Ciencia Nicolaita 95: 35-42; Diciembre de 2025 https://doi.org/10.35830/cn.vi95.856

A morphometric assessment of Lake Camecuaro, Tangancicuaro, Michoacan, Mexico

Arturo Chacón Torres[1]*, Catalina Rosas Monge[1], Frida Sauno Contreras[2], Alma Itzel Jacobo Escamilla[2], Gustavo Adolfo Reyes Alvarado[3], Carlos Alberto Fernández Ledesma[3]

[1] Instituto de Investigaciones sobre los Recursos Naturales (INIRENA). Universidad Michoacana de San Nicolás de Hidalgo (UMSNH)
[2] Panorama Ambiental A.C.
[3] Consultora Ambiental Limnos S.C.

Historial
Manuscrito recibido: 10 de marzo de 2025
Manuscrito aceptado: 5 de septiembre de 2025
Manuscrito publicado: diciembre 2025

***Autor para correspondencia**
Arturo Chacón Torres
arturo.chacon@umich.mx
ORCID: 0000-0002-8123-5455

Abstract

A morphometric study was conducted in Lake Camecuaro, Michoacan, employing a digital echosounder equipped with a geopositioning system; 15 transects were traced perpendicular and parallel to the maximum length of the lake in parallel intersections and in zig-zag patterns. A total of 946 sounding points were registered in 4,200 meters of transects. The results indicated that Camecuaro is a very shallow aquatic system of water springs with a total surface of 3.45 ha, a maximum depth of 4.5 m, and a mean depth of 1.65 m. The system contains up to 55,875.86 m³ and has a hydraulic residence time of 8.62 hours. It is a slightly convex system with a single inflection point. The informative value of this study was 0.9724. This is the first comprehensive morphometric assessment developed for Lake Camecuaro, in which the environmental importance of water conservation in water springs is fundamental to ensuring the human right to access high-quality water, as outlined in the 6th Sustainable Development Goal.

Introduction

Lake Camecuaro was the first national park in Mexico. It is located in the municipality of Tangancicuaro, northwest of the State of Michoacan. In 1940, President Lázaro Cárdenas del Río designated it a national park and protected area to guarantee wildlife protection (*SEMARNAT,* 2016). Tangancicuaro is in the Mexican Transvolcanic Belt, within the physiographic subprovince known as "Sierras y Bajíos Michoacanos." The physiography is characterized by volcanic sierras and lava flows, dispersed cinder cones or dense aggregations, broad basalt shield volcanoes, sand and ash deposits, and other forms dispersed between extensive plains. This intricate volcanic orography is complemented by the Lerma Depression, which favours diverse climates and vegetation. Forests, including fir, pine, oak, and others, characterize the region, which is rich in areas of hydraulic recharge and has numerous aquifers and water springs. Part of these aquifers originated Lake Camecuaro *(*Rojas-Ruiz. *et al.,* 2007*).*

The water-spring shoreline vegetation consists of an old gallery forest of Moctezuma cypress regionally known as Ahuehuete (*Taxodium mucronatum*), with ages above 500 years; these trees distribute irregularly along the main channel mixed with some willows (*Salix chilensis*), ash trees (*Fraxinus uhdei*), and Australian pine (*Casuarina equisetifolia*), and other tree species with perennial leaves. The Universidad Michoacana de San Nicolás de Hidalgo (UMSNH), through the Instituto de Investigaciones sobre los Recursos Naturales (INIRENA), contributed to the elaboration of a bathymetric and morphometric study to determine the most critical morphometric parameters and create the bathymetric map that is the focus of the current report.

The study area

Location

Lake Camecuaro is 2.8 km from Tangancicuaro de Arista city (**Figure 1**). The Universal Transverse Mercator cartographic projection (UTM) coordinates are 0791947 E y 2203198 N, 13Q, at an altitude of 1,700 masl (**Table 1**; **Figure 2**).

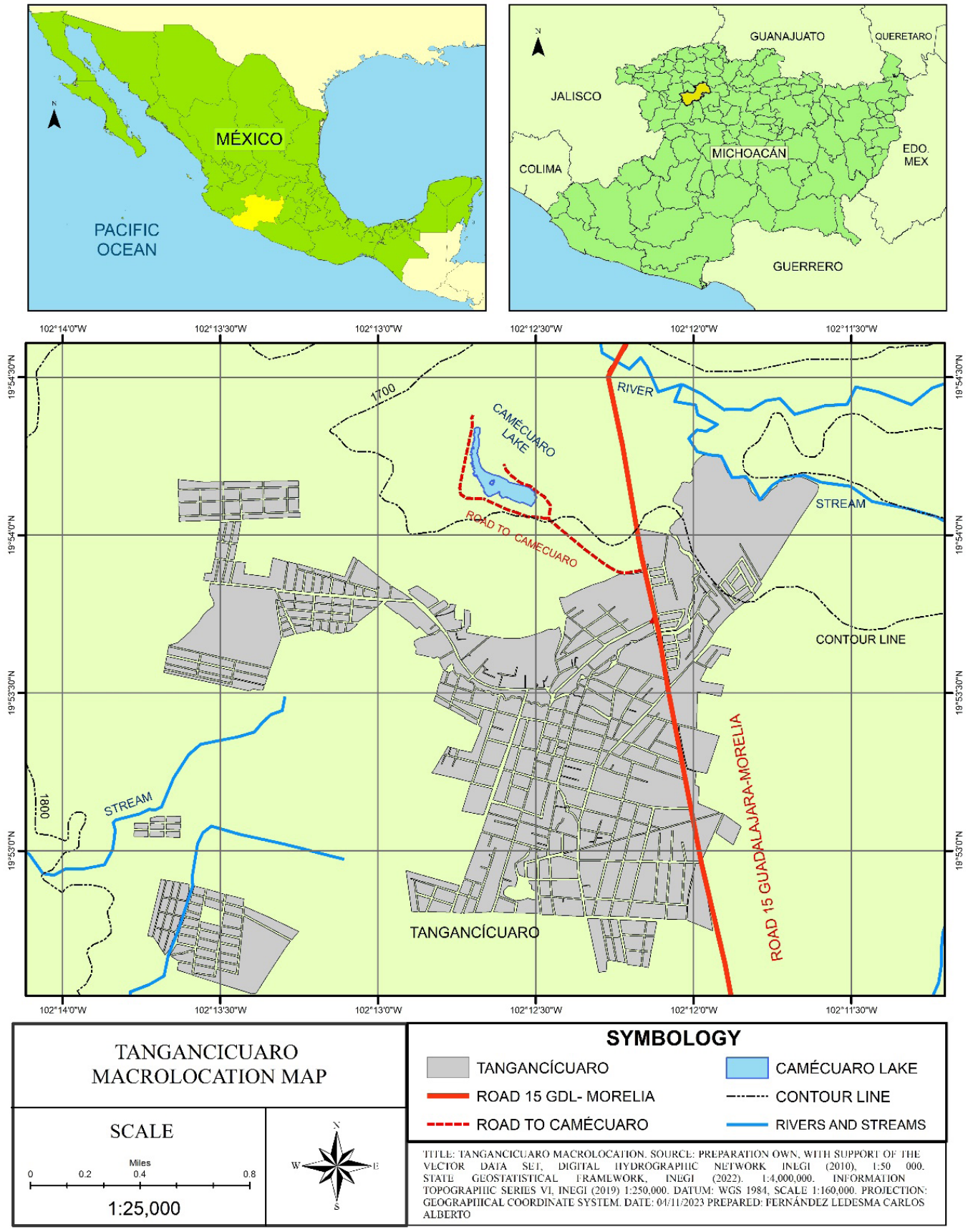

Figure 1. Location of Lake Camecuaro, Tangancicuaro, Michoacan, Mexico.

Table 1. Coordinates of Lake Camecuaro, Tangancicuaro, Michoacan, Mexico

Coordinates UTM			
Point	**E**	**N**	**Quadrant**
1	791919	2203461	13 Q
2	792322	2203461	13 Q
3	792322	2203009	13 Q
4	791919	2203009	13 Q

Climate

According to García (2004), the formula of the regional climate is ***(A)Ca(w1)(w)(e)g***, corresponding to semi-warm to temperate with warm summer, sub-humid with summer rainfall (winter rainfall less than 5.0%), extreme annual temperature oscillation, annual temperature running Ganges type; this means that the month with the highest temperature is before the summer solstice. The mean annual temperature is 18.5 °C; May is the warmest month with an average value of 22.1 °C, whereas January is the coldest month with an average value of 14.4 °C. The annual rainfall is 899.9 mm, with July being the wettest month, receiving 210.0 mm, and March the driest, with 4.2 mm (**Figure 3**) (*SMN, CONAGUA*, 2023).

Water quality

Lake Camecuaro has water mean values of 22.4 °C, with Hydrogen potential (pH) value of 7.50 (7.70 – 7.2), and water hardness of 1.74 mg of $CaCO_3$/L. Dissolved solids have an average concentration of 0.150 mg/L. Dissolved oxygen has a mean value of 4.25 mg/L, its highest concentration on the surface (Silva-García *et al*., 2015).

Environmental status

The surrounding environment of Lake Camecuaro National Park exhibits a high level of ecological fragmentation resulting from the progressive intensification of irrigated agriculture. Lake Camecuaro is a recreational space with a high visitor influence of up to 250,000 tourists annually.

Methods

Bathymetry

The Lake Camecuaro bathymetric survey was performed using 15 transects positioned perpendicular and parallel to the lake's maximum length in a zigzag pattern, resulting in 946 sounding points. The equipment used included a GPS "Garmin" model 65st and an echosounder "Garmin" model Echomap Plus 74cv, both equipped with GPS and a 200 kHz transducer.

The echosounder was calibrated using a manual lead graduated in centimeters throughout the entire bathymetric survey. Sounding points were recorded in Universal Transverse Mercator (UTM) coordinates, corresponding to the WGS84 reference datum and ITRF 92, in zone 13Q, with units expressed in meters. The navigation followed a nearly straight line with minimal boat speed. The start and end of the transect were marked using a Garmin GPS 65st.

The construction of the bathymetric map, the estimation of morphometric parameters, and the accuracy of the bathymetric survey were assessed following the criteria proposed by Håkanson (1981; 2004). Cartographic points were added into a Geographical Information System (GIS) in vector format and verified by tracing contour lines on millimeter paper.

Since the certainty of the information depends on the bathymetric map, which in turn relies on sampling intensity, the optimization model proposed by Håkanson (1981; 2004) uses the following equation.

$$I = I' \cdot I'' \quad (1)$$

Where:
I = The information value of the bathymetric map. This value is between 0.0 and 1.0. If it is 1.0, the information in the bathymetric map is complete and correct.
I' = Correctly identified area in the bathymetric map.

The value of I' also varies between 0 and 1.0. All contour lines are correctly placed when I' is equivalent to 1.0.

The area error (***E***) can be estimated as

$$I = 1 - E \quad (2)$$

I" = The information number depends on the number of contour lines (***n***) in the bathymetric map. The I" also varies between 0.0 and 1.0. A map with few contour lines does not provide adequate information about the bottom topography, unlike a bathymetric map with many contour lines.

To determine ***I'*** and ***I"*** values, the following expressions proposed by Håkanson (1981; 2004) were applied:

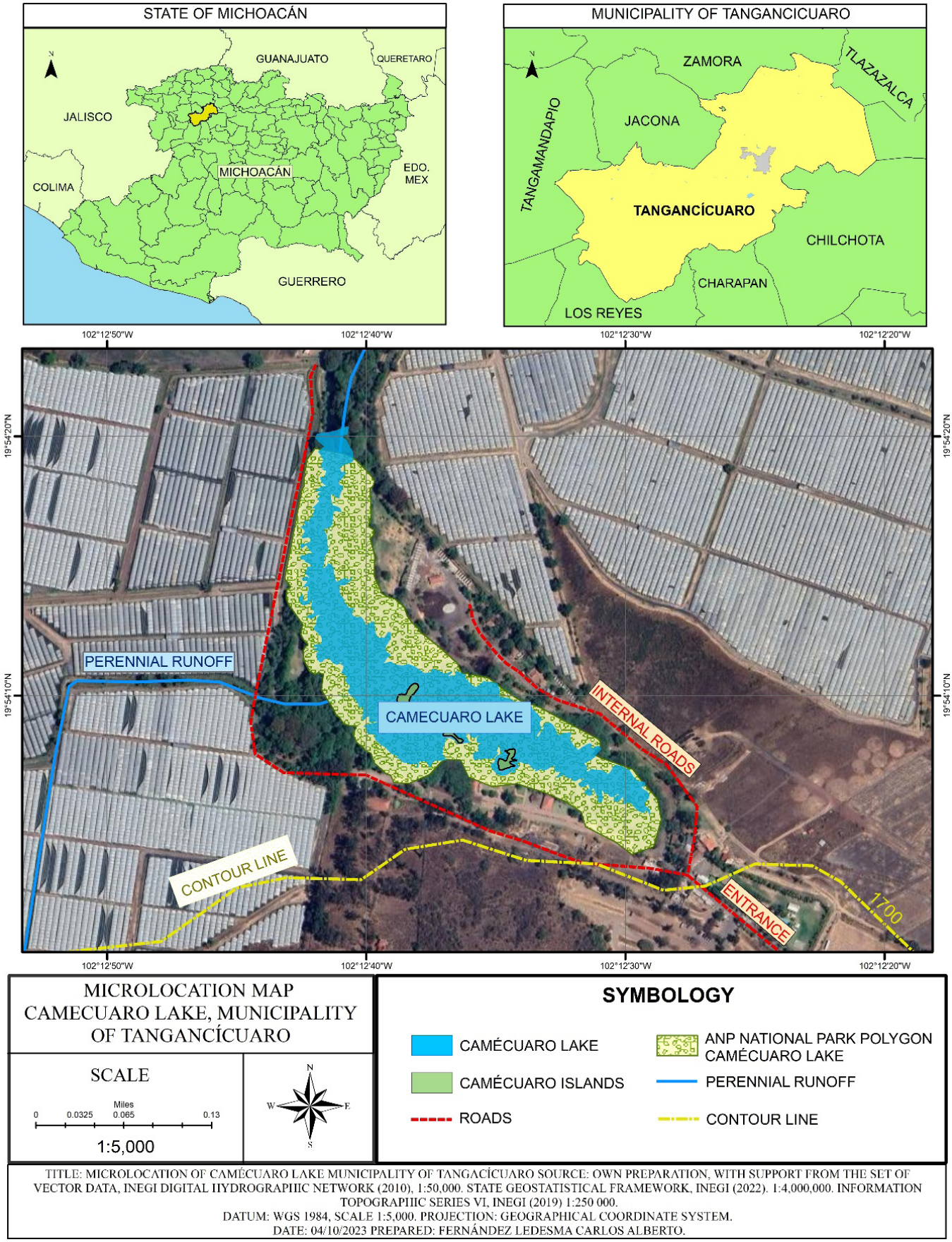

Figure 2. Micro location of Lake Camecuaro, Tangancicuaro, Michoacán, Mexico.

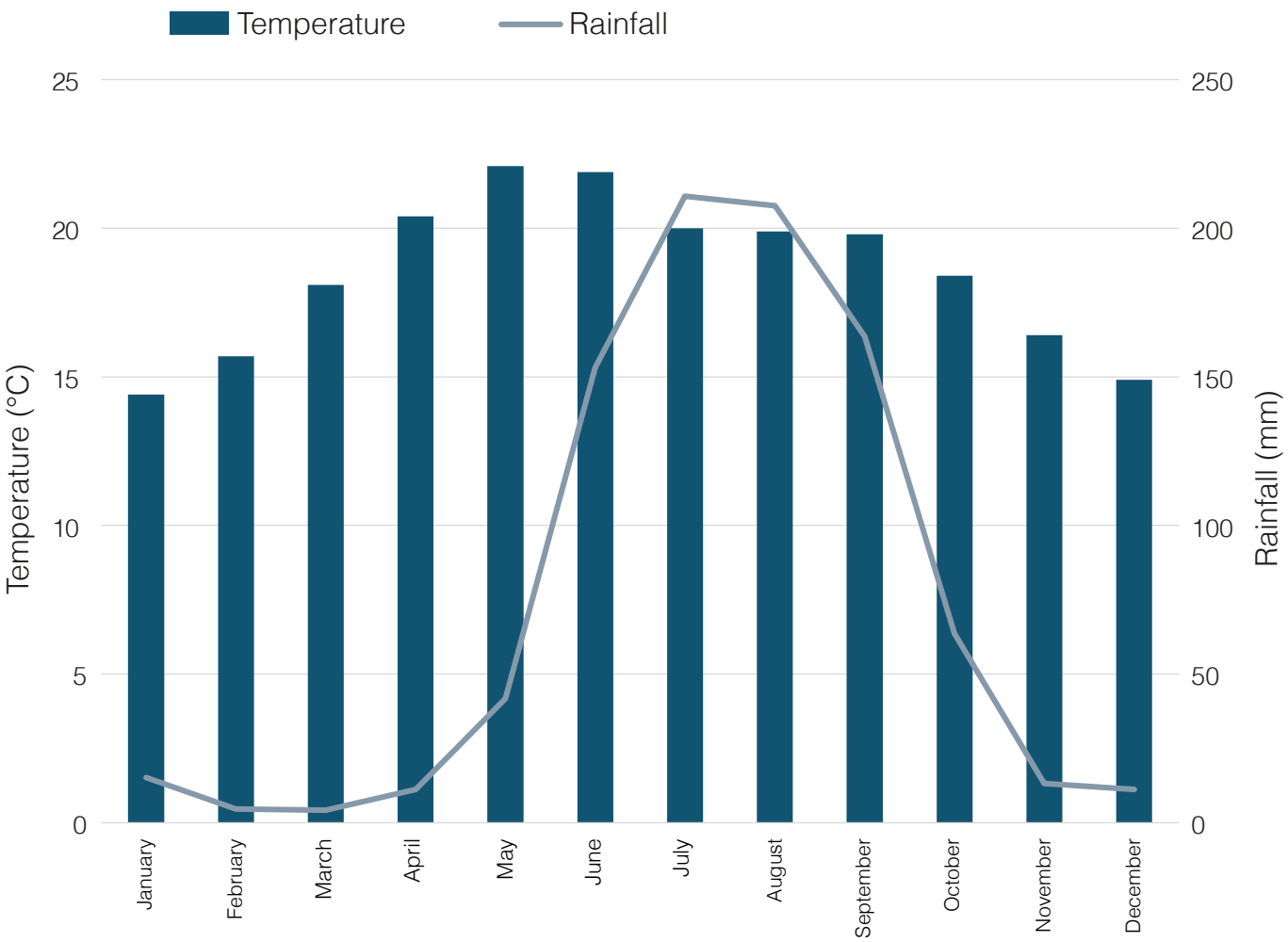

Figure 3. Climogram from the meteorological station 16014 Camecuaro elaborated from data 1951-2010 (SMN, CONAGUA, 2023).

$$I' = \frac{1}{a}\left[a - 0.14 \cdot Lr \cdot F^2 \cdot \sqrt{\frac{1}{n+2}} \cdot \sum_{i=1}^{n} \cdot \sqrt{a_i} \right] \quad (3)$$

$$I'' = \frac{e^{0.4 \cdot n} - 1}{e^{0.4 \cdot n} + 0.2} \quad (4)$$

Where:
a = the lake area in km^2
Lr = intensity of the survey, the distance in km between parallel tracks. An ***Lr*** value of less than 1.0 km is adequate for small lakes.
F = is the value of normalized shore development. A dimensionless parameter indicates the degree of irregularity of the shoreline and the lake bottom (Håkanson, 1974). A lake with irregular topography requires a greater intensity than a regular basin.
a_i = the total area (cumulative area) in km^2 within the limits of a given contour line (l_i).
n = the number of contour lines in the bathymetric map.
e = the base for natural logarithms; $e = 2.718$

Results

Echo profile

The bathymetric profile (**Figure 4**) derived from the echogram shows a very low profile, indicating a gradual buildup of bottom sediments. The transect runs from southeast to northeast, starting at UTM coordinates 0791947 m E and 2203198 m N.

Bathymetry and morphometry

Results from morphometric calculations indicate that the maximum depth is 4.5 meters, with an average depth of 1.65 meters. **Figure 4** shows the results of the bathymetric survey, and the map was generated at a 1:2,000 scale. The contour line interval is 0.5 meters. The total area of Lake Camecuaro is 33,836.26 square

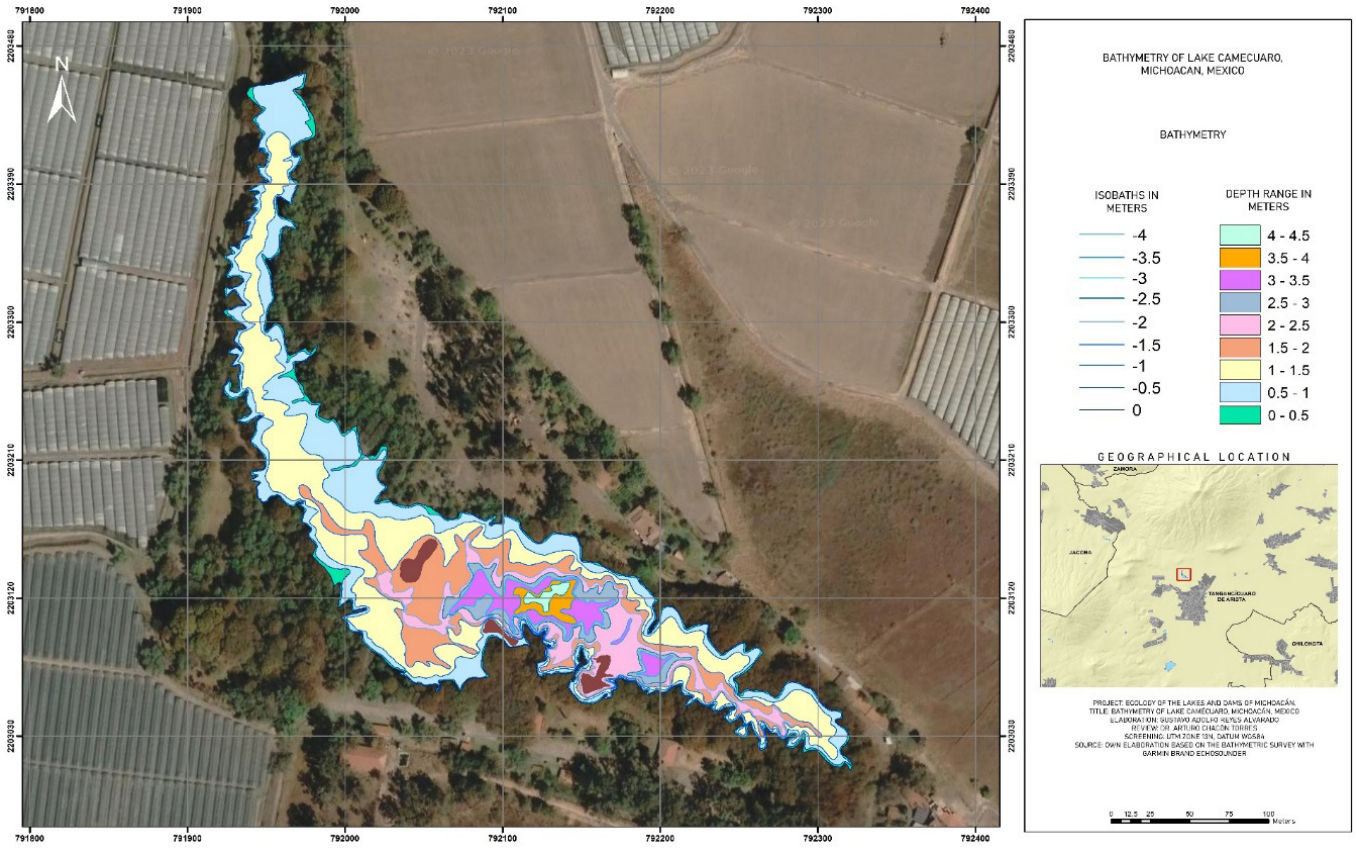

Figure 4. Bathymetric map of Lake Camecuaro, Tangancicuaro, Michoacan, Mexico.

meters, which equals 3.38 hectares.

Figures 5 and **6** show the profiles derived from the maximum length and maximum width of the aquatic ecosystem. As observed, the maximum length exhibits a very rough bottom profile due to water upwelling. Most of the upwelling flow occurs in the lake's center, where the maximum depth is found. In contrast, the outer points show the minimum depth values, including the outflow channel. Nevertheless, upwelling water points are visible across most of the lake. **Table 2** provides the relevant morphometric values describing Lake Camecuaro's morphometry, according to the criteria proposed by Håkanson (1981; 2004). The estimated volume of this small lake is 55,875.86 m³. The first and third depth quartiles suggest that Camecuaro is a very shallow lake. Shore development is a dimensionless parameter indicating the degree of shoreline irregularity. A circular basin has an F value of 1, while more irregular lakes

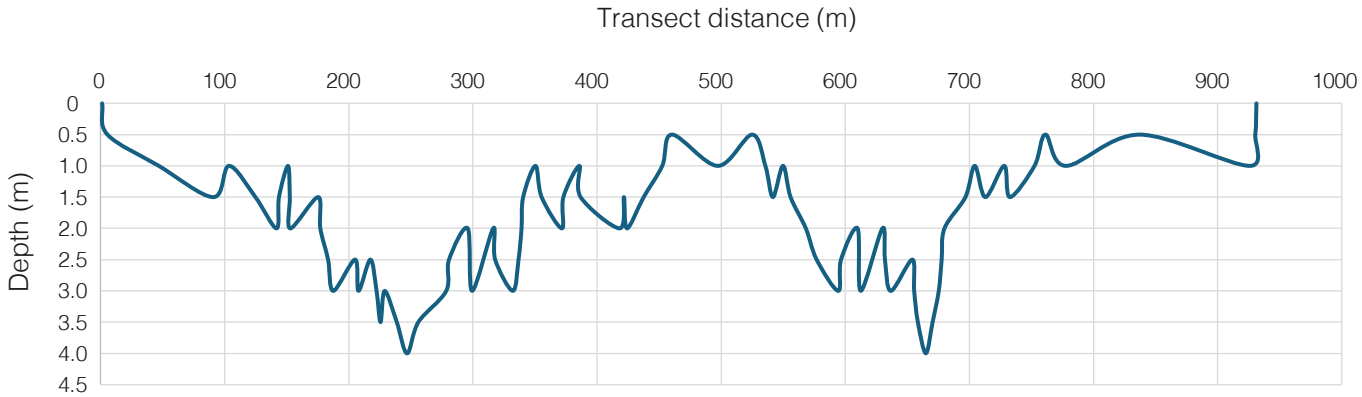

Figure 5. The bathymetric profile was obtained from the maximum length orientation from southwest to northeast in Lake Camecuaro, Tangancicuaro, Michoacan, Mexico.

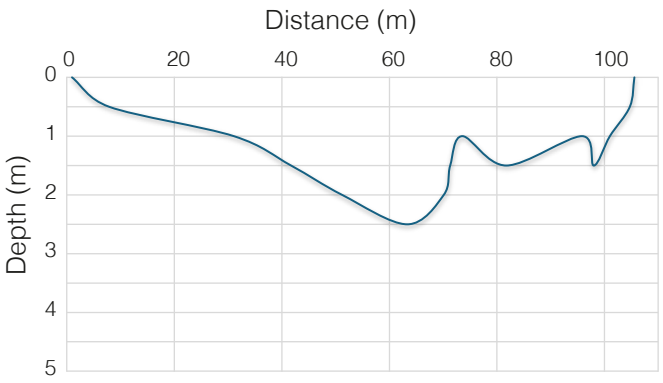

Figure 6. Maximum width profile from a transect oriented North to South Lake Camecuaro, Tangancicuaro, Michoacan, Mexico.

have higher F values. **Figure 7** presents the hypsographic direct, relative, and percentage curves, indicating that Lake Camecuaro is a slightly convex form.

Substituting the required values in equation 2, the value of the correctly identified area in the bathymetric map was estimated (**I'**) with the information of **Table 3**.

According to the proposed model by Håkanson (1974), the obtained value of area correctly identified in Lake Camecuaro is **0.9849**

Thus, substituting in Equation (1)

$$I = I' \cdot I''$$

$$\mathbf{I = 0.9849 \cdot 0.9874}$$

The informative value of the bathymetric survey is **0.9724**, so the area correctly identified is 97.24% precise, with an estimated error of **2.76%**.

Conclusions

Lake Camecuaro is an aquatic ecosystem characterized by numerous water springs at the bottom of the lake. This situation favours its high transparency and continuous flow from East to West. The system presents a relatively low dissolved oxygen concentration, reflecting the underground nature of the water flow.

The aquatic ecosystem is very shallow, with a mean depth of 1.65 m. More than 75% ($\mathbf{D_{75}}$) of the lake's volume is at a depth of less than a meter (0.86 m). The maximum depth measured is 4.5 m, located in a small area with UTM coordinates 13Q 0792129 E and 2203124 N. The shoreline development of Lake Camecuaro is 3.78, indicating a significantly irregular shoreline.

The maximum volume of Lake Camecuaro is 55,875.86 m³, which flows toward the confluence with the Duero River. With an estimated flow of 1.8 m³/s, the hydraulic residence time is 8.62 hours (8 hours, 37 minutes), allowing it to replenish approximately 56,000 cubic meters of water. According to the lake form classification proposed by Håkanson (1981, 2004), Lake Camecuaro is an aquatic ecosystem with a slightly convex shape (f = 0.5) and one inflection point at the meso level. This is the first comprehensive morphometric assessment of Lake

Table 2. Morphometric values of Lake Camecuaro. Tangancicuaro. Michoacan, Mexico.

Parameter	Value
Total lake area (**A**), including isles, ha	3.45
Lake area (**a**). Excluding isles, ha	3.38
The surface area of isles and islets, ha.	0.069
Volume (**V**), m^3	55,875.86
Maximum depth ($\mathbf{D_{máx}}$), m	4.5
Mean depth (**D**), m	1.65
Median depth ($\mathbf{D_{50}}$), m	1.2
First quartile depth ($\mathbf{D_{25}}$), m	1.68
Third quartile ($\mathbf{D_{75}}$), m	0.86
Relative depth (**Dr**), %	2.16
Maximum length ($\mathbf{L_{max}}$), km	0.627
Maximum effective length (**Le**), km	0.124
Maximum width ($\mathbf{B_{máx}}$), km	0.106
Maximum effective width (**Be**), km	0.106
Mean width (**B**), km	0.051
Shoreline length ($\mathbf{l_o}$), km	2.472
Mean slope (**α**), %	9.4
Shoreline development (**F**), dimensionless	3.78
Bottom roughness (**R**), dimensional	3.2
Volume development ($\mathbf{V_d}$), dimensionless	1.33
Insularity (**In**), %	2.03
Direction of maximum length (bearing)	southeast-northwest
Lake form	SCx-Me

Table 3. Informative value of the bathymetric survey in Lake Camecuaro, Michoacan, Mexico.

Parameter	Value
Lake area (**a**), km^2	0.03452
Intensity of hydrographic survey (**Lr**), km	0.0042
Shore development (**F**), dimensionless	3.78
Total cumulative area ($\mathbf{\Sigma\sqrt{a_i}}$) km^2	0.03383
Number of contour lines (**n**)	11
Informative value (**I"**)	0.9874

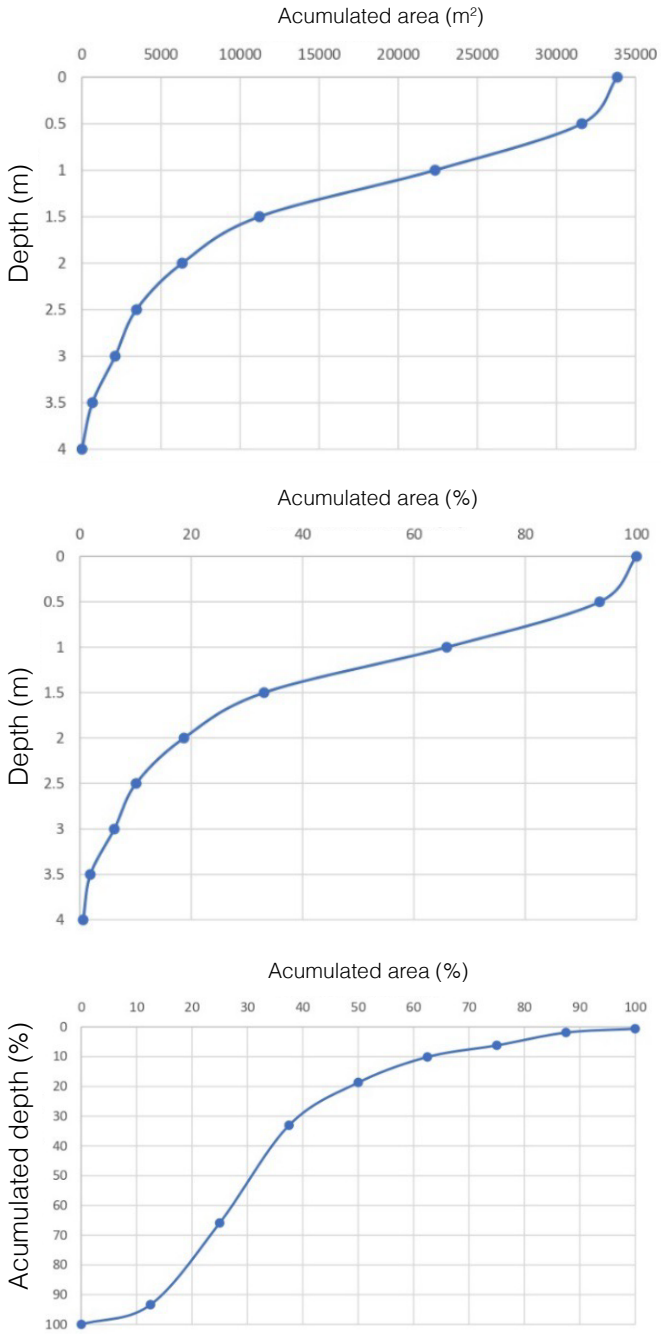

Figure 7. Hypsographic curves, direct, relative, and percentage of Lake Camecuaro, Michoacan, Mexico

Camecuaro, emphasizing the environmental importance of water conservation in water springs to ensure the human right to access high-quality water, as outlined in the 6th Sustainable Development Goal. Environmental values of Lake Camecuaro include its high transparency, water quality, low residence time, native shoreline vegetation, and aquatic biological diversity. Therefore, this Mexican aquatic ecosystem should be protected for research, sustainable recreation, and as a source of clean water.

References

García E (2004). *Modificaciones al sistema de clasificación climática de Köppen (para adaptarlo a las condiciones de la República Mexicana)*. Quinta edn. Instituto de Geografía, Universidad Nacional Autónoma de México, México.

Håkanson L (2004). Lakes: form and function. The Blackburn Press. 201p.

Håkanson L (1981). A manual of lake morphometry. Springer, Berlin, Heidelberg. 78 p. doi:10.1007/978-3-642-81563-8.

Håkanson L (1974). A mathematical model for establishing numerical values of topographical roughness for lake bottoms. *Geografiska Annaler* 56A:3-4.

Jiménez González VM (2018). Parque Nacional Lago de Camécuaro. Michoacán en tu bolsillo. México. p.18. Recuperado de la fuente: [https://books.google.com.mx/books?id=QMtfDwAAQBAJ&pg=PA18&dq=como+se+form%C3%B3+el+lago+de+-camecuaro&hl=es&sa=X&ved=2ahUKEwjc95nLjdz9AhUQJUQIHWL8Ao8Q6AF6BAgFEAI#v=onepage&q=como%20se%20form%C3%B3%20el%20lago%20de%20camecuaro&f=false]

Ruiz Rojas J (2007). Criptohumedales del Sistema Acuático Camécuaro: listado florístico y su importancia para la gestión integral de la microcuenca. Recuperado de la [https://www.researchgate.net/publication/235988593_Criptohumedales_del_Sistema_Acuatico_Camecuaro_listado_floristico_y_su_importancia_para_la_gestion_integral_de_la_microcuenca]

SEMARNAT (2016). El 8 de marzo de 1941 fue decretado el Parque Nacional Lagos de Camécuaro, Tangancícuaro, Michoacán, México. Verified in: [https://www.gob.mx/semarnat/articulos/el-08-de-marzo-de-1941-fue-decretado-el-parque-nacional-lagos-de-camecuaro-tangancicuaro-michoacan?idiom=es]

Silva García JT, Ochoa Estrada S, Cruz Cárdenas G, Nava Velázquez, J, Villalpando Barragán F (2016). Manantiales de la cuenca del Río Duero, Michoacán: Operación, calidad y cantidad. *Revista Internacional de Contaminación Ambiental* 32(1):55-68.

Sistema Meteorológico Nacional (SMN) (2023). Normales Climatológicas por Estado (1951-2010) *CONAGUA. Estación Camécuaro*, Michoacán de Ocampo. Consultada el 17 de mayo del 2023 en: [https://smn.conagua.gob.mx/es/informacion-climatologica-por-estado?estado=mich]