THE DETECTION OF LEAKS FROM TAPACURÁ DAM, BRAZIL

Heldio Villar[1,2], Antônio Celso Dantas Antonino[3], Ricardo de Andrade Lima[1], Marco Otávio Menezes[2], Carlos Alberto Brayner de Oliveira Lira[3], Jefferson Vianna Bandeira[4], Afonso Viana[5], António Plata-Bedmar[6] & Edmundo García-Agudo[7]

Abstract - One of the many applications of stable isotope analyses is in hydrological studies. As the isotope concentration of elements in water vary as a result of fractionation due to physico-chemical processes, each water has its own "fingerprints", so that identification of its origin is made possible. This technique has been used in the investigation of the possible leaks through the geologic formation underneath the Tapacurá Dam, near Recife, Brazil. Samples were collected from the reservoir and from several collection points downstream. These samples have been analysed for their deuterium, ^{18}O and ^{13}C concentrations. The comparison between results from these analyses indicated that water from the reservoir and from the other collection points had distinct origins. These findings were corroborated from standard chemical analyses and tracer studies, thus pointing to the absence of any significant underflow at the Tapacurá Dam

Keywords - isotope hydrology, dam investigations, tracer techniques

[1]Centro Regional de Ciências Nucleares, CNEN-Brazil – Rua Cônego Barata, 999, Tamarineira, Recife, PE, Brasil 52110-120 – email: ral@elogica.com.br – tel: 81-4417168; fax: 81-4417196
[2]Escola Politécnica da UPE, Brazil – Praça do Internacional, 455, Madalena, Recife, PE, Brasil 50750-470 – email: mnogue@nlink.com.br – tel: 81-4453855; fax: 81-4454125
[3]Departamento de Energia Nuclear da UFPE, Brazil – Av. Prof. Luís Freire, 1000, Cidade Universitária, Recife, PE, Brasil 50740-540 – email: acda@npd.ufpe.br – tel: 81-2718251; fax: 81-271-8250
[4]Centro de Desenvolvimento da Tecnologia Nuclear, CNEN-Brazil – Rua Prof. Mário Werneck, s/n, Cidade Universitária, Belo Horizonte, MG, Brasil 30123-970
[5]Companhia Pernambucana de Saneamento, Brazil – Rua da Aurora, 777, Boa Vista, Recife, PE, Brasil 50060-010
[6]Centro de Estudios y Experimentaciones de Obras Públicas, Spain
[7]International Atomic Energy Agency, Austria

INTRODUCTION

The present work describes the first application of stable isotopes in hydrological studies in the state of Pernambuco. Located in the Northeast of Brazil, most of the state lies within the “Polygon of Drought”, the name given decades ago to the region’s backlands.

In contrast, Pernambuco’s shoreline, where the state capital, Recife, is located, used to be quite humid, with an average annual precipitation around 2,000 mm (40 inches). As a result of heavy rainfall during certain periods, Recife was every 4 or 5 years plagued by intense floods.

The Tapacurá Dam was built in the early 70s to serve a dual purpose: to supply water to about 40 % of the metropolitan area of Recife, about 40 km to the east, and also as a protection against the periodic floods. The whole system is composed of one 35-meter high, 390-meter long concrete dam, and two auxiliary earth dams.

The reservoir, which lies on the basin of the Tapacurá River, covers an area of 130 km^2 when full, which translates into 1.7×10^8 m^3 of water (see Figure 1).

Underneath the dam the geological formation is mainly of foliated and fractured migmatites. The fractures are normally sub-vertical or sub-horizontal, with the sub-vertical fractures partially filled with intrusive rocks. Four to eight fractures per meter have been observed, which renders the rock relatively permeable.

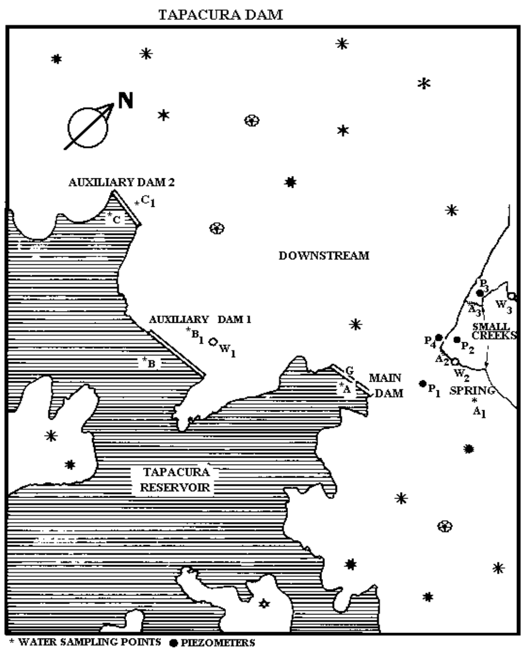

Fig. 1 – Reservoir and collection points

Since its commission the dam has been operated by COMPESA (the state of Pernambuco's water and sanitation company). The lack of maintenance was highlighted in 1992, when a survey of the concrete dam showed its poor condition. Several leaks through the concrete body were detected, so that the lives and property of thousands downstream were at risk.

An exhaustive programme for refurbishment of the dam was immediately put forward by the state government. The major leaks in the concrete body were all repaired in just over one year. The remaining leaks were judged as of minor importance. The consultants hired for the refurbishment programme, however, suggested that an investigation of groundwater flow through the dam's foundations should be carried out.

This recommendation prompted COMPESA to sign a cooperation protocol with the Universidade Federal de Pernambuco. As this type of investigation was within the scope of International Atomic Energy Agency's Programme ARCAL XVIII, the cooperation of the Agency was obtained for the project. As part of the Programme, several analytical procedures were employed:

Piper and vertical column diagrammes were drawn with the results of relevant cation and anion concentration analyses of water collected from the sampling points shown in Figure 1.

The technique of "labelling of total column" (Plata-Bedmar, 1970), which involved the introduction of non-radioactive tracers in piezometers downstream from the dam, was used to verify the existence, direction and magnitude of groundwater flow.

Finally, the isotopic concentration of water samples from the reservoir and other points has been determined.

The analysis of the results of the above methods helped establish the presence or not of leaks through the geologic medium under Tapacurá Dam.

MATERIALS AND METHODS

SAMPLE COLLECTION POINTS

Water for stable isotope studies has been collected from 11 different points, in and out of the reservoir. These points are described in Table 1 (cf. Figure 1).

TABLE 1. Characterisation of samples

Sample	Location
A, B	Reservoir
A1, A2, A3	Springs and creeks downstream from the main dam
B1	Spring downstream from the auxiliary dam, close to the concrete wall
G	Dam's gallery
P1, P2, P3, P4	Piezometers purposely built downstream from the main dam

SAMPLE COLLECTION AND ANALYSIS

Water samples were collected at the selected points in special vials for each different purpose.

Most chemical analyses were carried out at COMPESA's laboratories. Some samples were also taken to the IAEA for verification.

Mass spectrometry analyses for deuterium and ^{18}O were performed at the CEDEX (Centro de Estudios and Experimentación de Obras Públicas, Madrid, Spain). Experimental errors for these determinations are estimated at 2% for δD and 0.1% for $\delta^{18}O$. All ^{13}C analyses were performed at the IAEA.

OUTLINE OF THE TECHNIQUES.

Both Piper and vertical-column diagrammes are representations of relevant cation and anion concentrations which serve to identify the possible origin of the water. These concentrations are commonly obtained by standard laboratory analyses. In the present work, cations selected included sodium, magnesium, potassium and calcium, whereas the anions included sulphates, chlorides, bicarbonates and nitrates.

The stable isotope technique is based on the fractionation of the isotopic components of the elements present in water as it undergoes many physico-chemical processes in the environment. As concentrations ***R*** of the commonly employed isotopes are small, any changes due to fractionation are minor. For this reason, they are commonly reported as positive or negative deviations from an adopted standard, the so-called δ-values, expressed in $^0/_{00}$ and defined as (Domenico and Schwartz, 1990; Bowen 1994; Faure, 1986).

$$\delta = \left[\frac{\left(R_{sample} - R_{standard} \right)}{R_{standard}} \right] \text{ x } 1{,}000 \tag{1}$$

In the case of water analyses this standard is known as SMOW (Standard Mean Ocean Water).

RESULTS

VERTICAL-column diagramme

Fig. 2 shows the vertical column diagramme for samples collected from the reservoir and other collection points indicated in Fig. 1.

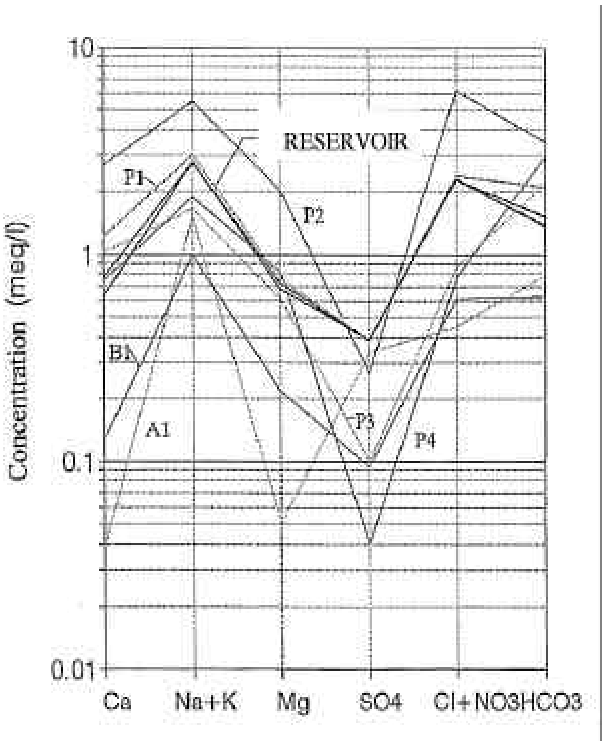

Fig. 2 – Vertical column diagramme for all water samples.

RESULTS OF ISOTOPE ANALYSES

δD, $\delta^{18}O$ and $\delta^{13}C$ results are shown in Tables 2, 3 and 4, respectively.

TABLE 2. Stable isotope analyses: δD

Sample	δD(⁰/₀₀)
A	5.3
A1	-2.89
A2	0.79
A3	1.54
B	4.9
B1	1.71
G	4.74
P1	0.07
P2	-0.82
P3	-13.3
P4	-7.18

TABLE 3. Stable isotope analyses: $\delta^{18}O$

Sample	$\delta^{18}O$ ($^{0}/_{00}$)
A	0.1
A1	-2.0
A2	-1.4
A3	-1.6
B	0.2
B1	-1.5
G	0.08
P1	-1.5
P2	-1.4
P3	-3.21
P4	-2.6

TABLE 4. Stable isotope analyses: ^{13}C

Sample	$\delta^{13}C$ ($^{0}/_{00}$)
A	-8.94
A1	-18.18
G	-9.59
P1	-17.3
P2	-14.02
P3	-15.16

Samples A and B come from the reservoir and G from the dam's gallery, which certainly contains water from the reservoir. δ-values for deuterium and ^{18}O, accordingly, show very small discrepancies for these samples. Based on these results, an average δD of 4.98 $^{0}/_{00}$ has thus been calculated for the water from the reservoir. Data for other samples, on the other hand, are significantly different from this average.

The same way as with δD, $\delta^{18}O$ figures for samples A, B and G were very similar, thus indicating that they have the same origin. That being the case, an average $\delta^{18}O$ of 0.12 $^{0}/_{00}$ has been calculated for the water from the reservoir. Figures for the other collections points were very different from this average.

One way to visualise these discrepancies is through a graph relating δD and $\delta^{18}O$. This graph is shown in Fig. 3.

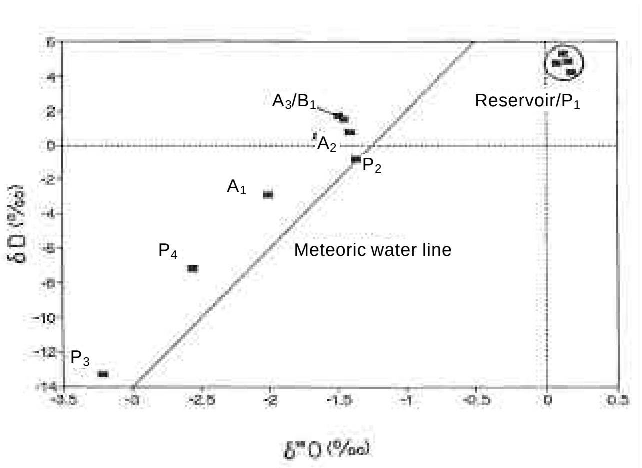

Fig. 3 - $\delta D/\delta^{18}O$ diagramme for water samples

The physico-chemical processes occurring in nature result in different values for $\delta^{13}C$ in surface waters (ca. -8.5 $^{0}/_{00}$) and in groundwater (-12 to -18 $^{0}/_{00}$). These values have been confirmed in this investigation. Samples A and G show a $\delta^{13}C$ just below the acknowledged standard for surface water, as it is in equilibrium with atmospheric CO_2. The other four samples presented much lower figures. This is an indication that the dissolved HCO_3 in these waters is of biogenic origin.

DISCUSSION AND CONCLUSIONS

The analysis of the results from the above figures tables indicated that the water from all collection points downstream from the dam has an origin other than the dam itself. As mentioned in Section I, Piper diagrammes have been drawn and labelling of total column was also performed. The results in both cases merely corroborated the findings from the isotope and vertical-column analyses, i.e., the chemical composition of the water from the collection points downstream from the dam was significantly different from that of the water from the reservoir.

Thus, on the basis of what has been presented so far, the following conclusions may be drawn:

No evidence of flow through the geologic medium underneath the Tapacurá Dam has been found

Findings of the isotopic technique have been confirmed by other independent procedures

The feasibility of the use of isotope techniques for the investigation of underflow at the Tapacurá Dam has thus been demonstrated

ACKNOWLEDGMENTS

The support given to this study by the International Atomic Energy Agency and by COMPESA is gratefully acknowledged.

REFERENCES

(1) Plata-Bedmar, A., **Isótopos en Hidrología**, Alhambra, Madrid (1972)

(2) Domenico, P.A. and Schwartz, F.W., **Physical and Chemical Hydrogeology**, Wiley (1990)

(3) Bowen, R., **Isotopes in the Earth Sciences**, Chapman & Hall, London (1994)

(4) Faure, G., **Principles of Isotope Geology**, Wiley (1986)