Geofísica Internacional (2002), Vol. 41, Num. 1, pp. 63-74

Lake Chapala and the Cienega aquifer: Chemical evidence of hydraulic communication

J. T. Silva García[1], R. Rodríguez Castillo[2], S. Ochoa Estrada[1] and S. López Díaz[1]
[1] *Centro Interdisciplinario de Investigación para el Desarrollo Integral Regional, CIIDIR-IPN-Michoacán-México,*
[2] *Instituto de Geofísica-Universidad Nacional Autónoma de México, México*

Received: April 6, 2001; accepted: November 28, 2001

RESUMEN

Se propone un mecanismo de comunicación hidráulica entre el lago y el acuífero de la ciénega de Chapala localizado en la margen oriental del mismo. Se consideran indicadores químicos como los fosfatos (fósforo total) y cloruros, incorporando aspectos como temperatura, conductividad eléctrica y piezometría, sobre todo por la posibilidad de que el lago (dado su continuo deterioro ambiental, disminución de volumen, incremento de nutrientes) pudiera ser considerado como área preferencial de recarga y por lo tanto fuente potencial de contaminación de los acuíferos de la ciénega. Las formaciones sedimentarias que subyacen al lago permiten suponer la continuidad hidráulica hacia la Ciénega. Hasta 1910, cerca del 56 % de la ciénega era ocupada por el lago. Aunque predominan materiales arcillosos, las alternancias de sedimentos de grano más grueso le dan un carácter permeable al relleno del graben que define al lago. La hipótesis de comunicación se soporta por los gradientes piezométricos, así como los de cloruros y fosfatos que indican flujos del lago hacia el acuífero. El alto contenido de arcilla en los estratos someros limita la incorporación de fosfatos de origen agrícola. Como una primera aproximación para la zona se propone un modelo funcional mixto del tipo lagos de flujo directo, basado en el modelo hidroestratigráfico del acuífero, en los principales mecanismos de recarga y en las tendencias químicas y piezométricas de la ciénega.

PALABRAS CLAVE: Lago de Chapala, Ciénega de Chapala, fosfatos.

ABSTRACT

A hydraulic communication mechanism between Lake Chapala and the Cienega de Chapala aquifer system is proposed. The lake is a recharge area and a potential source of aquifer pollution. In 1910, 56 % of the Cienega was occupied by the lake. The communication hypothesis is supported by piezometry, phosphate and chlorine gradients that suggest flows from the lake to the aquifer.

The high content of clay in the shallow layers controls the agriculture phosphate leakage. A proposed mixed functional model is based on the aquifer hydrostratigraphic model, the main recharge mechanisms and the chemical and piezometrical tendencies.

KEY WORD: Lake Chapala, Chapala “Cienega”.

INTRODUCTION

Lake Chapala is a large shallow lake, with a very slow hydraulic continuity with its surroundings due to fine grained soil texture. Remson *et al.* (1971), Frezee (1969), Cooley (1974), Winter (1976), Anderson and Munter (1981) and Brown and Bradley (1995) have discussed lake-groundwater interaction systems.

In this study we describe the mechanisms of hydraulic communication between Lake Chapala and the adjacent marshland because of the possibility that groundwater might be polluted with lake water. The wetland groundwater is being used in domestic and agricultural activities. Phosphates (total phosphorus) chlorides, temperature, electrical conductivity and piezometric tendencies are considered as indicators of pollution.

HYDRAULIC MECHANISMS

Winter (1976) proposes three main methods for the quantification of underground flow toward and from lakes: (1) Direct piezometric measurement; (2) numeric simulation; (3) hydraulic balance of the lake.

Hydraulic balance is the most common method to determine the source and volume of water that flow into a lake. In order to obtain the balance it is necessary to have adequate data on evaporation, evapotranspiration, precipitation, incoming and out coming flows and the same parameters for the aquifer system under study. However, the application of this method is complicated here due to the degree of uncertainty of some important variables such as evaporation and water extraction from the lake.

Domenico and Schwartz (1990) have classified the majority of lakes according to their mechanism of interaction with groundwater. These mechanisms are determined basically by the relative position of the potentiometric level (Figure 1):

(a) Discharging lakes, which receive groundwater flows supplied by an aquifer system.

(b) Recharging lakes, which contribute water to the aquifer.

(c) Direct flow lakes. These types of lakes combine both features; they receive and provide water to the underground flow.

(d) Isolated lakes, which do not maintain any hydraulic relation with aquifer systems in their geologic surroundings.

We propose a functional mixed model of direct flow corresponding to case (c) above, based on recharge of precipitation on the Cojumatlan hills and on the piezomety of the Wetland. This agrees with the geologic regional framework (Figure 2).

HYDROGEOCHEMICAL EVIDENCES OF HYDRAULIC COMMUNICATION

In May 2000, chemical sampling for the determination of total phosphorus was carried out in 14 pilot wells located in the northern part of the Cienega between the lake and the Duero river. Chloride, boron, temperatures and electrical conductivities were measured in 80 wells of the Cienega area (Figure 3).

Samples from the lake were obtained in the same period at two localities where river Lerma discharges into the lake.

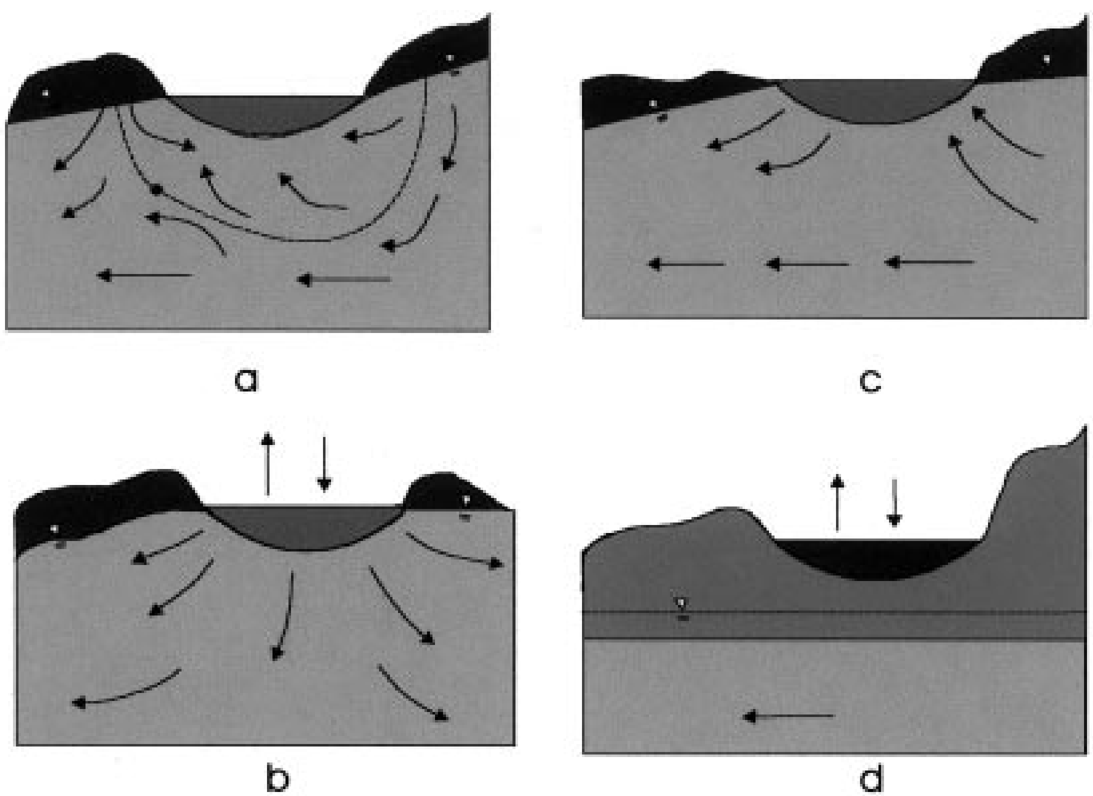

Fig. 1. Mechanisms of interaction between lakes and groundwater. Case C is appropriate to the region under study (adapted from Anderson and Munter, 1981).

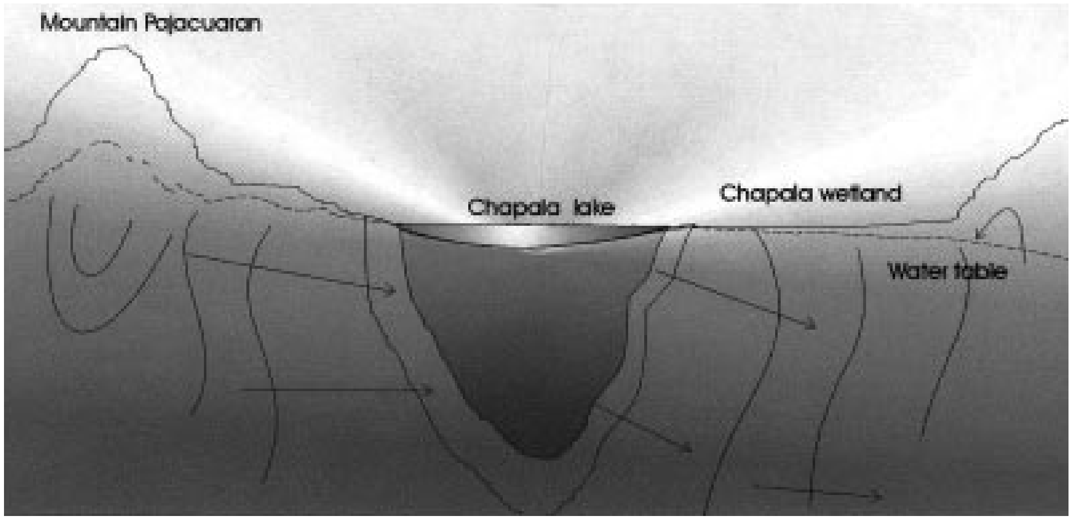

Fig. 2. Functional scheme of hydraulic communication between Lake Chapala and the Cienega de Chapala, as in case (C) from Brown and Bradley (1995).

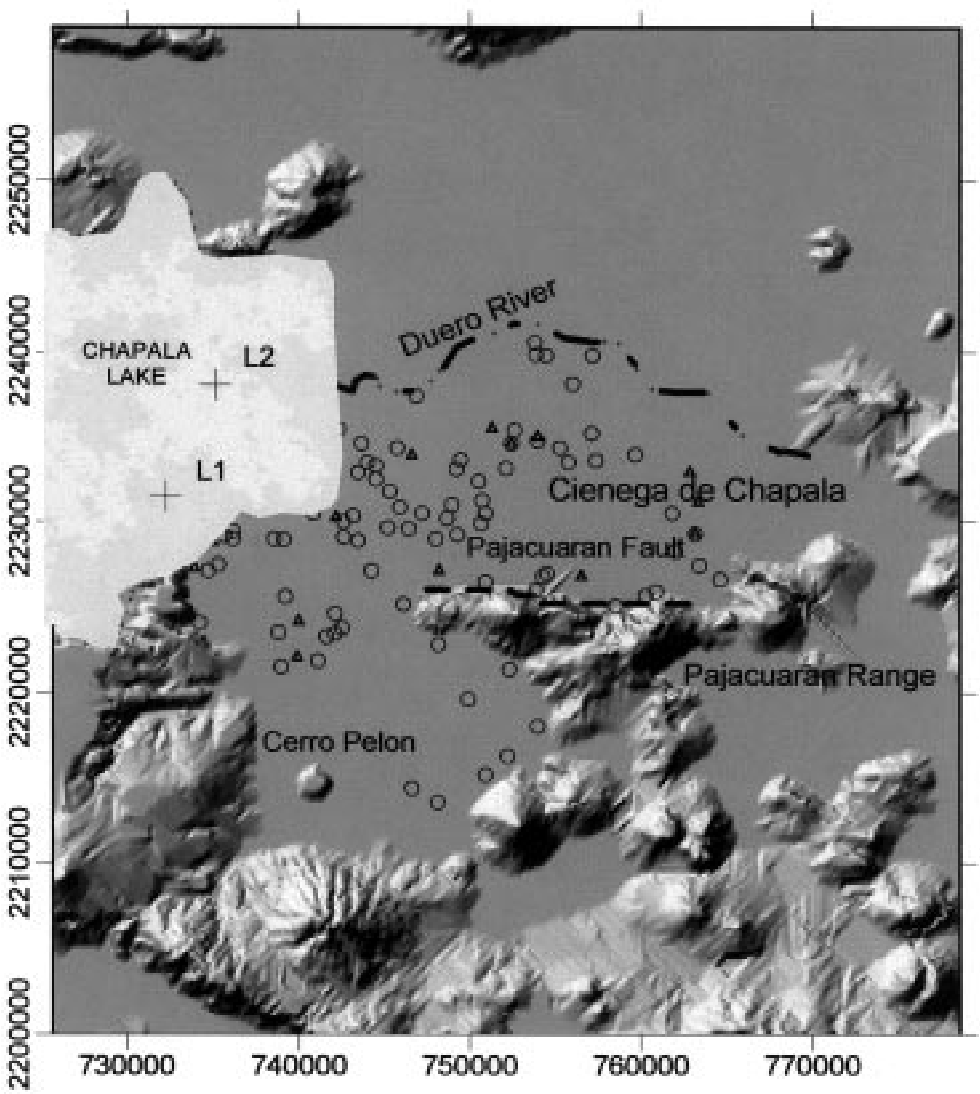

Fig. 3. Sampling sites at Cienega de Chapala. (△phosphate wells).

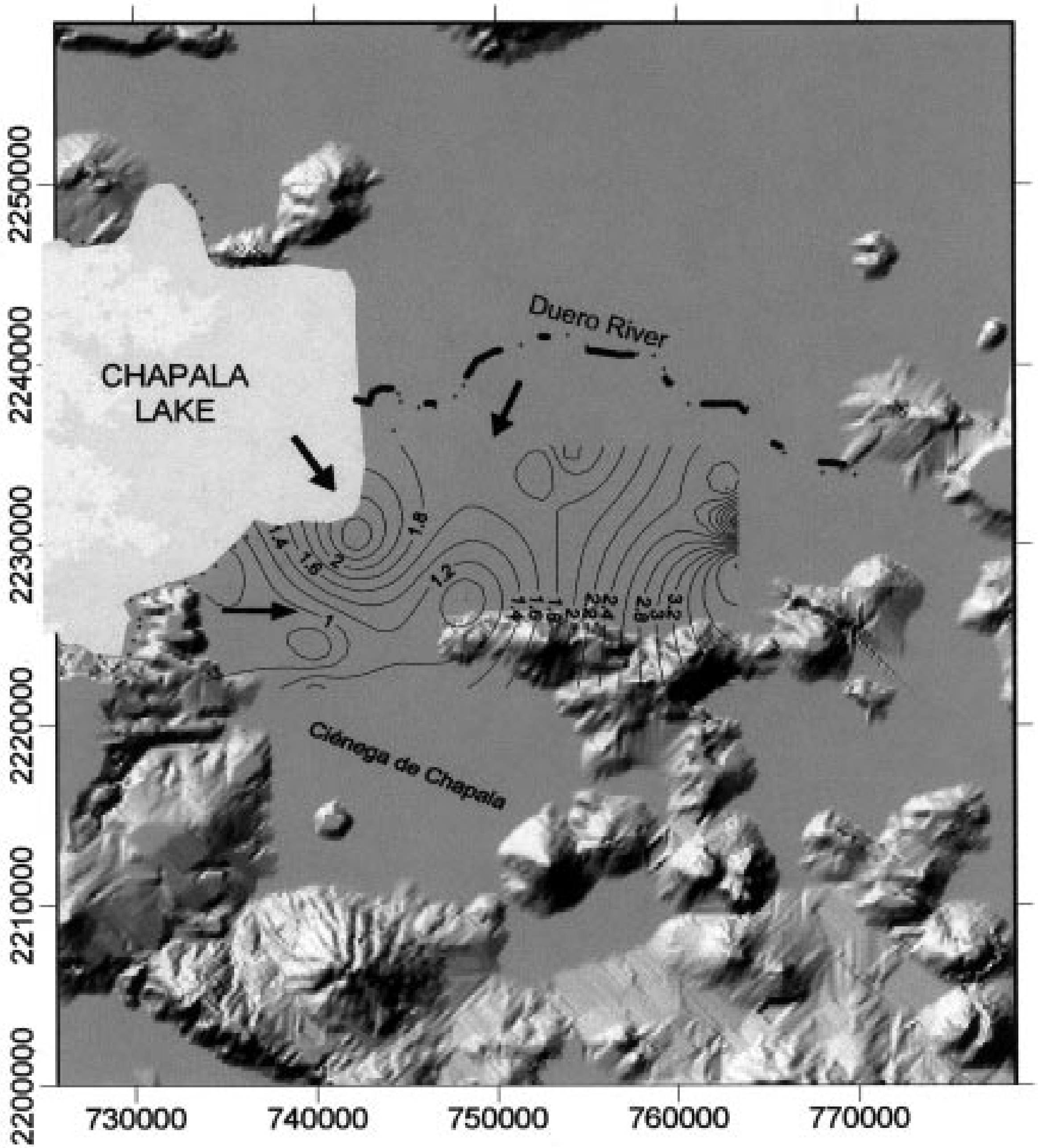

Fig. 4. Isoline map of total phosphorus concentrations in the study area (May, 2000).

All wells tap the same aquifer, and their mean depth is 60 m. The samples were analyzed for total phosphorus and chlorides, pH, temperature, alkalinity and electric conductivity (Table 1). Data were interpolated using Kriging, and isoline maps were obtained.

Phosphates

Phosphorus is one of the nutrients which is abundant in Lake Chapala. De Anda (2000) reports concentrations of total phosphorus of 0.517 mg/l near the Lerma river discharge. Elsewhere in the lake phosphorus varies from 0.35 to 0.40 mg/l.

The concentration of orthophosphates varied from 0.55 to 4.12 mg/l whilst in the lake water, it varied from 0.6 to 1.05 mg/l. The higher values were found close to the lake shore and near Duero river in the northern part of the study area (Figure 4). At some distance from the lake, the lowest orthophospate values are found in the Pajacuarán Range

Table 1

Values of parameter measured in each well. (F: farming; bdl: below detection limit; L: lake sampling site)

Well No.	Well Name	Use	Phosphates mg/l	Chlorides meq/l	Boron mg/l	Temperature °C	pH	Electrical Conductivity (μmhos)	TDS mg/l
1	L. Macías	F	2. 66	5.0	bdl	21.4	7.5	4550	3180
2	R. Sánchez	F	1. 60	0.8	bdl.	20.7	8.1	1880	928
3	P. Montejano	F	1. 68	1.3	bdl	21.7	7.6	2010	1014
4	J. Zepeda	F	2. 07	0.8	bdl	20.5	7.7	2050	1030
5	J. Cervera	F	1. 28	0.7	bdl	21.0	7. 8	1920	938
6	La Luz	F	4. 12	0.6	bdl	21.6	7. 0	941	941
7	J. Padilla	F	0. 61	1.4	bdl	29.9	6.4	549	384
8	La Palma	F	0. 61	0.7	bdl	30.4	8.5	430	300
9	J. Zapien	F	2. 84	1.9	bdl	21.4	7.3	2600	1820
10	R. Bravo	F	2. 04	0.8	bdl	20.6	5.4	1670	713
11	E. Arceo	F	1. 50	0.5	bdl	23.6	7.9	855	598
12	Casa Blanca	F	0. 55	0.4	bdl	31.5	8.5	565	395
13	L. López	F	0. 81	0.4	bdl	37.4	9.1	438	307
14	B. Alcaraz	F	0. 76	0.4	bdl	23.7	7.1	350	245
15	CHAPALA 1	L1	0.60	1.4	bdl	22.1	8.7	898	630
16	CHAPALA 2	L2	1.05	1.3	bdl	21.1	8.4	904	639

(0.65 mg/l) and toward Cerro Pelón in the southern part of the Cienega.

We conclude that phosphate is barely present and does not yet represent an environmental hazard. However, the gradient from Duero River toward the Cienega supports a possible hydrological connection.

Chlorides

Chloride is an ideal tracer due to its high solubility. It does not interact with the ground and it is stable (Custodio y LLamas, 1976). Chloride concentration is shown in Figure 5. It varies between 1 and 12 meq/l. It was determined by the APHA method (Standard Methods, 1998).

A gradient concentration of chlorides from the lake and the Duero river towards the Cienega was found. The lower concentrations are found along the shore (1-2 meq/l). In the center and southeast values of 7 to 9 meq/l are found. This finding suggests a regional flow toward the southeast.

Electric conductivity

A range of conductivity from 500 to 4500 mmhos was found (Figure 6). The lowest values are found near the foothills of the higher mountains, and in Duero river and Lake Chapala. This gradient (low to high) indicates flow directions and possible recharge from the Lake to the aquifer.

Values of low mineralization (low conductivity) in the mountain area are associated with the litology. Wells in volcanic zones show electric conductivities of less than 1000 mmhos while in the lacustrine sediments values up to 4500 mmhos are found. Such values represent a high risk for some agricultural crops.

Temperature

Water temperature varies from 20° to 30°C (Figure 7). The high values are located towards the southern part of the study area, and in wells close to geological faults which may

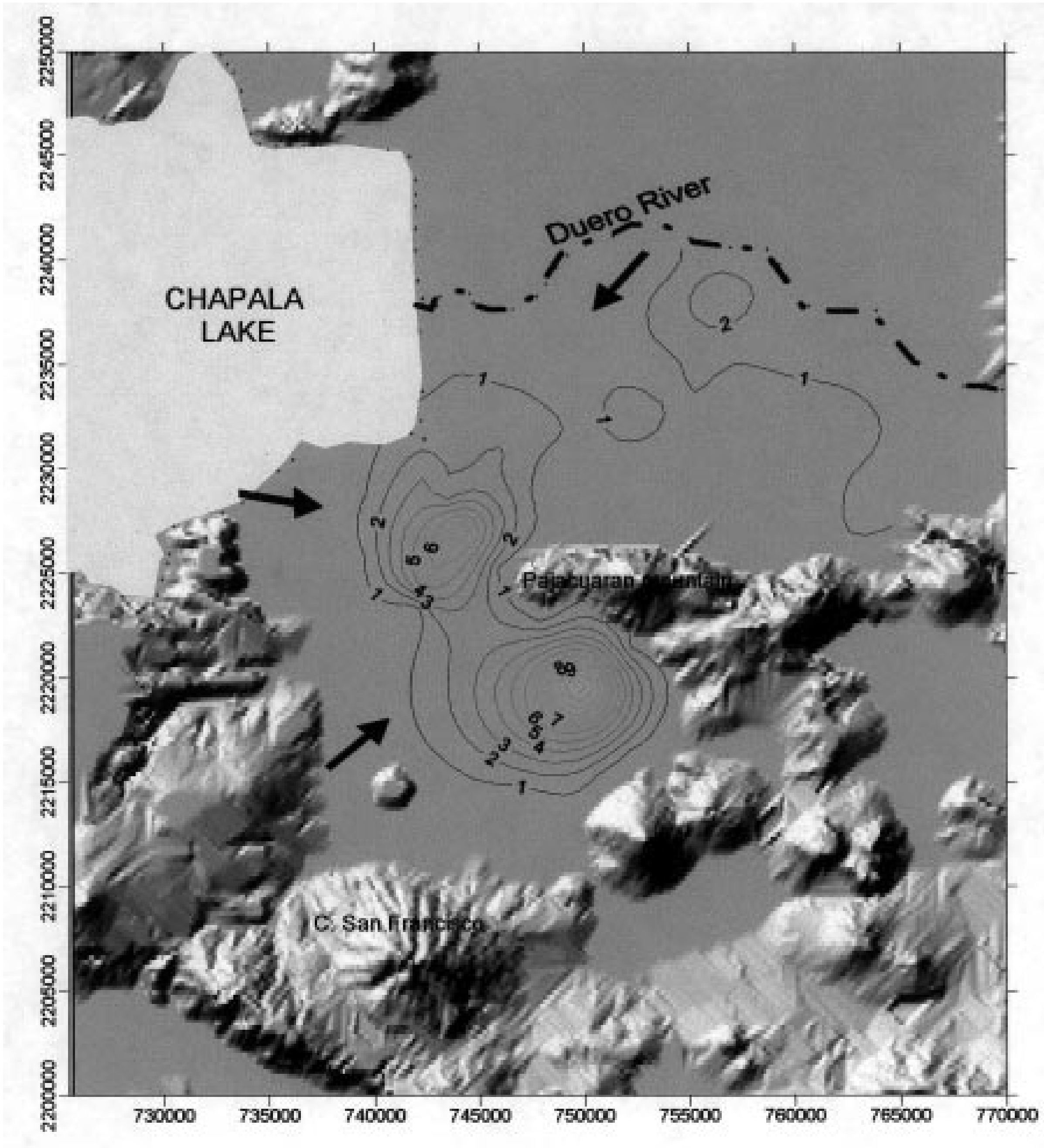

Fig. 5. Chloride isoconcentration pattern in the Cienega de Chapala (May, 2000).

conduct deep geothermal fluids (San Pedro, La Palma and Cumuatillo wells).

A correlation between conductivity and temperature was found. It can be related to the recharge mechanism. Deep regional flows associated to the fault system are represented by high temperature and low electrical conductivity, whereas low temperature and high conductivities correspond to intermediate flows in the lacustrine sediments. Hot water was found only in wells near the faults, and cool water in wells located far from the faults (Figure 8)

Piezometry

Piezometric levels were measured in a set of pilot wells. As in other basins in Mexico there are no systematic piezometric data. The water table is relatively shallow, one meter deep near the lake shore to 16 m deep in the southern area, in July 2000.

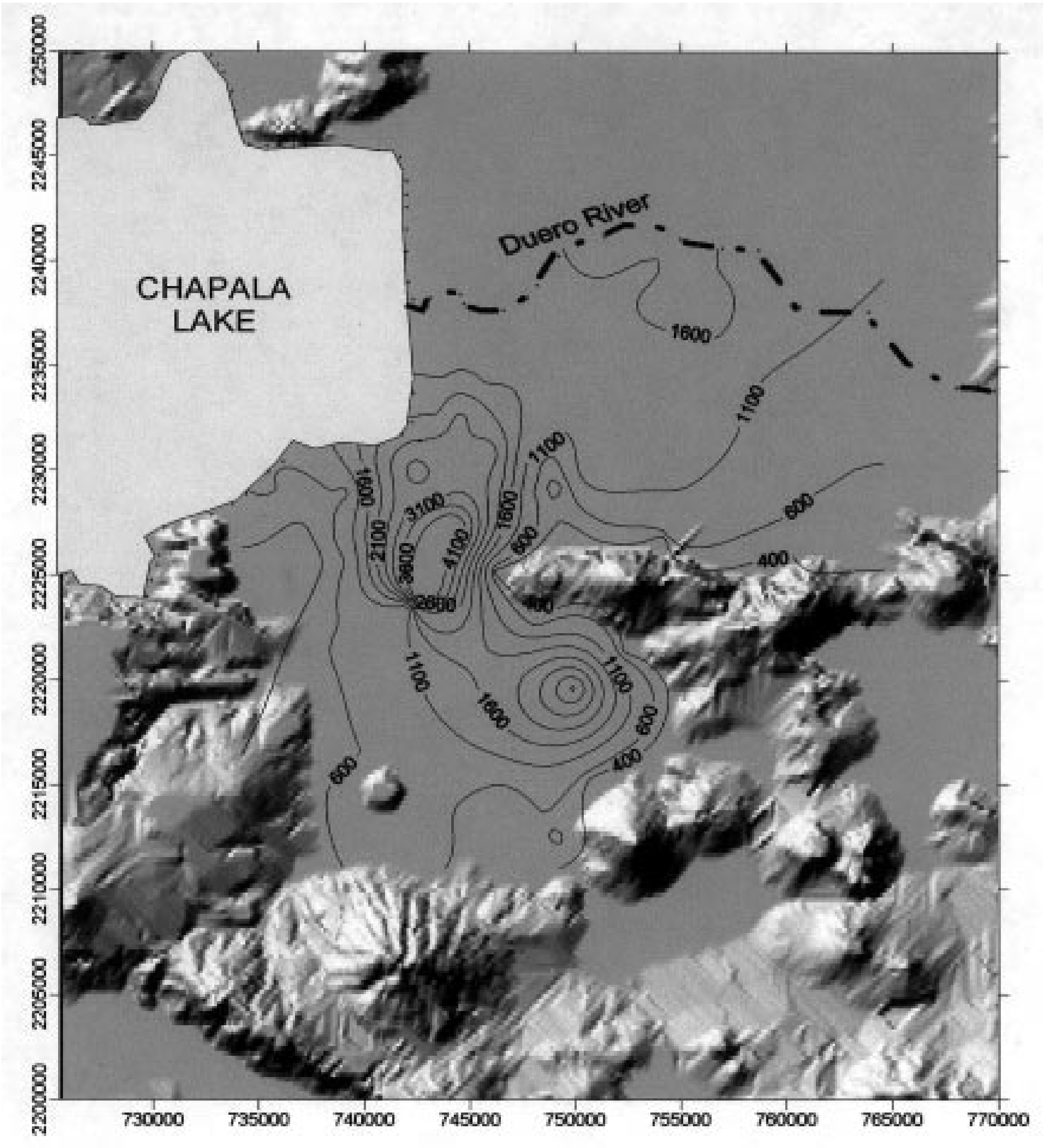

Fig. 6. Electrical conductivity in the study area (May, 2000).

The Cienega has a mean altitude of 1526 masl. Shallow dug wells or *norias* located in perched aquifers were not included. A piezometric map is shown in Figure 9.

The lowest heads are found near the lake shore, as expected. Heads of 1524 m decrease toward the east of the lake. In the Cienega central area a head of 1516 m was measured. In the northern area a gradient of 2 m per 5 km is reported. To the south we find twice this value. The difference could be explained in terms of the recharge volumes, as the recharge in the southern area is higher.

The piezometric level decreases to the south. The head was 1505 m between Cerro Pelón and Cerro San Francisco. This was the lowest value in the study area. The groundwater flow preferential direction from the piezometry is N-S. It suggests recharge from the lake to the aquifer.

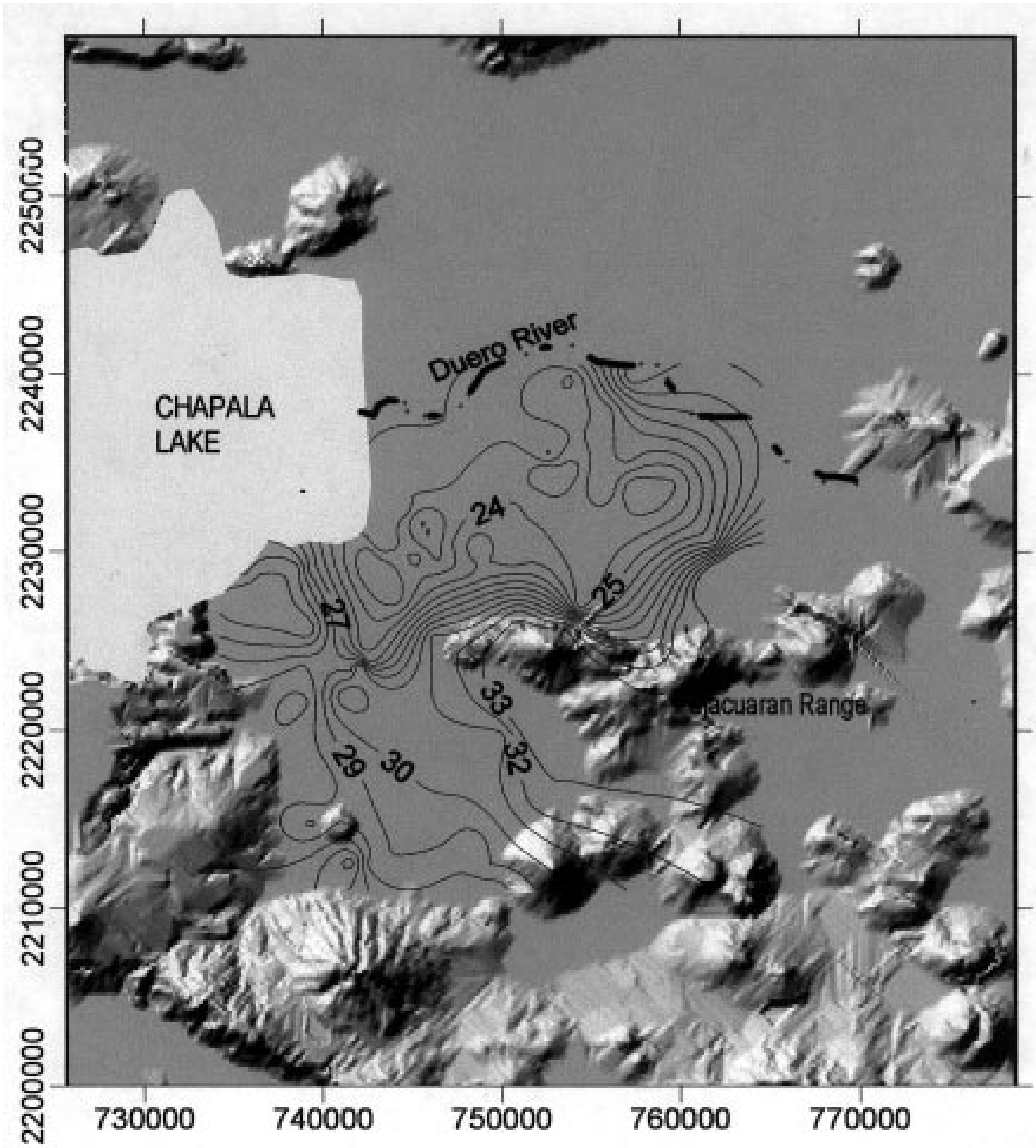

Fig. 7. Isoline map of temperatures in the Cienega de Chapala (May, 2000).

5. DISCUSSION

The high clay content of the lacustrine sediments could impede hydraulic communication between the lake and the aquifer. Furthermore, the surrounding ranges suggest that infiltration from rainfall is the main recharge mechanism. This favors flows from the aquifer to the lake and hinders flows from the lake to the aquifer, as in case (a) (Winter, 1996). However preliminary piezometric data showed gradients from the lake to the aquifer (Silva, 2001).

The Duero river may also be considered as a recharge area to the river mouth but not to the east where head isolines indicate no flow. The piezometry shows flows coming from the river, that may explain the phosphate gradient in the river mouth. The P maximum detected to the east is related to a well with casing problems and no head protection. Irrigation water may have contaminated this well through the casing.

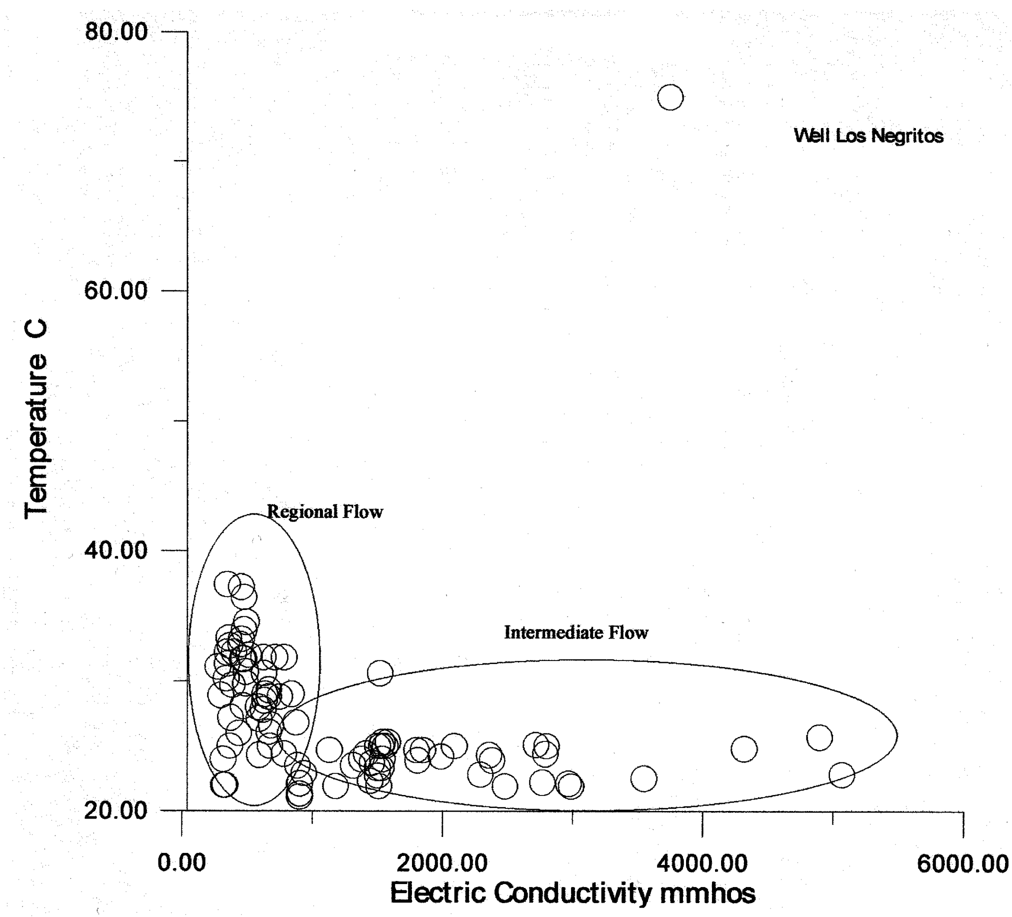

Fig. 8 Correlation between electrical conductivity, EC, and temperature, T. Intermediate flows (low T and high EC) and regional flows (high T and low EC) are shown.

Boron was not detected at least within analytical detection limits (1.0 mg/L). However boron was included in the monitoring.

Temperature values indicate thermalism in most of the southern Cienega region. The wells in this area have temperatures exceeding the mean annual value, 19° C, plus the thermal gradient. The highest values correspond to wells located along the Pajacuaran fault. Arsenic and lithium should be included in future surveys in order to understand the hydrodynamics of deep flows.

CONCLUSIONS

The piezometrical gradient of aquifers located in and around Lake Chapala suggests an hypothesis about preferential flows from lake to the aquifer. In the study area, the piezometric gradients indicate flows from the lake to the aquifer. The concentration gradients of total phosphorus and chlorides show similar tendencies. Electrical conductivity also reflects the same pattern.

Chloride and phosphorus could also be related to contamination by fertilizers. The low values in wells far from the lake shore suggest that shallow clay layers may be acting as impervious barriers to vertical flows from agricultural leakages. One way to confirm this hypothesis could be by nitrogen compounds monitoring. Phosphorus could also be the result of leakages from agrochemicals and fertilizers.

ACKNOWLEDGMENT

This projects was partially financed by the SIMORELOS- CONACYT grant 19990306021. The authors thank CAN-Sahuayo for access to well information. Dr. Samuel Desentis helped to early drafts of this manuscript. COFAA provided a grant.

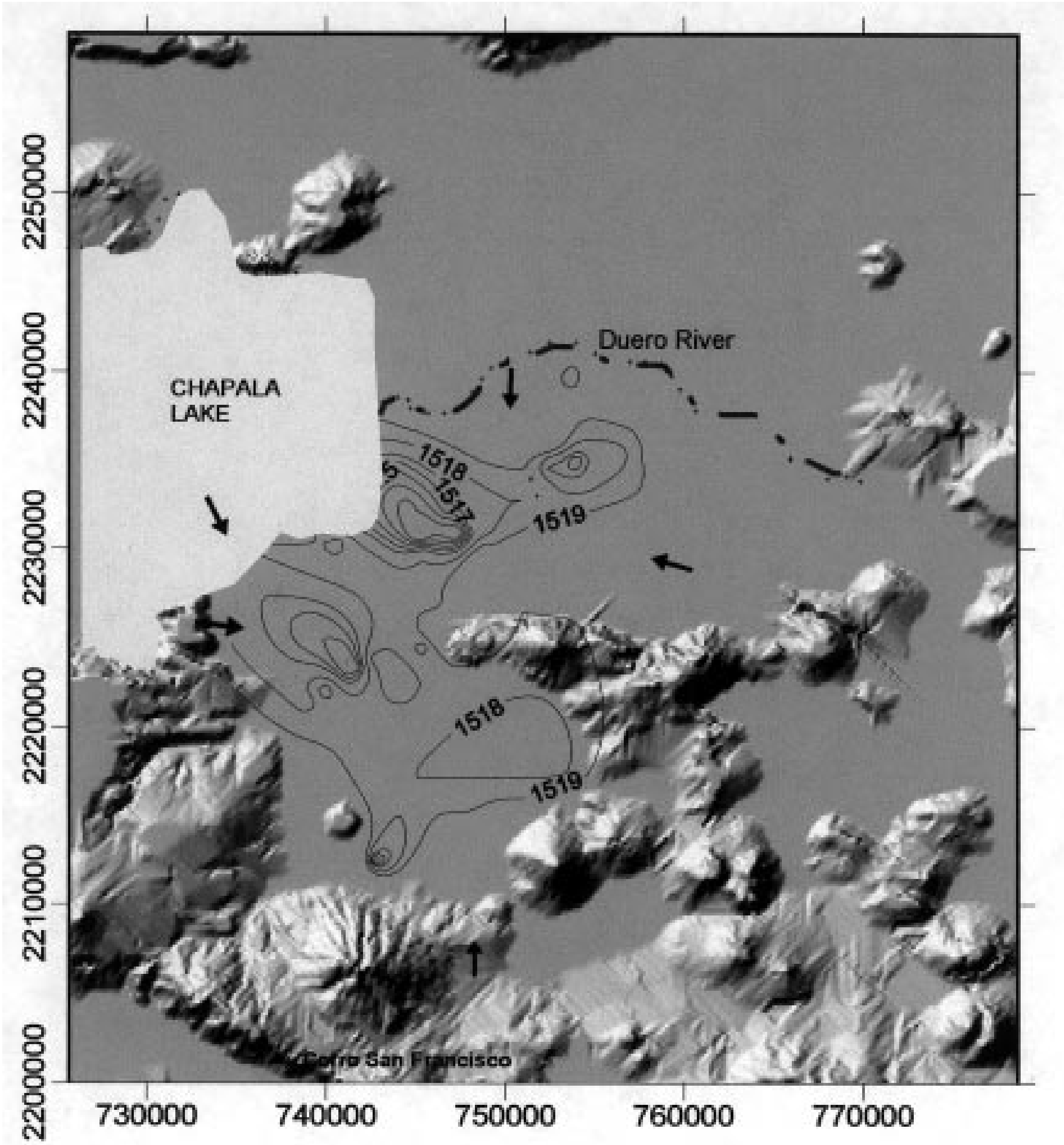

Fig. 9. Piezometric isolines in the Cienega de Chapala (July, 2000).

BIBLIOGRAPHY

ANDERSON, M. P. and J. A. MUNTER, 1981. Seasonal reversal of groundwater flow around lakes and the relevance to stagnation points and lakes budget. *Water Resource Research. 17(4),* 1134-1150.

BROWN, A. G. and C. BRADLEY, 1995. Geomorphology and Groundwater: Convergence and Diversification. Wiley Publ. pp. 15-17.

COOLEY, R. L., 1974. Finite element solutions for the equations of groundwater flow. Univ. of Nevada Desert Res. Inst. Hidr. and Water Res. Publ.18, 134 p.

CUSTODIO Y LLAMAS, 1976. Hidrología Subterránea. Tomo 2, Ed. Omega, pp. 1197

DE ANDA, J., H. SHEAR, U. MAVIAK and G. RIEDEL, 2000. Phosphorus Balance in Lake Chapala, (Mexico). *Journal of Great Lake Res. 26 (2)*, 129-140.

DOMENICO, P. A. and T. W. SCHWARTZ, 1990. Physical and Chemical Hydrogeology: Wiley,

FREEZE, R. A., 1969. Theoretical Analysis of Regional Groundwater Flow: Canadian dept. of Energy, Mines and Resources, Sci. Ser. No.3, 147 p.

REMSON, I., 1971. Numerical Methods in Subsurface Hydrology: New York, Wiley- Interscience, 389 p.

SILVA, T., 2002. Estudio hidrogeológico del sistema acuífero de la Ciénega de Chapala, Mich. enfocado a una gestión sustentable. Tesis doctoral, Posgrado en Ciencias de la Tierra, UNAM. (en proceso)

STANDAR METHODS, 1998. 20th edition, APHA- aawwa-wef, 1998.

WINTER, C. T., 1976. Numerical Simulation Analysis of the Interaction of Lakes and Groundwater. *U.S. Geol. Surv. Prof. Pap.* 1001, 1-45.

J. T. Silva García[1], R. Rodríguez Castillo[2], S. Ochoa Estrada S.[1] and S. López Díaz[1]

[1] *Centro Interdisciplinario de Investigación para el Desarrollo Integral Regional, CIIDIR-IPN-Michoacán-México. Email:*

[2] *Instituto de Geofísica-Universidad Nacional Autónoma de México, México*