Acta Cient. Venezolana 34: 248-251, 1983

WATER BUDGET OF LAKE VALENCIA, VENEZUELA

William M. Lewis, Jr.
Department of Environmental, Population, and Organismic Biology
University of Colorado
Boulder, Colorado 80309.

ABSTRACT

A water budget for Lake Valencia was constructed for each of 5 years (1977-1981) using data on lake level, lake evaporation (determined from heat budget residuals), and measurable surface inflow at monthly intervals around the lake. Ground water input (geologic) was quantified from the residual of other variables during the dry season when the budget is least complex. In mm/yr for 1976-1981, rain averaged close to 950 (near the lake), surface inflow ranged from 480 to 1600 depending on amount of rain, ground water was near 300, and evaporation was close to 2100. Surface flow from the watershed was by far the most variable element in the budget. The watershed yield is very sensitive to variations in annual rainfall. Ground water flow rates suggest that the age of ground water proposed by Tamers and Thielen (1966) from C-14 dating may be far too high. The water budget and discharge/rainfall relationship show that about 1200 mm/yr rainfall would suffice to keep the lake full with no base flow (no pumping). The data support the conclusion from analysis of cores from the lake that the lake probably would not discharge water at present even if the basin were uninhabited. Curves are presented which approximate the equilibrium size of the lake under present climate. With no pumping (zero base flow), equilibrium size is about 280 km^2. With the present, recently increased base flow, the equilibrium size is about 430 km^2, which implies substantial increase of the lake from its mean size between 1977 and 1981 (350 km^2).

BALANCE DE AGUA PARA EL LAGO DE VALENCIA, VENEZUELA

RESUMEN

Mediante el estudio efectuado, se calculó y elaboró un balance de agua para el Lago de Valencia, para cada uno de los cinco años (1977-1981) que duró el estudio, usando información de nivel del agua del lago, evaporación (determinada por residuales de balances térmicos) y entradas de agua superficiales alrededor del lago, obtenidas a intervalos mensuales. La precipitación, expresada en mm/año, para los años 1976-1981, promedió cerca de 950 (en la vecindad del lago); la entrada superficial (escorrentia superficial) fluctuó de 480 a 1600 mm/año, dependiendo de la cantidad de lluvia; la entrada de agua subterránea estuvo cerca de 300 mm/año, y finalmente, la evaporación fue de aproximadamente 2100 mm/año. La entrada o flujo superficial de la cuenca fue el elemento más variable en el balance. El aporte de agua de la cuenca al lago es muy sensible a las variaciones de la precipitación anual. La tasa de flujo subterráneo sugiere que la edad del agua subterránea propuesta por Tamers and Thielen (1966), mediante fediamiento con ^{14}C, es muy alta. El balance de agua y la relación descarga/precipitación muestran que aproximadamente 1200 mm/ /año de precipitación sería suficiente para mantener el lago lleno, sin un flujo de bombeo de fuente externa. La información en este estudio corrobora la conclusión obtenida de los análisis de los núcleos de sedimentos del lago, de que el lago, probablemente, no descargaría agua por rebose, en el presente, aunque la cuenca estuviese deshabitada. Se presentan curvas anuales que aproximan el tamaño de equilibrio del lago bajo el clima actual.

Recibido: 19/10/82
Aceptado: 12/4/83

INTRODUCTION

The water budget of Lake Valencia has been the subject of much commentary since the time of Humbolt because of the steadily declining lake level. Schubert[1] gives a comprehensive historical overview. The declining volume of this endorheic lake is of obvious regional importance, but is also of general interest in that steadily negative water budgets for existing major lakes are unusual: such lakes obviously have a short lifespan and either reach a new equilibrium or disappear quite quickly in a geological sense. The present study of the water budget was undertaken as part of a comprehensive ecological study of the lake spanning 1976-1981. Three previous government studies are directly relevant. An early study by Convit *et al.*[2] estimates the water budget and is especially valuable for its extensive analysis of rainfall distribution over the entire watershed. A more recent study by Iturriza *et al.*[3] focuses on the interval 1962-1976 and offers simulations that predict future water balance under various contingencies. A study by Bueno[4] deals specifically with ground water.

METHODS

Water entering the lake through streams or canals was measured at monthly intervals for 5 years (1977-1981). The five major sources were Central, Roble, Guey, Tapatapa, and Guigue (Fig. 1). During the wet season the number of streams and canals to be measured was sometimes as high as 10 to 15, most of which had zero discharge in the dry season. Discharge of each stream or canal was computed from current speed and cross-section measurements. Current speeds were obtained with a General Oceanics Model 2030 digital flowmeter.

Rainfall records (daily) were obtained from Base Mariscal Sucre Fuerzas Aéreas de Venezuela, Ministerio de la Defensa, which operates a standard shielded gauge. From the isohyets given in Convit *et al.*[2], it is clear that the Base Sucre station will give an amount of rainfall very close to that which actually falls on the lake surface and about 20 % below the average for the watershed as a whole (watershed average, 1024 mm). Lake level records were obtained from the Instituto para la Conservación del Lago de Valencia. Evaporation records were available from the Base Sucre Class A pan. However, a detailed study of the heat budget of Lake Valencia[6] showed that the pan evaporation is not an accurate representation of the lake evaporation. No fixed factor could adjust the pan evaporation to match the lake evaporation because of seasonal variation in wind and humidity. For this reason, evaporation was estimated as a residual term (Q_E) in the heat budget.[6] The Q_E values were converted to mm of water per day to be used in the water budget. This type of evaporation estimate is only available for 1977 and 1978, and is extrapolated for the other years.

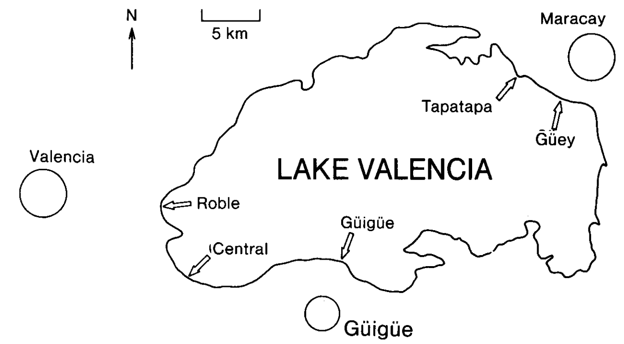

Figure 1. Map of Lake Valencia showing entry points of the main inflows.

RESULTS

Surface discharge to the lake is summarized in Figure 2 and Table I. Low discharge from January through April corresponds to the dry season. The dry-season flow is sustained at a steady level by pumped water. This will be called the «base flow». Base flow in 1977 and 1978 was about 2000 l/sec. By 1979 it rose to about 5500 l/sec due to additional diversion of pumped water,[3] and remained near this level through 1981.

The discharge data show a definite seasonal trend. Except in 1977, discharges tended to climb steadily from the beginning of the rainy season in April or May to a peak in September or October, then decline. Irregularities appear but are not artifacts; they are explained by actual rainfall irregularities. For example, the unseasonal departure from base flow in February of 1981 is explained by unseasonal rain at that time. The variation in total discharge among years is considerable, partly as a result of variation in annual rainfall.

COMPLETION OF THE WATER BUDGET

As no water is discharged from the lake, the water budget is as follows:

Lake Level Change = Rain + Surface Flow + Ground Water Flow − Evaporation (1)

No direct measurements of ground water flow are available, so it is not possible to check the correctness of the other estimates by comparing their sum with the change in lake level. A solution to this difficulty can be obtained by use of the simplified budget of the dry season:

TABLE I

ANNUAL SUMMARIES FOR SOME IMPORTANT ELEMENTS OF THE WATER BUDGET

	Rain, mm	*Average Measured Surface Flow (l/sec)*	*Lake Level Change, mm*
1977	817	4264	− 600
1978	950	6630	− 50
1979	722	10494	+ 340
1980	934	11348	+ 310
1981	1602	14324	+ 1410

Lake Level Change = Base Flow + Ground Water Flow − Evaporation (2)

As base flow is low and relatively steady, the equation provides a sensitive estimate of ground water flow if evaporation and lake level change are known rather exactly, as they are in this case. As ground water flow is buffered against short-term weather variation, it can be inserted as a constant into the annual budget once an estimate is obtained from the dry season data.

Figure 3 shows the lake level changes for the time span over which valid evaporation estimates are available (1977, 1978). The intervals used in the estimation of subsurface flow are marked on the figure. The lake level drop in 1977 was 5.04 mm/day and in 1978 it was 5.09 mm/day. The two dry seasons were also similar in other respects. We therefore use the composite of the two years in equation (2) to estimate subsurface flow. The result is 0.82 mm/day added to the lake from ground water flow, or 3379 l/sec.

As a test of the water budget, the estimate of ground water flow is applied to the wet season data using equation (1). The result is shown in Table II. Table II shows that the agreement between predicted and observed water level changes is close (5 to 10 % of total input), but there is still a small input that is unaccounted for. We believe that the unaccounted input is unmeasured runoff, including the aggregate effect of small discharges and shallow ground water during very wet weather. Also, very brief but large pulses of discharge may contribute. It is logical to relate this to measured discharge: for 1977, unmeasured surface input is 25 % of measured, and in 1978 it is 30 %, for an average of 28 %. This percentage is applied to the other three years to complete the budgets.

The data for discharge are in good agreement with other studies. For a year of average rain, Convit *et al.*[2] predict a total surface input of 8 m^3/sec. In 1978, a year of near-average discharge, our estimate is 8.3 m^3/sec.

Table III shows the complete, balanced budgets for all 5 years. Slight changes in the lake area that would affect the conversion of l/sec to mm/yr have been ignored. For the 3 years in which no heat budget evaporation data are available, evaporation is computed as the difference between lake level change and total input. Comparison of the lake evaporation in Table III with the Class A pan at Base Sucre shows that pan evaporation is about 90 % of true lake evaporation. If the

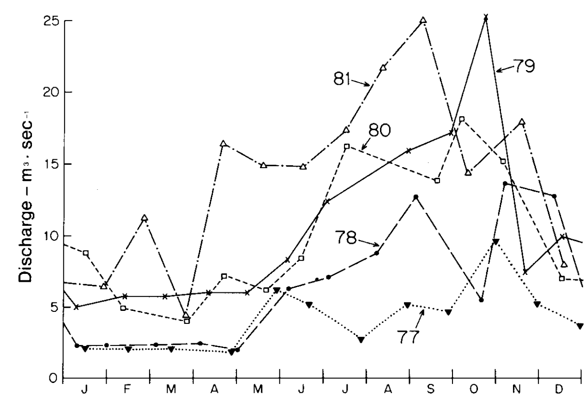

Figure 2. Total measured discharge into the lake at monthly intervals for 5 yr.

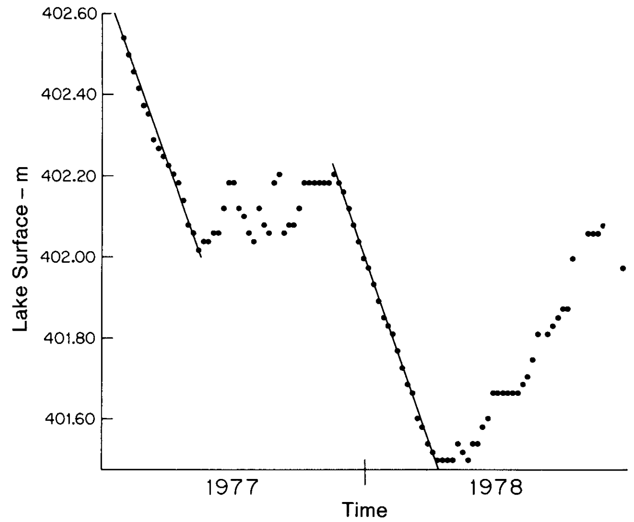

Figure 3. Lake levels for 1977 and 1978, showing the time intervals used for dry season water balance calculations.

numbers of Table III are correct, previous estimates of evaporation have been too low by 20-25 %. Pan error is highest for the dry season and lowest for the wet season.

DISCUSSION

Runoff was by far the most variable portion of the budget from one year to the next. Figure 4 shows the relationship between annual discharge and annual rainfall for the 5-yr period. There was considerable variation in discharge among years with similar rainfall. This is at least partly explained by the time distribution of rainfall. For example, 1977 and 1979 had similar rainfall but 1979 produced more runoff because the rainfall of 1979 was distributed much less evenly than in 1977.

The ground water flow estimates are of special interest in relation to the work of Tamers and Thielen[5] on ground water ages. Water entering the lake from aquifers was estimated by them to be 5000 to 6000 yr old. They believed ground water to be an important part of the water budget, as confirmed by the present studies and all other previous studies. Using the data from Table III, we place the ground watrer entry at 1.07 × $\times 10^8$ m^3/yr. The estimate of Convit *et al.*[2] is about 3 times this amount, and the estimate of Iturriza *et al.*[3] is about half this amount. If the ground water inflow were stable over the last 6000 yr at the amount we estimate for the present study, it would imply a ground water reservoir size of about 6000 × $\times 1.07 \times 10^8$ m^3, or 642 km^3, about 100 times the present lake volume. It seems unlikely that the ground water reservoir could be this large. The ground water reservoir graphed by Tamers and Thielen appears more likely to have a volume of the same order of magnitude as the lake. These inconsistencies may be resolved in one of 3 ways. First, our ground water input estimates, and those of government studies, could be high. However, the error would have to be well over an order of magnitude to bring the ground water flow and ground water ages into line; this would imply negligible ground water input, which seems very unlikely. Second, the radiocarbon ages might greatly overestimate the true ground water ages due to old carbonates in the lakebed. Third, the ground water entry may have been much lower in the past due to higher lake levels. We cannot resolve these possibilities, but we believe the data best support the possibility that the ground water is not as old as the carbon dates would indicate.

From Figure 4 and Table III we can approximate the rainfall required to stop the water level of the lake from dropping. Gains and losses would be balanced with a lake surface rainfall of about 1100 mm/yr (= watershed average of 1300 mm/yr), assuming no change in runoff characteristics and no pumped flow from aquifers (i.e., zero base flow). Higher rainfall might well alter the responsiveness of the surface input to rain, however, by increasing transpiration loss. A rise in lake level would also increase lake surface and thus increase evaporation loss without a compensating increase runoff or ground water, so as much as 1200 mm/yr of rain might be required to make the lake rise to the outlet sill. Such computations are entirely speculative in view of continuing water budget manipulation by man.[3]

Analysis of cores from the lake indicates a decrease in rainfall beginning as much as 2000 yr B.P.[7] This implies that the present desiccation is at least partly caused by a climatic change that antedates human influence. Human impact on the water budget is difficult to judge. Deforestation is thought to increase water yield from a forested catchment,[8] but irrigation and other use of surface water can offset this by increasing evaporation. The present weight of evidence, plus the known previous desiccations, suggest that Lake Valencia would be below the outlet sill even if humans had not entered the water-

TABLE II

WET SEASON DATA FOR SELECTED ELEMENTS OF THE WATER BUDGET IN 1977-78

	1977	*1978*
Number of Days	263	290
Rain (mm)	817	950
Discharge (mm)	244	565
Groundwater (mm)	216	238
Total Input (mm)	1277	1753
Evaporation (mm)	1028	1450
Observed Rise (mm)	+249	+470
Predicted rise (mm)	+189	+295
Observed-Predicted (mm)	+ 60	+175

TABLE III

BALANCED WATER BUDGET FOR LAKE VALENCIA OVER THE 5-YEAR STUDY PERIOD. ALL NUMBERS ARE MM/YR

	1977	*1978*	*1979*	*1980*	*1981*
Rain	817	950	722	934	1602
Measured Surface Flow	375	538	923	1001	1261
Unmeasured Surface Flow	103	148	254	280	347
Subsurface Flow	299	299	299	299	299
Total Input to Lake	1594	1935	2198	2514	3509
Lake Level Change	−600	−50	+340	+310	+1410
Lake Evaporation	2194	1985	1858	2204	2099

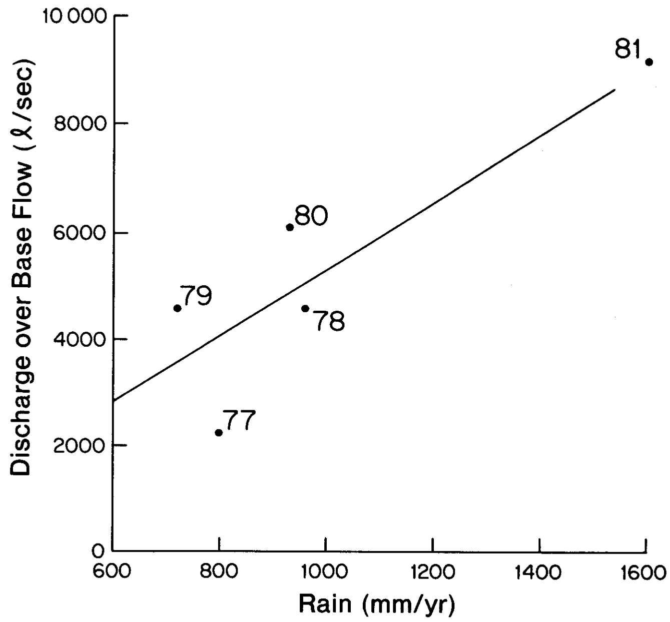

Figure 4. Relation of discharge, after subtraction of base flow, to total rainfall.

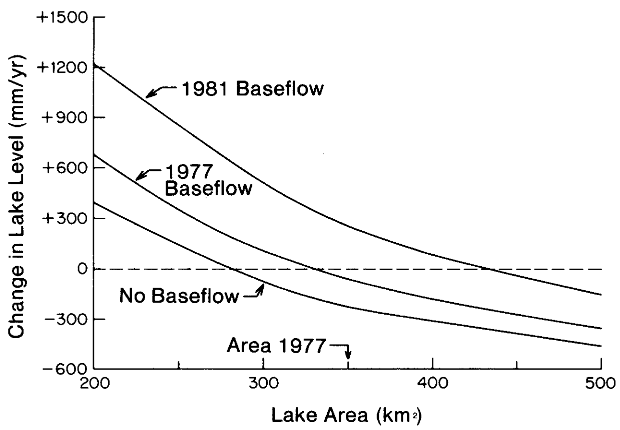

Figure 5. Predicted water balance as a function of area for 3 base flow conditions.

shed. In contrast, Convit *et al.*[2] concluded that the water budget would be slightly positive in the absence of human intervention. Evaporation, which we have estimated higher than they, is critical to this conclusion. The relatively small amount of water required to zero the water budget also suggests that lake level is quite vulnerable to human control by pumping. Effects of recent additional water diversions to the lake are already evident (cf. Iturriza *et al.*).[3]

Lake Valencia would not continue decreasing in volume indefinitely even without pumping. A new equilibrium must be reached. This is evident from examination of the water budget terms. The only negative term (evaporation) is directly related to lake area: as the lake shrinks, the volume lost decreases. One major positive term (rain) is likewise area dependent, but two other terms (surface input, ground water input) are not. The area independent sources will obviously compensate for excess of evaporation over rainfall at some critical lake size. We can approximate this size from the means of the water budget elements in Table III. The year 1978 is very near the mean rainfall, so we use it as a basis for projection. The result is shown in Figure 5. With no base flow (i.e., no pumping), the lake would stabilize at about 280 km^2, 80 % of its mean area over the period of our study. Figure 5 shows that the old base flow (2000 1/sec) would have been in equilibrium with a lake of a about 340 km^2, i.e., that the lake has essentially stopped shrinking by 1977. The new base flow (5500 1/sec) is in equilibrium with a much greater area (430 km^3). The lake has grown substantially since the new base flow was established and this trend can be expected to continue but we would not expect it to culminate in discharge over the outlet sill unless the base flow is increased still further.

ACKNOWLEDGMENTS

I am especially grateful to the Meteorology Group of the Venezuelan Air Force at Base Sucre for allowing our project to use their records, and to the Instituto para la Conservación del Lago for collecting and allowing us access to lake level data.

I thank the Fundación Eugenio Mendoza for valuable logistical support of the field work, and to my collaborator Prof. Franz Weibezahn for many kinds of assistance. The work was supported by NSF grants DEB 7604300, 7805342, and 8003883 as part of the Venezuelan – North American Lake Valencia Ecosystem Study.

REFERENCES

1. Schubert, C.: *Paleolimnología del Lago de Valencia: Recopilación y proyecto.* Bol. Soc. Venez. Cien. Natur., *136:* 123-155, 1979.
2. Convit, R., V. E., Zapata, G., A. A., Guerra, Y., and A. Quintero, G.: *Estudio de la cuenca tributaria del Lago de Valencia.* INOS, 54, 1967.
3. Iturriza, F. M. *et al.: Balance hidráulico-hidrológico anual de la cuenca del Lago de Valencia.* MARNR, Serie de Informes Técnicos DGSPOA/IT/71, 1980.
4. Bueno, E.: *Cuenca del Lago de Valencia , análisis hidrogeológico e hidrogeoquímico.* MARNR, DGIIA, 1979.
5. Tamers, M. A., and Thielen, C.: *Radiocarbon Ages of Ground Water Flowing into a Desiccating Lake.* Acta Científica Venezolana, *17:* 150-157, 1966.
6. Lewis, W. M., Jr.: *Temperature, Heat and Mixing in Lake Valencia, Venezuela.* Limnol. Oceanogr., *28:* 273-286, 1982.
7. Lewis, W. M., Jr., and Weibezahn, F. H.: *Chemistry of a 7.5-Meter Sediment Core from Lake Valencia, Venezuela.* Limnol. Oceanogr., *26:* 907-924, 1981.
8. Jackson, I. J.: *Climate, Water, and Agriculture in the Tropics.* Longman, New York, 248, 1977.