AMAZONIANA	XIII (3/4): 245 - 258	Kiel, Dezember 1995

Morphological characteristics of an Amazon floodplain lake (Lake Batata, Pará State, Brazil)

by

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(Accepted for publication: April, 1995).

Abstract

A bathymetric survey of an Amazon floodplain lake adjacent to the Trombetas River, the Lake Batata (Pará State, Brazil), was done in order to characterize the lake morphology. This study serve as a tool for limnological interpretation data and in environmental impact assessment due to the disposal of tailings from bauxite processing. Lake area, volume, shoreline lenght, maximum effective length and width, shoreline development, maximum, relative and mean depth, volume development and a hypsographic curve were calculated. Lake Batata is shallow (mean depth 2.19 m) and its area is approximately 18 km^2 at low water level. Based on the configuration of the shoreline, the lake can be divided into differents compartments: the main body, the bay, the channel and the outlet. The basin of the lake is slightly convex with a typical U-shaped configuration. The lake is submitted to a significant seasonal variation of its surface area and shoreline lenght. The distribution of maximum effective fetch, at the main body, is coincident with the maximum turbidity values, evidencing the wind effect over the lake.

Keywords: **Amazon, floodplain lake, morphometry, tailings.**

ISSN 0065-6755/1995/245/ © MPI für Limnologie, AG Tropenökologie, Plön; INPA, Manaus

Introduction

The significance of morphometry for the evaluation of productivity in lakes has been recognized since the work of Thienemann and Naumann in temperate regions at the beginning of the century (reviewed by WETZEL 1981). In tropical lakes, morphology can exert an important role in determining the dynamics of nutrients, aquatic communities, ecological and hydrological processes (LEWIS 1982; SCHWARZBOLD & SCHÄFER 1984; DE MEIS & TUNDISI 1986; TUNDISI & MUSSARRA 1986; TORRES et al. 1989; DRAGO 1989; HAMILTON & LEWIS 1990). Nevertheless, research with a focus on morphological characteristics of Amazon floodplain lakes is scare, except for studies of MELACK (1984), MELACK et al. (1991) and SIPPEL et al. (1992).

The present work is a morphological characterization of Lake Batata, an Amazon floodplain lake, partly impacted by tailings from bauxite mining pumped into the lake during ten years (1979-1989). This kind of impact is not found elsewhere in Brazil and possibly abroad (ESTEVES et al. 1990).

This study is a basic requirement for environmental impact assessment related to Lake Batata and contribute to knowledge of the morphology of the Amazonian floodplain lakes.

Study area

Lake Batata is located at 1°25'-1°35'S and 56°15'-56°25'W, near Porto Trombetas in the municipality of Oriximiná, Pará State, Brazil (Fig. 1). The lake is connected throughout the year to the Trombetas River, a clear water river according to SIOLI (1984). Changes in water level (about 7 m) occur during the year and the exchange of water between the lake and the river increases substantially during the high water period.

Bauxite has been mined in Porto Trombetas by the company Mineração Rio do Norte since 1979. This mineral is processed by washing with water jets, producing a liquid effluent (tailings), composed of 7 to 9 % of fine-grained solid particles (ca. 96 % smaller than 50 µm), mainly represented by aluminum oxide (21 %), silicates (4 %) and iron oxides (LAPA & CARDOSO 1988). Until 1989, these tailings were pumped into Lake Batata, at an annual volume of 18 million m^3.

Material and method

A bathymetric survey was carried out at low water level (December1992), with a high-frequency (208 kHz) echo sounder. A map of the lake contour at a scale of 1:15000, surveyed in december 1980, was supplied by Mineração Rio do Norte and was used as a base map for navigation and position of the profiles. Sixty-three transects, approximately perpendicular to the longest axis of Lake Batata were made. Bathymetric data were first transformed to a regularly spaced grid which was further submitted by kriging in order to create depth contour lines trough the use of the computer program "Surfer", developed by Golden Software Inc. The same program was also used for the calculation of surface area (A) and volume(V) of the lake. The length of the shoreline (l_0) was calculated on the map. From these data the following morphometric parameters were calculated, the first one according to WETZEL (1981) and the others according to HÅKANSON (1981):

Shoreline development (F). The ratio between the length of the shoreline (l_0) in km, and the length of the circumference of a circle with area equal to that of the lake:

$$F = \frac{l_0}{\left(2\sqrt{\pi A}\right)}$$

maximum depth (D_{max}). The greatest measured depth (m) of the lake;

relative depth (D_r). The ratio of maximum depth to mean diameter of the lake, where the lake area (A) is expressed in km^2;

$$D_r = \frac{D_{max} \cdot \sqrt{\pi}}{20 \cdot \sqrt{A}}$$

mean depth (D_m). The quotient between lake volume (km^3) to lake area (km^2;

volume development (V_d). The quotient of the lake volume (km^3) ($A \cdot D_m$) and the volume of a cone whose base area is equal to the lake area (A) and whose height is equal to the maximum depth (D_{max}) of the lake;

$$V_d = \frac{A \cdot D_m}{\frac{1}{3} \cdot D_{max} \cdot A} \therefore V_d = \frac{3D_m}{D_{max}}$$

maximum effective length (L_e). The straight line (km) connecting the two most distant points on the shoreline over which wind and waves may act without interruptions from land or islands;

maximum effective width (B_e). The straight line (km), on the lake surface, perpendicular to the maximum effective length, which connects the two most distant points on the shoreline;

relative hypsographic curve, obtained by plotting the cumulative area (in percentage) on the positive abscissa and the cumulative depth (in percentage) on the negative ordinate.

effective fetch (km). Defined according to a method introduced by the Beach Erosion Board (1972), described in HAKANSON (1981).

The water turbidity was measured by a turbidity meter La Motte Model 2008, at transects made in september 1993.

Results

A bathymetric map of the entire lake and of the lake compartments is presented in figs. 2 and 3 and morphometrical parameters for Lakė Batata and for each compartment, taken at low water, are given in table 1.

The area and shoreline length of the largest compartment, the main body (Figs. 2, 3 A), is respectively 10.0 km^2 and 32.2 km. This compartment has a nearly flat bottom without topographic irregularities. The margins of this compartment are mostly steep, a result of valley incision prior to the development of the lake. A sandy barrier built up by fluvial sediments forms part of the south shore. Downstream this compartment converges to a narrow channel. Upstream, in the northern extremity of the compartment, the bottom is covered by the clayey sediments from the bauxite tailings. About 1/3 of the area of the main body was affected by the tailings discharge. The rest of the area is covered with original, sandy, sediments.

Another compartment, situated laterally to the main body and separated from it by remnants of the former land surface (Figs. 2, 3 B), was named bay. The bathymetry of this compartment is similar to the main body, but the margins are steeper. This compartment is different from the others in some morphometrical aspects. The volume development (Vd) of the bay was 2.36 due to the very flat bottom of this compartment, while the Vd-values of Lake Batata and the other compartments were between 1.19 and 1.54. The superposition of relative hypsographic curves from different compartments is shown in fig. 4. The mean form of the lake basin is "slightly convex" as are the different lake compartments, except for the bay, due his more uniform depth distribution. As already expressed by the higher Vd-value, the relative hypsographic curve for this compartment also differs from the other curves in showing a concave configuration.

The third compartment, the channel, is long, narrow and deep (Figs. 2, 3 C), connecting the distal end of the main body to the outlet compartment. A thalweg of up to 5 m incision indicates strong bottom currents, as does the presence of sandy sediments. Lateritic outcrops at the margins of the channel explain the prevalence of vertical over lateral erosion and the increase in depth here compared to the other compartments. Finally, the outlet (Figs. 2, 3 D) is a transitional compartment between the lake and the Trombetas River, a transition provided by a well-incised thalweg of up to 4 m depth below the level of the lake bottom.

In general, Lake Batata is shallow, specilly during the low water period. The form of the lake, expressed by the Vd value (1.19), is typically U-shaped. Through the F-values the differences in shape between the various morphological compartments were clearly defined. The channel, with an F-value of 4.63, is elongated. The outlet, with an F-value of 1.69 is approximately circular. The main body and the bay have F-values intermediate to circular and elongated.

The Maximum Effective Lenght and Width were larger in the main body. Consequently, the effect of wind and waves will be more pronounced than in the others compartments. However, the effective fetch (Fig. 5) is the most appropriate morphometric parameter to express the potencial wind and wave effects on the water column.

The wind effect on the main body is more effective in direction to the right margin of the northern extremity (Fig. 5). This explain the increase in turbidity values in this direction (Fig. 6).

Discussion

Based on the elongated shape ($F < 4.4$), the position parallel to the Trombetas River, and the morphometric and sedimentological characteristics, the origin of Lake Batata seems to be related to a former channel position of the Trombetas. The lake is separated from the main channel by sedimentary deposits and could be classified as a lateral levee lake (HUTCHINSON 1957). The sedimentary origin of the whole river basin with its low resistance to shear stress favor erosion and the relative facility to change the position of river channels. The river's low declivity (< 0,4 cm/1000 m) favors the lateral evidenciando o efeito do vento sobre o lago.

Acknowledgments

Financial support for this work was provided by Mineração Rio do Norte (MRN) and Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq). We are also very grateful to Mr. Delmo Fonseca for his advise during the bathymetric profiling and to M.Sc. André Furtado for his assistance during the field work.

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deposition of sediments.

The magnitude of seasonal variation in the lake's dimensions becomes evident by comparing the area of the lake at low water (18.02 km^2) and at high water (30.17 km^2, according SILVA 1991). This significant seasonal variation of the lake's surface area and shoreline length changes the amplitude of interactions between the lake and its floodplain.

The mean depth plays an important role for the establishment of lake productivity (RAWSON 1952; RAWSON 1955; KEREKES 1975) and is also an indicator of the stratification stability of a lake (HÅKANSON 1981). The greater the relative depth, the higher will be the potential for stable thermal stratification (SCHÄFER 1985). The low relative and low mean depths of Lake Batata, promote a low stability of the water column. In fact, long lasting thermal stratification doesn't exist in Lake Batata. At high water stratification is destroyed at night (ESTEVES et al. 1994) and at low water, the thermal gradient are reduced and thermal stratification may occur (PANOSSO 1993).

The effective length (L_e) and relative width (B_e) as a measure of the longest distance for wind and wave action are also important parameters for evaluation of potential for maintenance or destruction of thermical stratification in a water body. The channel and main body with the longest lengths are potentially most affected by wind and waves, considering that their lengths are oriented in the direction of the prevailing winds. Nevertheless these parameters should not be evaluated without considering other characteristics of lake morphometry. For instance, in spite of its largest relative length and width, the channel is also deep, a condition favourable for a greater water column stability. Effectively the channel shows better pronounced thermal gradients than the other compartments (PANOSSO 1993).

The fetch values clearly show the increase in turbulence of the water column at the northern extremity of the main body. This effect is also evidenced by the higher turbidity values in that area. On the upper portion of the lake, the increase of the fetch length and decrease in water depth, are the cause of the ressuspension of the smal sediment particles of the bauxite tailings with the consequent increase in water turbidity.

Finally, the identification of compartments with different morphometric and hidrodynamic characteristics is of fundamental importance for the understanding of the spatial distribution of zooplanktonic (BOZELLI 1992) and phytoplanktonic (HUSZAR 1994) communities.

Resumo

Foi realizado um levantamento batimétrico em um lago da planície de inundação amazônica adjacente ao rio Trombetas, o lago Batata (Pará, Brasil), com o objetivo de caracterizar a morfologia do lago de forma a auxiliar na interpretação dos dados limnológicos e na avaliação do impacto ambiental causado pelo rejeito proveniente do processamento da bauxita, lançado no lago Batata. Foram calculados a área, volume, perímetro, comprimento e largura máximos efetivos, desenvolvimento de perímetro, profundidades média, máxima e relativa, desenvolvimento de volume e curva hipsográfica. O lago Batata é raso (profundidade média de 2.19 m) e sua área é aproximadamente 18 km^2 nas águas baixas. Com base na configuração da margem, o lago pode ser dividido em diferentes compartimentos: o corpo principal, a baía, o canal e a desembocadura. A bacia de acumulação do lago é levemente convexa, com uma típica configuração em "U". O lago Batata é submetido a uma significante variação sazonal na sua área superficial e perímetro. A distribuição do fetch máximo efetivo, no corpo principal, é coincidente com valores máximos de turbidez,

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Table 1: Morphometric parameters of Lake Batata as a whole and its different compartments at low water (December 1992). See text and figure 3 for descriptions of compartments.

Parameters	**Lake Batata**	**Main Body**	**Bay**	**Channel**	**Outlet**
Area (km^2)	18.04	10.00	2.04	2.95	3.43
Volume (x 10^6 m^3)	39.59	20.80	4.02	7.22	7.33
Volume Development	1.19	1.54	2.36	1.33	1.33
Maximum Depth (m)	5.5	4.0	2.5	5.5	5.5
Mean Depth (m)	2.19	2.05	1.97	2.45	2.45
Relative Depth	0.11	0.11	0.16	0.28	0.26
Shoreline Length (m)	66250	32200	12500	28200	11075
Shoreline Development	4.4	2.85	2.47	4.63	1.69
Max. Effective Length (m)	5000	5000	3000	5000	3850
Max. Effective Width (m)	2100	2100	780	1500	1730

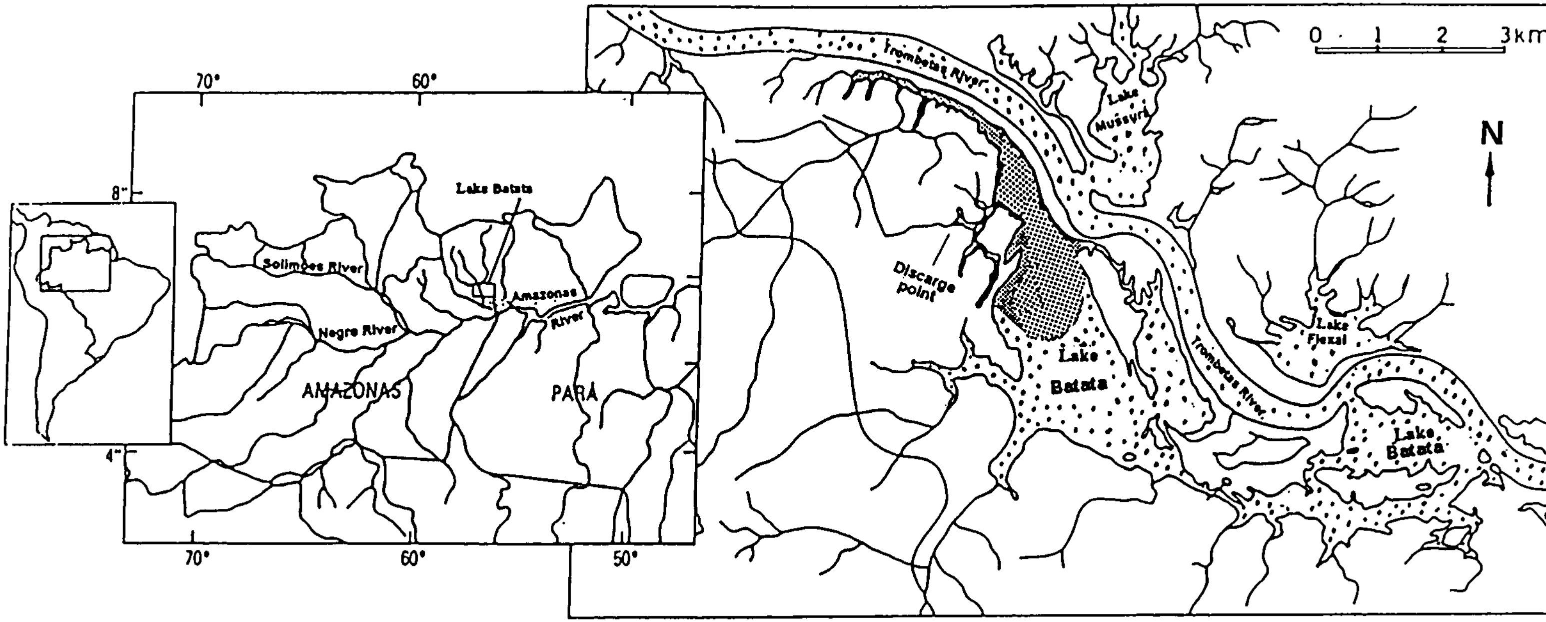

Figure 1:
Geographic location of study area, modified from FERRÃO-FILHO & ESTEVES (1994).

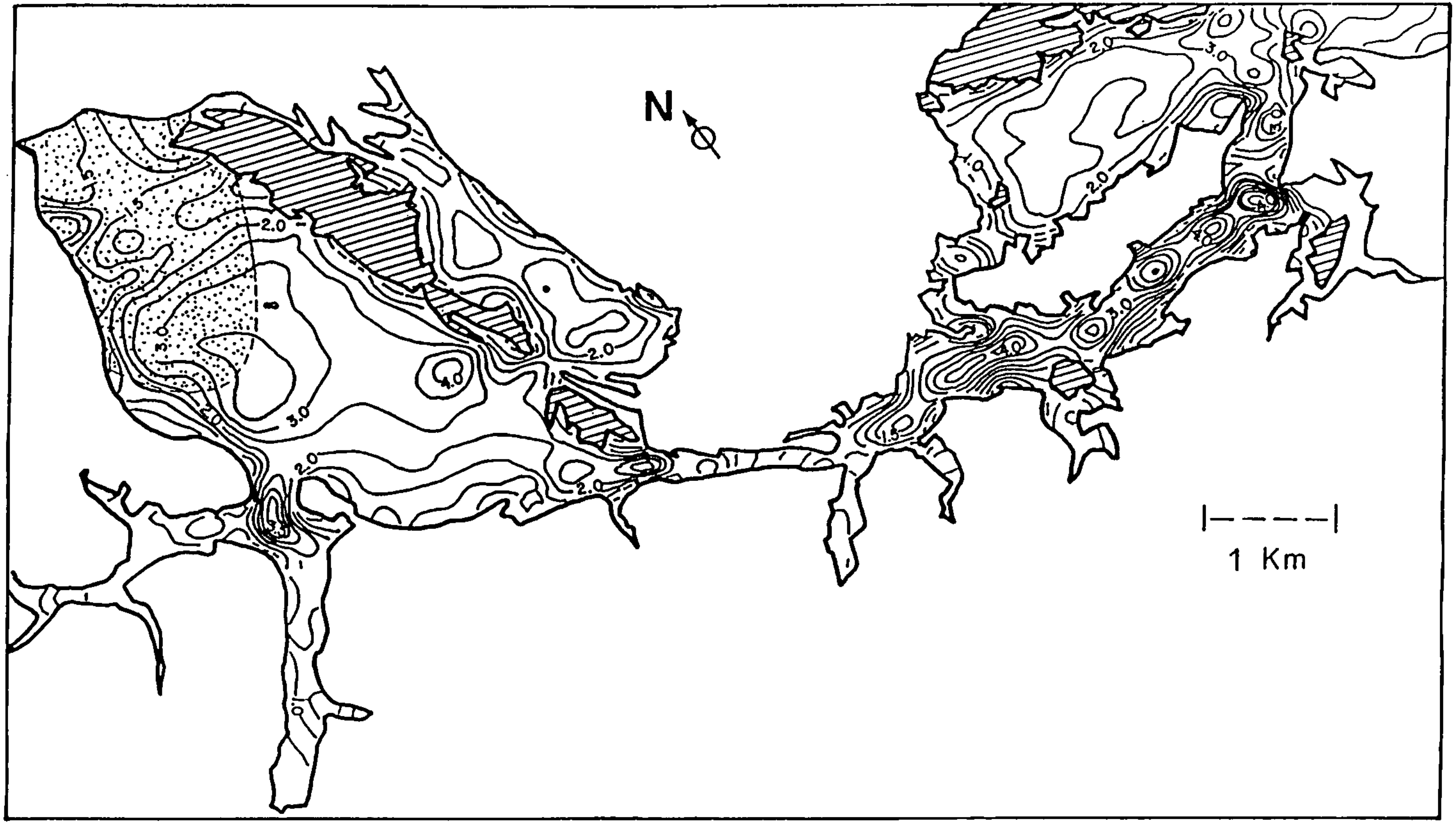

Figure 2:
Bathymetric map of Lake Batata. The dotted line indicates the limit between natural sediment and sediment covered by bauxite tailings. The isobates indicate 0,5 m difference in depth.

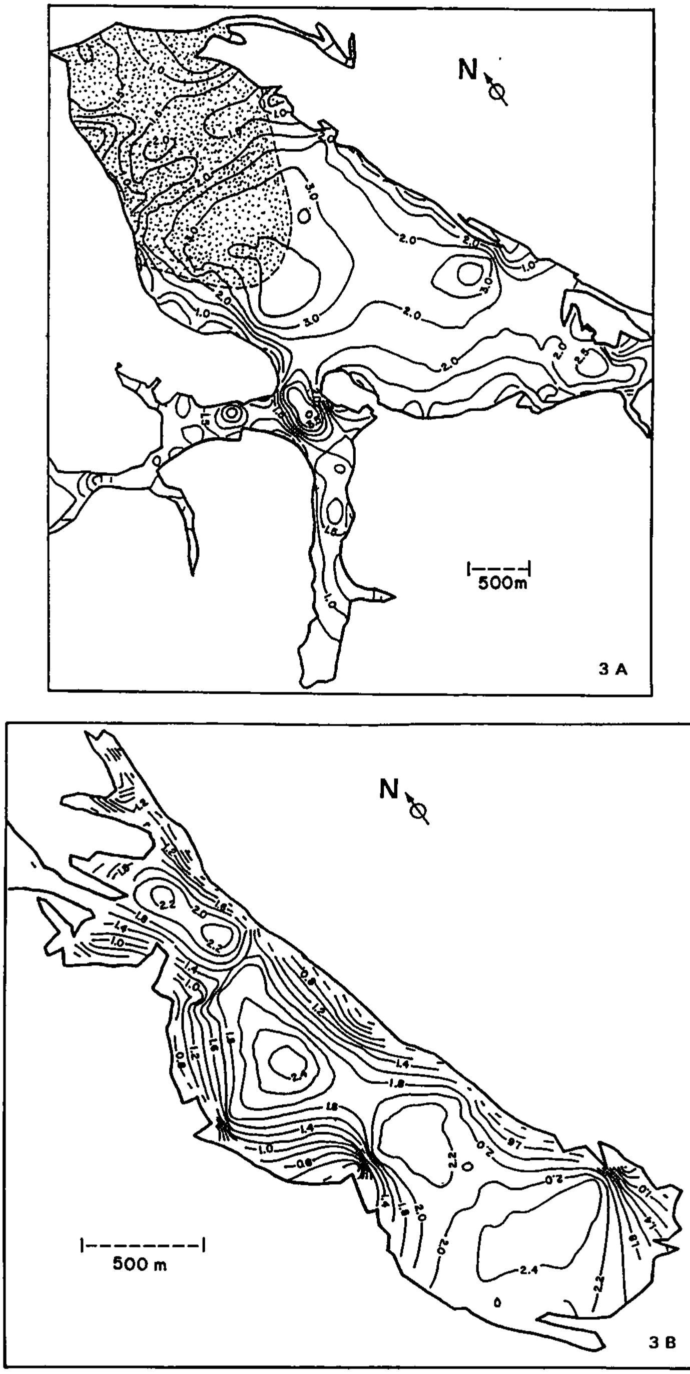

Figure 3 A + B:
Bathymetric maps of the four compartments of Lake Batata.
A: "main body" (N - natural sediment area; I - sediment area covered by bauxite tailings); B: "bay".
The isobates indicate 0.2 m difference in depth in map B, and 0.5 m in maps A, C and D.

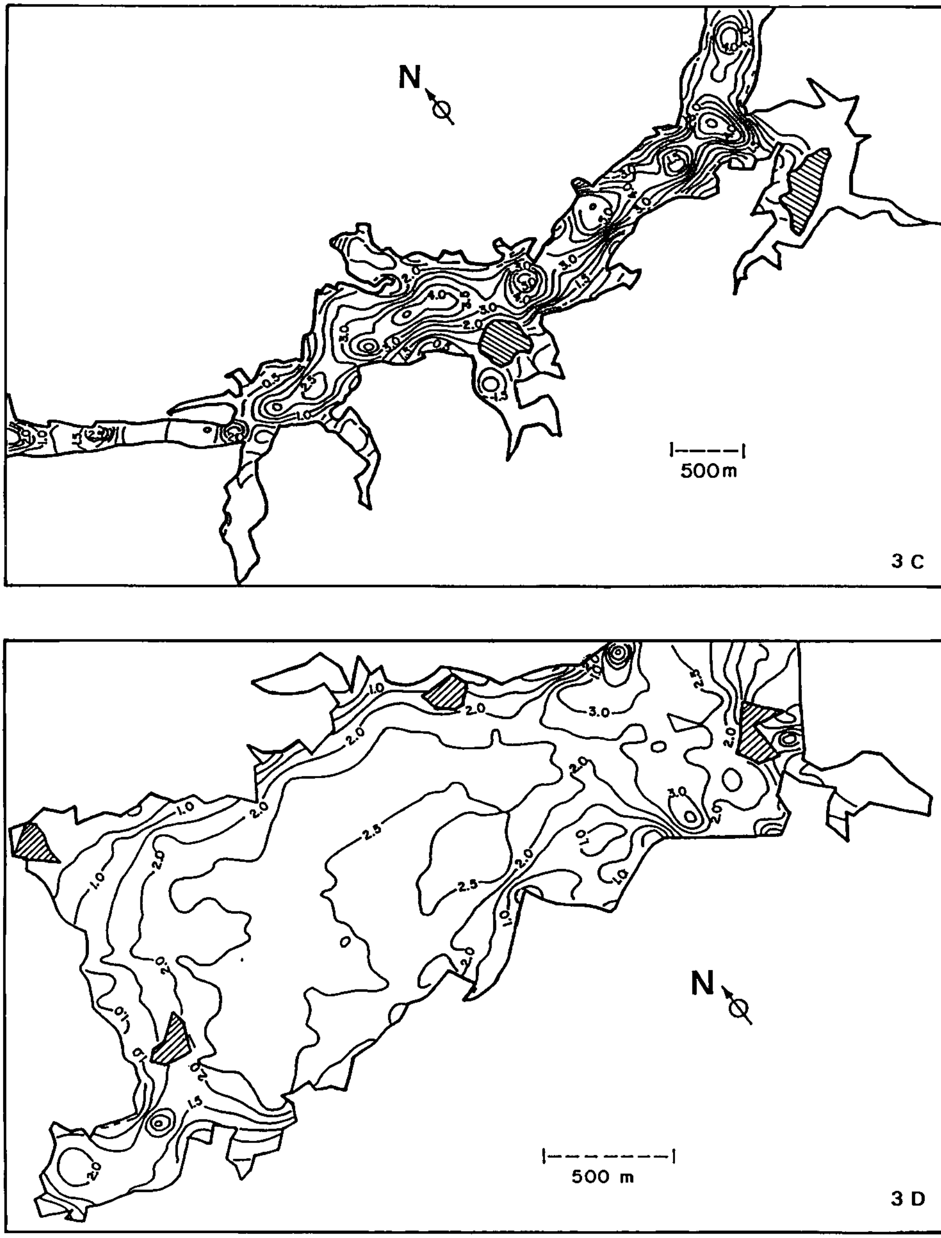

Figure 3 C + D:
Bathymetric maps of the four compartments of Lake Batata.
C:"channel"; D: "outlet". The isobates indicate 0.2 m difference in depth in map B, and 0.5 m in maps A, C and D.

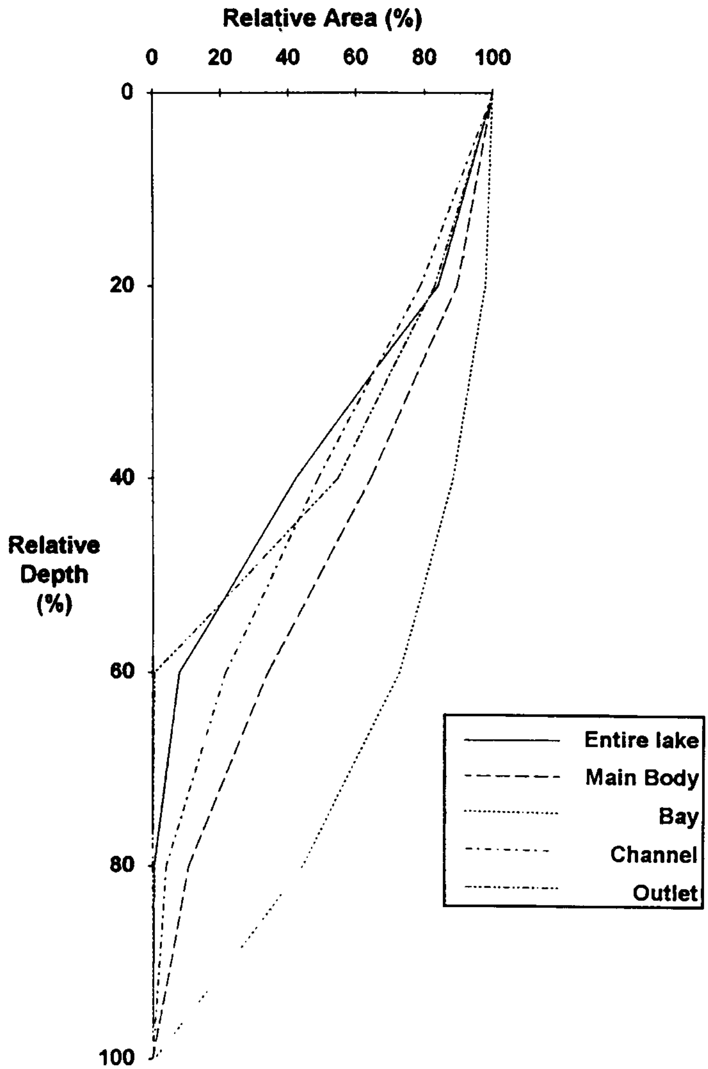

Figure 4:
Hypsographic curves of Lake Batata and the different compartments.

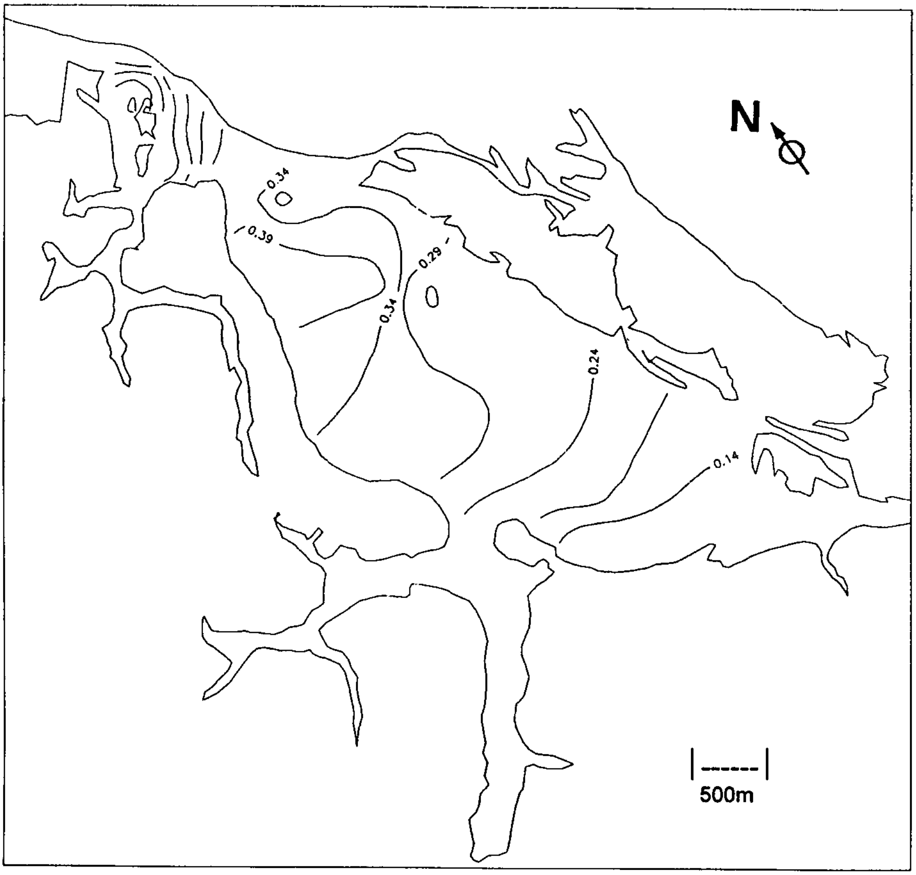

Figure 5:
Fetch values at main body of lake Batata.

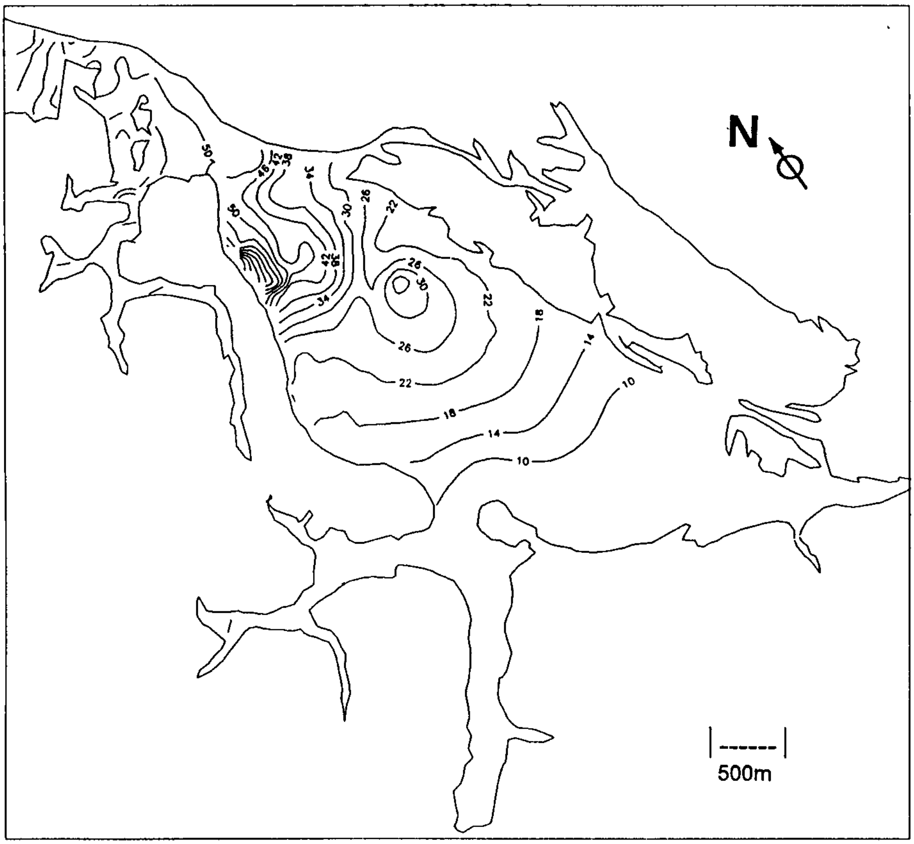

Figure 6:
Turbidity values (NTU) of water column at main body of Lake Batata in September 1993.