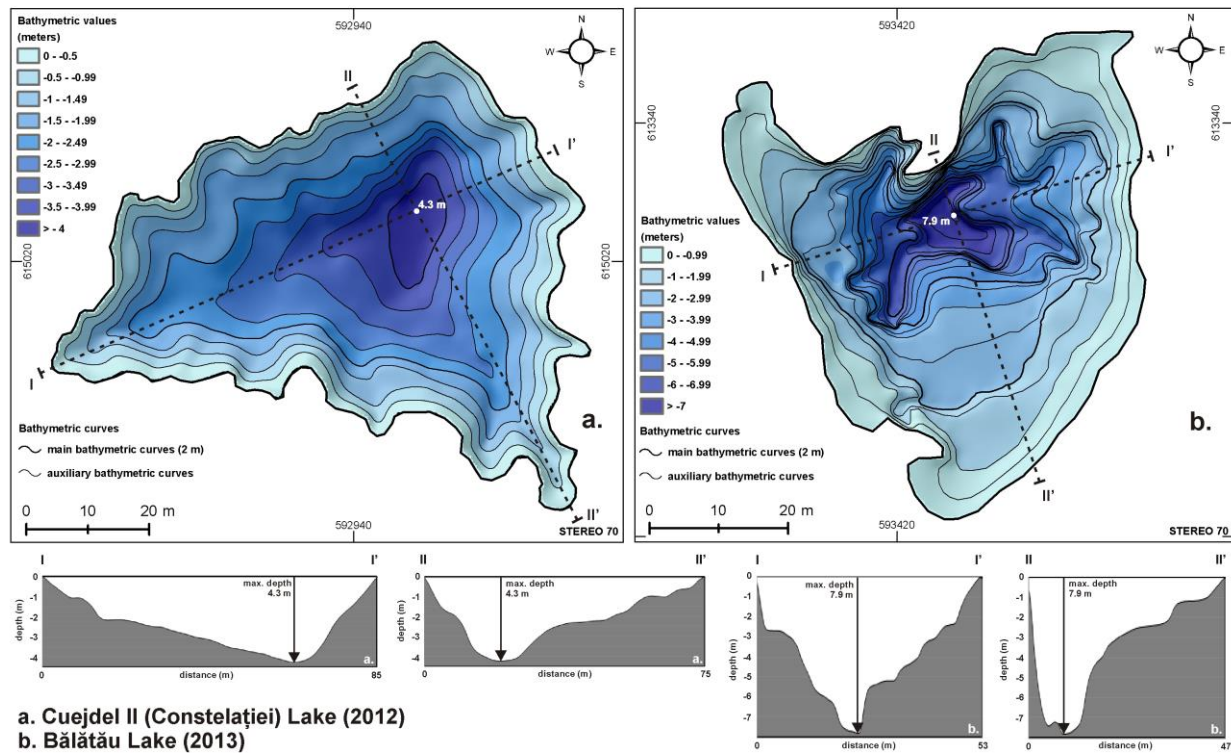


Figure 4. a. Bathymetric map of Lake Cuejdel II (Constelației) realized in 2012;
b. Bathymetric map of Lake Bolățau – Ponoarele realized in 2013

Synthesizing the information from several monographs and limnological studies from Romanian literature, as well as using a series of data provided by Romanian Water Administration has been made a comparison between the results of our research and the most important natural dam lakes formed in the area of Oriental Carpathians. Thus, out of 12 lake basins analyzed, Cuejdel Lake is the largest, and also one of the deepest natural dam lakes in Romania. Cuejdel II and Bălățau-Ponoare lakes, according to their size, are the most common natural dam lakes (Table 2).

4. CONCLUSIONS

Making bathymetric maps is not an easy task, their quality being much affected by rudimentary methods that lead most often in losing the morphometric details. A negative example was until recently the information related to Cuejdel Lake, which have issued a series of wrong values of morphometric parameters. In the present study an attempt was made by exemplifying the new non-invasive methods for mapping the lake bottom, a proposal for implementation how bathymetric maps could be made fast and very detailed. Also, using this equipment it is possible a monitoring program that would render the morphological evolution in real time of lakes, riverbeds, coastal areas, etc.

In other news, the maps resulted from the measurements of natural dam lakes from Cuejdel watershed can become an important support for hydro-geomorphological studies, as well for an interdisciplinary analysis of biodiversity within the lacustrine ecosystems from mountain areas of Romania.

Table 2. Morphometric and morpho-bathymetric parameters of the most important natural dam lakes from Oriental Carpathians

Lake	Location	River	Area (ha)	Max. depth (m)	Volume (m ³)
Cuejdel (Crucii)	Stânişoarei Mts.	Cuejdel	13.95	16.45	925347
Roşu	Hăşmaş Mts.	Bicaz	12.1	10.50	721404
Mocearu	Buzău Mts.	Buzău	7.0	8.0	-
Bălăţau	Carpaţii de Curbură	Zăbala	6.0	3.5	-
Bălăţau	Ciuc Mts.	Trotuş	4.5	3.0	-
Betiş	Maramureş Mts.	Ampoi	2.0	9.0	-
Iezer	Obcina Feredeului	Sadova	0.75	4.25	31414
Cuejdel II	Stânişoarei Mts.	Cuejdel	0.34	4.3	6541
Tăul Zânelor	Bărgău Mts.	Colibiţa	0.3	4.0	-
Bălăţau (Ponoare)	Stânişoarei Mts.	-	0.25	7.9	5899
Bolăţau	Obcina Feredeului	Sadova	0.23	5.20	-
Izvorul Măgurii	Bărgău Mts.	Ilva	0.2	2.0	-

ACKNOWLEDGEMENTS

Our thanks go to the Geo-archaeology Laboratory within the Faculty of Geography and Geology, Alexandru Ioan Cuza University of Iasi, which provided the equipment and made the processing of the data. Also, a part of this work was supported by the European Social Fund in Romania, under the responsibility of the Managing Authority for the Sectorial Operational Programme for Human Resources Development 2007-2013, grant POSDRU/159/1,5/S/133391 and Department of Geography from University „Al.I.Cuza” of Iaşi.

REFERENCES

- Alden, W. C. (1928), *Landslide and flood at Gros Ventre-Wyoming*, American Institute of Mining and Metallurgical Engineers Transactions, **76**: 347-358.
- Denziman C., Brevik E.C., Doolittle J. (2010), Ground-penetrating radar investigation of a rapidly developed small island in a lake in southern Georgia, USA, *Journal of Cave and Karst Studies*, **72**(2): 94-99.
- Gâştescu P. (1998), *Limnology and Oceanography* [In Romanian], Edit. H.G.A., Bucureşti.
- Glazzyrin G.Y. & Reyzykh V.N. (1968), Computation of the flow hydrograph for the breach of landslide lake, *Soviet Hydrology*, **5**: 592-596.
- Kalff J. (2003), *Limnology – Inland Water Ecosystems*, Prentice-Hall, pp. 85-93.
- Huss M., Bauder A., Werder M., Funk M. & Hock R. (2007), Glacier-dammed lake outburst events of Gornersee, Switzerland, *Journal of Glaciology*, **53**(181): 189-200.
- Ichim I. (1979), *Stânişoarei Mountains - geomorphological study* [In Romanian], Edit. Academiei Române, Bucureşti, pp.60-80.
- Ichim I., Rădoane N., Rădoane M. (1996), Geomorphological process with high frequencies in flysch mountains area. Examples from Neamţ County [In Romanian], *Studii şi cercetări – Extras*, Edit. Muzeului de Ştiinţe Naturale, Piatra-Neamţ, **8**: 15-24.
- Mihu-Pintilie A. & Romanescu Gh., (2011) Morphometric and morphological suitability of the relief from the Crucii Lake basin (Stânişoarei Mountains), In: *Air and water components of the environment*, Presa Univ. Clujeană, Cluj-Napoca, **3**: 305-313.
- Mihu-Pintilie A., Romanescu Gh. & Stoleriu C. (2012), Morpho-bathymetric parameters of recess Crucii Lake (Stânişoarei Mountains), In: *Air and water components of the environment*, Presa Univ. Clujeană, 2012, Cluj-Napoca, **4**: 445-452.
- Mihu-Pintilie A., Romanescu Gh. & Stoleriu C. (2014) The seasonal changes of the temperature, pH and dissolved oxygen in the Cuejdel Lake, Romania, *Carpathian Journal of Earth and Environmental Sciences*, B.M., **9**(2): 113-123.
- Marsh P. & Neumann N. (2003), *Climate and hydrology of a permafrost dammed lake in NW Canada*, *Permafrost*, In: Springman S.M., Arenson L.U. (eds), Phillips M. Swets & Zeitlinger, Lisse, pp. 729-734.

- Plado J., Sibul I., Mustasaar M. & Jõelet A. (2011), Ground-penetrating radar study of the Rahivere peat bog, eastern Estonian, *Estonian Journal of Earth Sciences*, **60**(1): 31-42.
- Proulx-McInnis S., St-Hilaire A., Rousseau A.N. & Jutras S. (2013), A review of ground-penetrating radar studies related to peatland stratigraphy with a case study on the determination of peat thickness in a northern boreal fen in Quebec, Canada, *Progress in Physical Geography*, In press, DOI: 10.1177/0309133313501106.
- Rădoane N. (2003), A new natural dam lake in the catchment of Bistriței Moldovenești – Lake Cuejdel [In Romanian], *Studii și Cercetări de Geografie*, Tom **XLIX-L**: 211-216.
- Romanescu Gh. & Stoleriu C. (2010), Morphobathymetrical parameters of the Red Lake basin (Haghimaș Mountains [In Romanian], In: Gâștescu. P. & Brețcan P. (eds) *Resursele de apă din România – Vulnerabilitatea la presiunile antropice* [Water resources from Romania - Vulnerability to the pressure of man's activities], Târgoviște, **1**: 308-314.
- Romanescu Gh., Stoleriu C. & Enea A. (2013), *Limnology of the Red Lake, Romania. An interdisciplinary study*, Springer, pp. 12-27, 96-121.
- Reynolds J.M. (1998), *An introduction to Applied and Environmental Geophysics*, Wiley-Blackwell, pp. 535-618.
- Sass O., Krautblatter M. & Morche D. (2007), Rapid lake infill following major rockfall (bergsturz) events revealed by ground-penetrating radar (GPR) measurements, Reintal, German Alps, *The Holocene*, **17**(7): 965-976.
- William S.L.B. & Carole D.J. (2011), Collection, Processing, and Interpretation of Ground-Penetrating Radar Data to Determine Sediment Thickness at Selected Location in Deep Creek Lake, Garrett County, Maryland, *Scientific Investigations Report 2011-5223*, U.S. Geological Survey, Reston, Virginia.