LAKE TITICACA: HISTORY AND CURRENT STUDIES

From the early Quaternary, the Altiplano, the flat region at about 4000 m a.s.l. in Peru and Bolivia between the eastern and western Andean Cordilleras, was occupied by lakes, in shape and extent different from the present ones. The history of these lakes is documented by lacustrine sediments.

After the end of the last glaciation, during the Holocene, the Lake Titicaca attained its present shape, at a mean altitude of 3810 m a.s.l., a total surface of 8400 km^2, and a volume of 930 km^3. It consists of three main water bodies, the largest (approx. 6500 km^2) and deepest (288 m) of which is by far the Lago Mayor in the North, mainly in Peruvian territory. The Lago Menor (approx. 1400 km^2) in the South, with a depth of 20-30 m, is mostly located in Bolivia and connected to the Lago Mayor through the Tiquina Strait which is 850 m wide. The third lake region is the Bahia de Puno, a large (approx. 500 km^2), shallow, highly contaminated bay in front of the town of Puno on the western coast of Lago Mayor.

Lake Titicaca is the major water source for about 1,000,000 people living in the lake region. In the native tradition the lake is consi-dered a gift of god, and is invoked by riparians as father of life.

Water balance of Lake Titicaca

As in all closed lakes, the water balance of Lake Titicaca is unstable, as indicated by the lake level oscillations of up to 5 m recorded in the current century. The minimum level (3807 m a.s.l.) was attained during the long drought of 1940-1945, and the maximum level (3812 m a.s.l.) was reached in 1987 after some rainy years. It is therefore of interest to briefly discuss here the water balance of Lake Titicaca. In fact, a good assessment of water inflow and outflow is of paramount importance for the lake water management.

Direct precipitation over the lake provides about 55 % of the water inflow. On the Altiplano, precipitation mainly occurs from December to March, in correspondence with the astronomic summer and the southern shift of the ITCZ (Intertropical convergence zone). The yearly precipitation amounts to about 700 mm around the Lake Titicaca, and decreases to about 400 mm in the South at the latitude of the town of Oruro, and to 200 mm in the salares (salt plains) region. Rains are more abundant on the lake where they range from 800 to 1400 mm/a: this is possibly an indication that part of the water removed by evaporation returns to the lake as rain.

Rivers and streams provide about 45 % of the water inflow to Lake Titicaca, i.e. about 20 % less than direct precipitation, and almost the whole salt inflow. The major rivers are Rio Ramis (mean discharge 74 m^3/s), Rio Coata (47 m^3/s), Rio Ilave (38 m^3/s), Rio Huancané (19 m^3/s), Rio Suches (11 m^3/s), Rio Keka, all flowing into the Lago Mayor; and Rio Tiwanacu which flows in the Lago Menor. The discharge varies largely in the course of the year, from practically zero during the dry season up to 10 times the average discharge in the rainy season.

Diffuse groundwater leakage into the lake from coastal aquifers is believed to represent a negligible term of water balance.

Evaporation from the lake is strong and accounts for more than 95 % of the water losses. Data provided by Class A evaporation pans range from about 2000 mm/a at Suana Island and Puno, to 1300 mm/a at Conima and Copacabana and 1200 mm/a at Isla del Sol. However, these evaporation data are affected by the pan conditions and temperature variations, which may differ considerably among stations. Therefore, it is difficult to assess the lake evaporation rate with sufficient accuracy from these data.

Water is removed by Rio Desaguadero (literally: river which removes water) from the Lago Menor, which accounts for the missing 5 % of water losses. Rio Desaguadero works as an overflow for the lake and helps to reduce the lake level changes. It flows towards the South across the Bolivian Altiplano and after 400 km reaches the Lake Poopó (3686 m a.s.l.), south of Oruro; the excess water ends up in the south-western salar de Coipasa (3657 m a.s.l.). With its limited discharge (mean value 30 m^3/s after collecting water from small tributaries all the way from Lake Titicaca to Lake Poopó), the Rio Desaguadero is the most important water resource for the arid Bolivian Altiplano.

Evaporation is therefore the largest water balance term and possibly the one which shows the least interannual variability. Unfortunately, evaporation is also the most difficult parameter to measure with good accuracy.

The Autoridad Autónoma Binacional del Lago Titicaca (ALT) [Binational Autonomous Authority for Lake Titicaca]

After the strong drought which struck the Altiplano in summer 1982-1983 – the rains were less than the half of the average amount, in a possibly fortuitous coincidence with a strong El Niño event – the Peruvian Government established the Proyecto Especial del Lago Titicaca (PELT), with Headquarters in Puno, with the general task of fostering studies and activities leading to a better assessment, exploitation and management of the resources of the region, including farming, cattle breeding, fishery, water resources, etc.

About the same time the preparation of a Binational Master Plan for water resources management and protection-prevention of floods, started with the support of the European Community. In the following year the Governments of Peru and Bolivia established the Autoridad Autónoma Binacional del Lago Titicaca (ALT) with Headquarters in La Paz, Bolivia. PELT became the executive arm of ALT and was converted into a binational body. The zone of activity was extended to the whole Lake Titicaca basin which has a surface of 144,000 km^2 including the Bolivian Altiplano. Among the PELT undertakings, worthy of mention is the creation of the lake research centre in Chucuito, about 20 km South-east of Puno.

The IAEA Technical Cooperation Project RLA/08/022

In December 1997, the International Atomic Energy Agency launched the Technical Cooperation Project RLA/08/022 for the application of isotope techniques to the investigation of Lake Titicaca, for which ALT and PELT were the major counterparts. Other important counterparts were the Instituto Peruano de Energia Nuclear (IPEN) in Lima and the Instituto de Investigaciones Químicas (IIQ) of the Universidad Mayor de San Andrés in La Paz. The major objective of the project was to improve the lake chemical and isotopic balances in order to better assess the water resources available from the lake. This objective implied the organization of an extensive network of stations for sampling the lake and its major tributaries, precipitation, groundwater, and the execution of experiments to improve the evaporation estimate. The sampling network and frequency were established in 1997, it includes 18 lake sites to be sampled bi-annually at various depths, 9 rivers and 11 precipitation stations for monthly sampling, and a number of wells and springs for groundwater sampling.

The activities carried out to present with the IAEA support are summarized below.

1. About 800 water samples were collected and their chemical and isotopic composition determined. A first assessment of chemical and isotopic results is being made. It would be desirable, however, that sampling and measurements continue for some years in order to obtain statistically meaningful data.

2. The PELT boat was equipped with a new system for deep water sampling by Nansen bottles and with probes to measure water temperature and conductivity at depth.

3. A new evaporation pan was constructed, in which the water temperature is fixed by using the lake water as thermostatic fluid. The energy for the lake water circulation pump is provided by solar panels. The whole system is now installed and tested in the Taquile island.

4. The equipment of the Instituto de Investigaciones Químicas was upgraded and strengthened with a new ion chromatograph to cope with the high number of chemical analyses to be done. Intercalibration with the chemical laboratory of the Istituto di Geocronologia e Geochimica Isotopica (Pisa) is going on.

5. In April 1999, a Regional Course on Isotope Limnology was held in Chucuito on the Lake Titicaca, which was attended by scientists and technicians from Columbia, Cuba, Mexico, Nicaragua, and Venezuela, in addition of those from Peru and Bolivia.

6. Lake samples were taken for determining the freon concentration deriving from dissolution of anthropogenic freon present in the atmosphere. Freon concentration is determined by gas chromatography at the IAEA Isotope Hydrology laboratory.

7. Various fellowships have been awarded and the training for staff will continue in 2000.

Preliminary short discussion of the Lake Titicaca data

Isotopic and chemical data on Lake Titicaca, obtained within the frame of the IAEA Technical Co-operation project RLA/08/022 are accumulating, and a preliminary, qualitative interpretation can be attempted. We summarize below the major observations and conclusions, and indicate activities to continue or initiate.

Closed lakes, where the major fraction of the inflowing water is removed by evaporation, exhibit a significant enrichment in heavy isotopes. This is due to the fact that the isotopically light water molecules ($^{1}H_2{}^{16}O$) evaporate from the liquid surface at higher rate than those containing heavy isotopes (^{2}H or ^{18}O), the concentration of which increases in the residual liquid phase. Therefore, Lake Titicaca water, like all closed lakes, is enriched in heavy isotopes. In particular, the Lago Mayor is enriched by about 60 ‰ in ^{2}H and 12 ‰ in ^{18}O with respect to rivers and precipitation feeding the lake. Due to the large size and depth, and the relatively long residence time of water, the isotopic and chemical composition of the Lago Mayor is very uniform and constant in time.

A further enrichment of about 10-20 ‰ in ^{2}H and 2-3 ‰ in ^{18}O is observed in water of Lago Menor with respect to the Lago Mayor, accompanied by a salt concentration and conductivity increase of about 20-30 %. The isotopic and chemical composition of the Lake Menor is less stable and uniform than that of Lago Mayor, due to the shallow depth and short residence time of water. Isotopic and chemical values similar to those of Lago Mayor are found in the Tiquina Strait, while intermediate values are observed at the sampling site closest to the Strait in the Lake Menor. This indicates that the water movement is essentially unidirectional from the Lago Mayor to the Lago Menor, and there is no significant return of water from the Lago Menor.

On the contrary, the bulk of Puno Bay water is isotopically and chemically almost undistinguishable from the Lake Mayor, indicating that the water moves in both directions, i.e. from the lake into the bay and vice-versa. The identification of lake water major circulation patterns is important not only for making water balances but also for predicting the contaminant dispersion and fate.

In all cases, the lake is isotopically quite different from groundwater in coastal aquifers (typical values vs. V-SMOW: $\delta^{18}O$ –15 ‰ and $\delta^{2}H$ –120 ‰), where in principle significant lake water contributions could be easily identified.

As already said, the isotopic and chemical composition values are quite uniform throughout the whole Lago Mayor indicating that the lake is vertically and horizontally well mixed. Thus, the application of models based on the isotopic and chemical material balances is quite straightforward.

More difficult is the estimate of mean values of input waters, and in particular the mean isotopic composition of rains and rivers and the chemical composition of rivers. Large variations occur for the rain isotopic composition as well as for the river, in spite of the fact that chemistry and isotopic composition of rivers are to some extent buffered by groundwater. This may require a long period of observation, in order to fully understand the processes governing the isotopic and chemical variations as a function of river discharge. To this aim, the sampling frequency may need to be increased during floods. Generally speaking, the design, installation and management of the sampling network may need to be revised on the basis of the acquired experience.

Evaporation rate is the major unknown in the Lake Titicaca balance. Evaporation experiments will be carried out in the special evaporation pans being built for the project (one is already installed in the Taquile Island). The scope is to establish the steady state isotopic composition of the evaporating water, and from this to contribute to assessing the characteristics of the evaporation pans for determining the evaporation rate. The new evaporation pans, when available in sufficient number, will hopefully contribute to reduce the current discrepancies between measurements carried out at different lake stations, thus improving the reliability of evaporation rate measurements.

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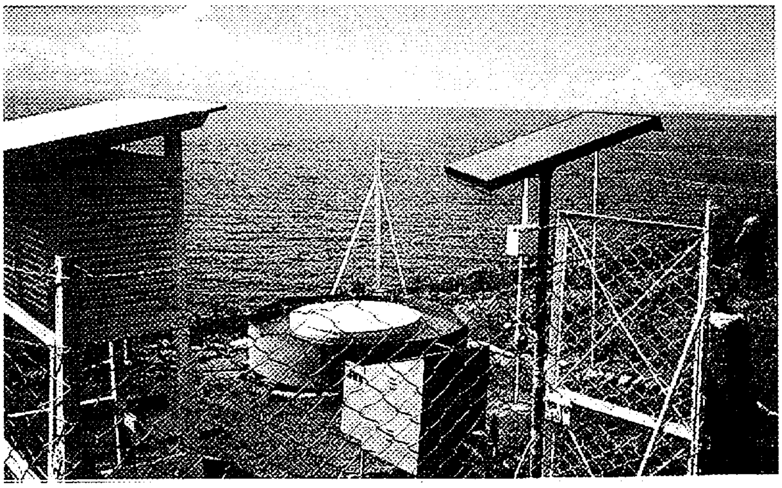
For more information see C. Dejoux and A. Iltis (Editors): Lake Titicaca. A Synthesis of Limnological Knowledge, Kluwier Academic Publishers, Dordrecht, 1992.



Meteorogical station in Taquile Island, Lake Titicaca (Photo credit : PELT)

ALT/IAEA joint Course on Isotope Limnology, Chucuito, Peru, 1999 Openning ceremony (Photo credit : PELT)