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# SOURCES OF LEAKAGES AT AL-JUMINE DAM, NW TUNIS, TUNISIA

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## ABSTRACT

Al-Jumine Dam (90 m high, 600 m long and 60 km NW of Tunis, Tunisia) is constructed on a nonperennial stream, which is storing more than 130 million cubic meters of water (irrigation and drinking for Tunis and Bizerte). Collected data from two drains, piezometers, injected tracers and environmental isotopes were interpreted to determine the possibility and extent of leakage (from the dam) as well as the different types of groundwater intercepted at varying distances from the site. The interpretation of the aforementioned data showed a sizable front of water leaking (at a rate decreasing away from the dam site) and that this fresh water front is being mixed with a local groundwater of higher salinity.The water seepage might constitute a potential risk threatening the integrity of Al-Jumine Dam.

## INTRODUCTION

The present work is carried out as a part of the African Regional Co-operative Agreement for Research, Development & Training Related to Nuclear Science & Technology (AFRA).[1]

In Africa, many dams and artificial reservoirs present leakage problems that are expensive to repair because diagnosis of the cause of leakage using conventional means is often inadequate. This investigation demonstrates the importance of using safe tracer methods for precise and rapid determination of sources of leakage, which if ignored might result in great repair costs. The Al-Jumine Dam (*Fig. 1*) is the only hydraulic structure, which controls surface runoff in the Versant Watershed. The whole watershed (418 $km^2$) is indicated with the punctuated area shown in *Fig. 1*. Dam site is accessible through Tunis – Mateur highway (60 km NW of Tunis) and Tunis - Beja highway (120 km SW of Tunis). Mean annual rainfall over watershed area may amounts to a more than 300 mm. The AFRA (1998) is currently addressing the problem of leaking dams by the utilization of safe tracer techniques.

## METHODOLOGIES AND TECHNIQUES

*A. Tracer techniques*

Tracer techniques involved tracer injection of Rhodamine and Uranine using both point dilution technique (HALEVY et al .1966) and continuous injection techniques (DROST et al.,1974) .However the equation of Turner solely (TURNER et al., 1990) was used for estimating the flow rates in both drains.

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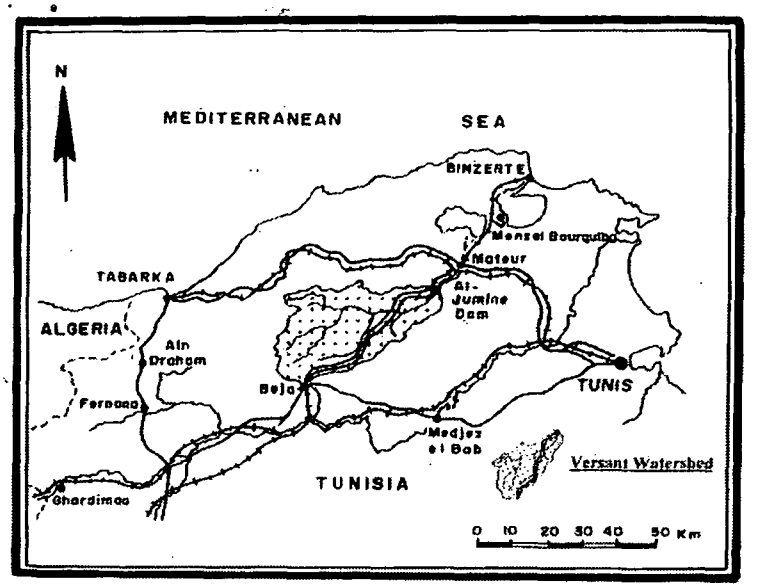


*Fig. 1.* Location map

*B. Environmental Isotope Techniques*

Water samples taken from reservoir water, groundwater and seepage water were collected in double capped plastic IAEA bottles . The analysis for environmental isotope; O-18 H-2 and H-3 were carried out in the IAEA Isotope Hydrology Section, Vienna.

## INJECTION SITES AND POINTS

The injection sites and piezometers were selected to represent as possible the zone of preferential infiltration at the reservoir and at a selected piezomters *(Fig. 2a)* tapping the riverbed layer (which is made of highly permeable materials) and the composite fault scarp. This situation may enhance a better hydraulic connection between the reservoir and both drains as shown in the geologic cross section of *Fig. 2.* Automatic samplers were used to collect point samples from detection sites.

*Injection in the lake*

The zone of preferential infiltration is selecteds at the composite fault scarp which corresponds to a level of 65 m a.s.l. and 20 m below surface water near the bottom where seepage current predominates. The injection was carried out upstream to detect underseepage (*Fig.2b*). The philosophy behind injecting the tracer into the reservoir is to find out as possible the zone of preferential infiltration as indicated by the presence of riverbed layer and the composite fault scarp. Before injection and as a prerequisite , the relationship between flow rates in both drains versus the riverbed elevation was constructed (*Fig. 3*) whereas, the variation of conductivity and chloride ion with time for both the reservoir and the sampled waters from the two drains are shown as *Fig.4*. The main reason behined constructing such diagram is to elucidate the difference in the solute chemistry (of the leaked water) expressed as total dissolved solids (TDS) and the most conservative chloride ion (Cl) versus time since the time of dam construction

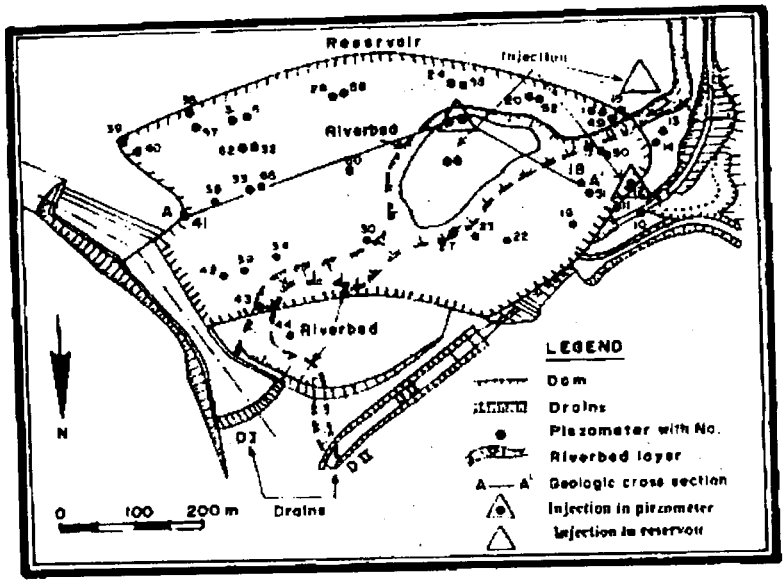


*Fig. 2a*. Injection sites and points

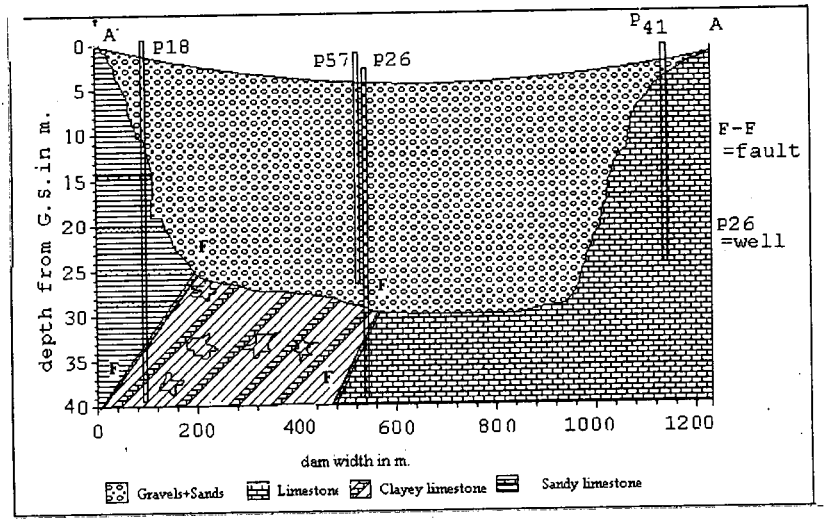


*Fig. 2b*. Geologic cross section A - A'

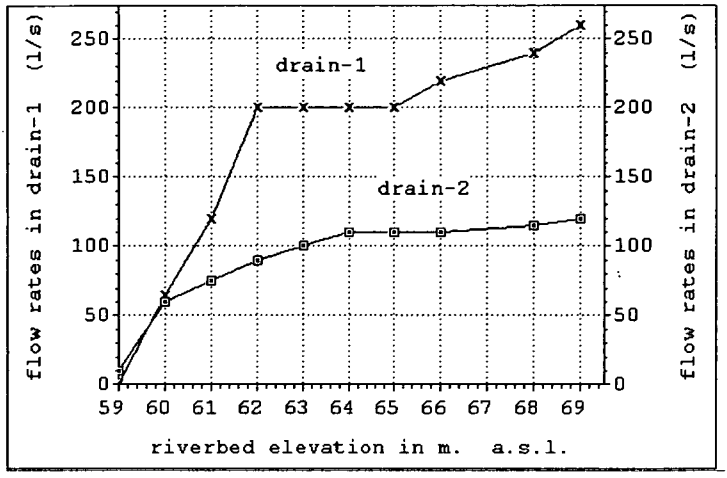


*Fig 3.* Riverbed elevation and discharge rates at both drains

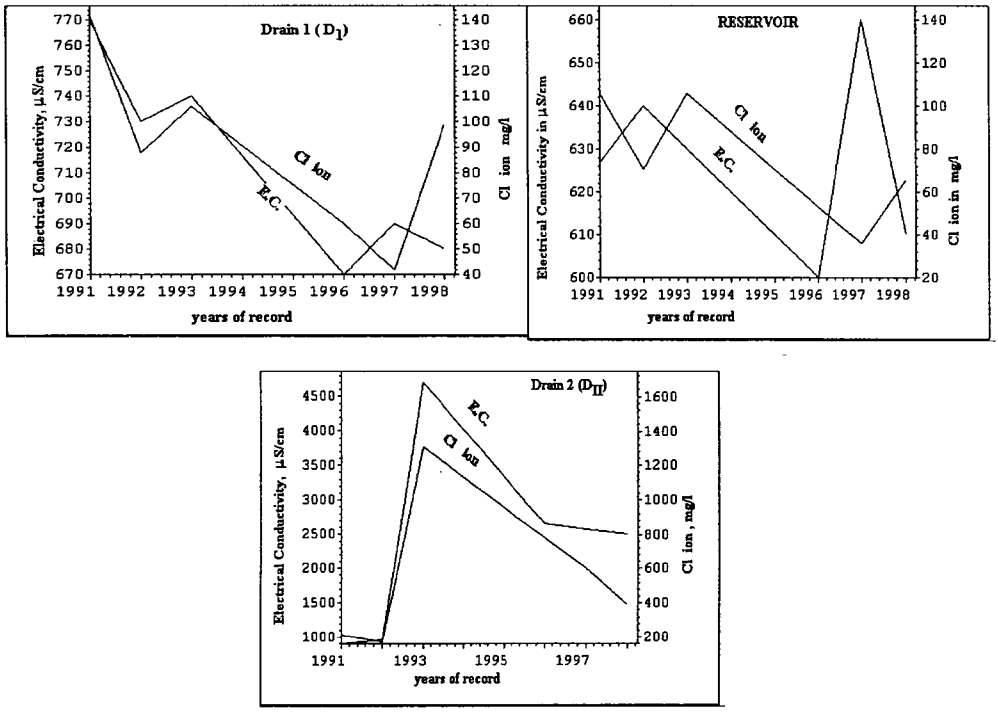


*Fig. 4.* Variation of conductivity and cl ion with time for reservoir and drains waters

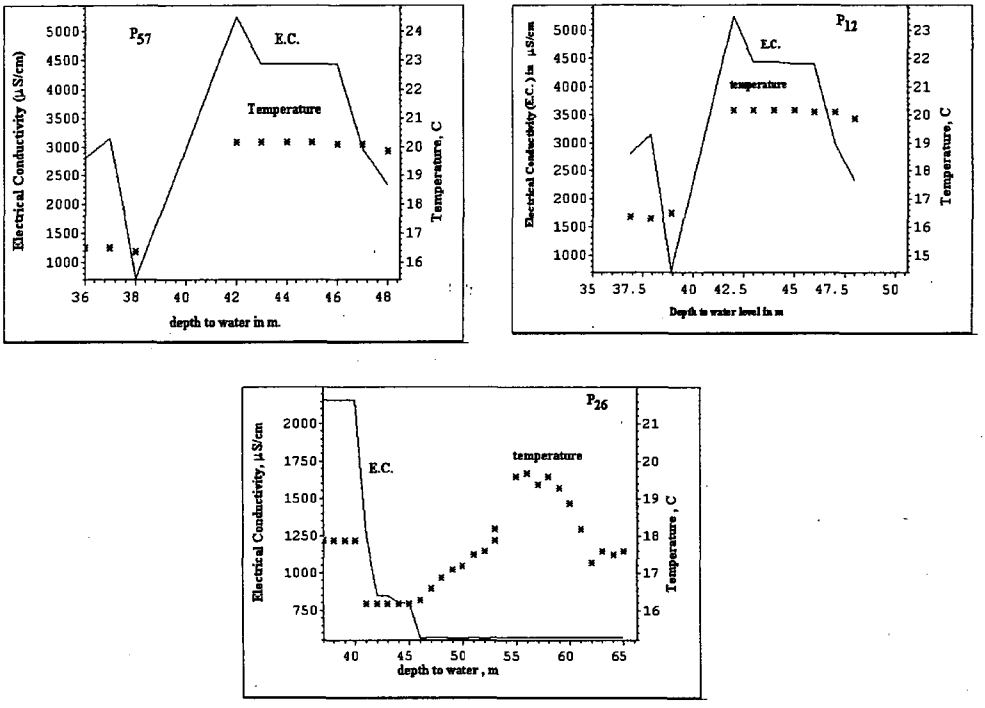


*Fig. 5.* Vertical flow observed in selected piezometers

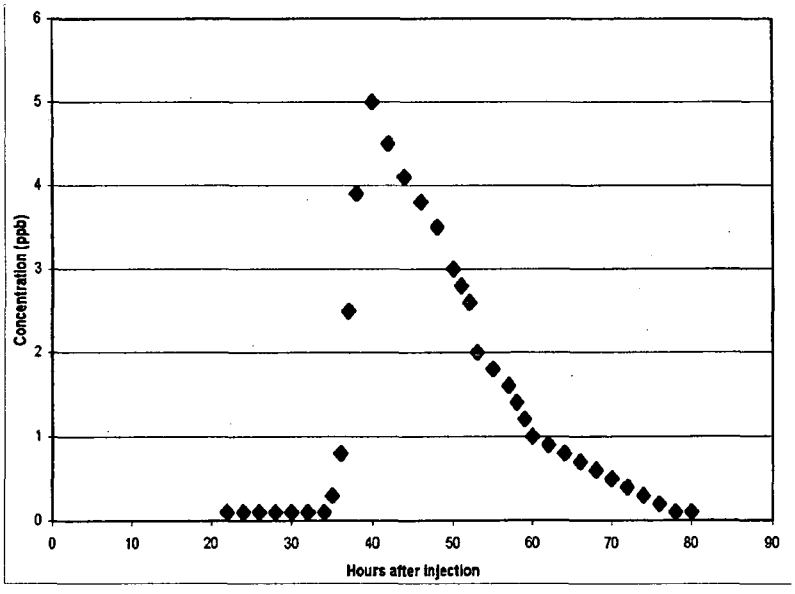


*Fig. 6.* Breakthrough curve for the detected tracer in drain -1

*Injection in the boreholes*

Information on the flows existing in the piezometers were collected before injection. Vertical flow was observed in piezometers 57, 12 and 26 (*Fig. 5*) The vertical flow observed in these piezometers (as indicated by salinity and temperature profiles) suggests a better hydraulic connection with reservoir via riverbed and composite fault scarp shown earlier in the geologic cross section of *Fig. 2b*. This hypothesis was tested by injecting the tracers in the aforementioned piezometers. Breakthrough curves for the detected tracers in both drains are shown as *Fig. 6* and *7*.

The diagenesis of emerging water (based on isotopic composition) is shown as *Fig. 8*. Whereas the piezometry of local aquifer, aerial distribution of conductivity, isotherm pattern of emerging water and tritium are displayed as *Figs. 9* through *12* respectively.

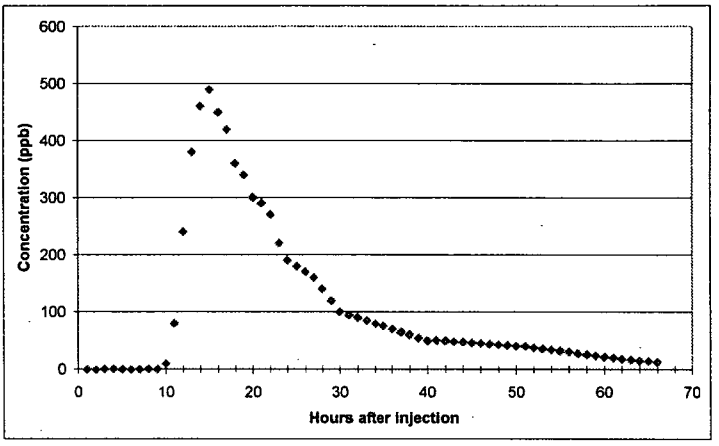


*Fig. 7.* Breakthrough curve for the detected tracer in drain- 2

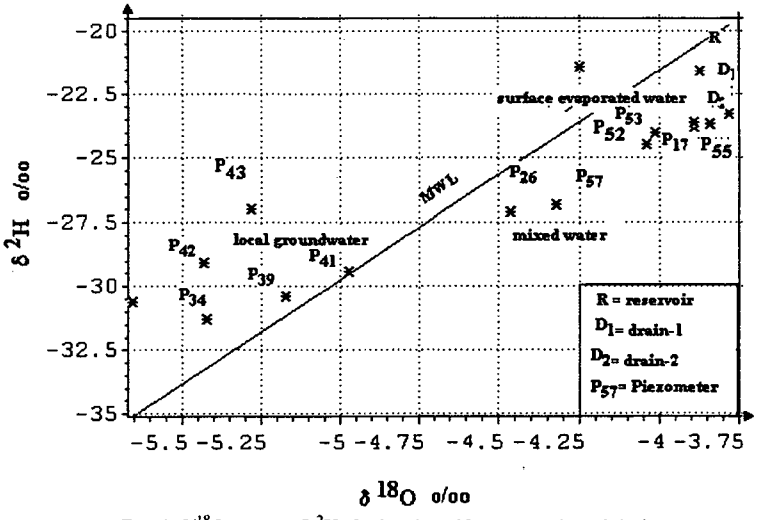


*Fig. 8.* $\delta\,^{18}O$ versus $\delta\,^{2}H$ for local aquifer, reservoir and drain waters

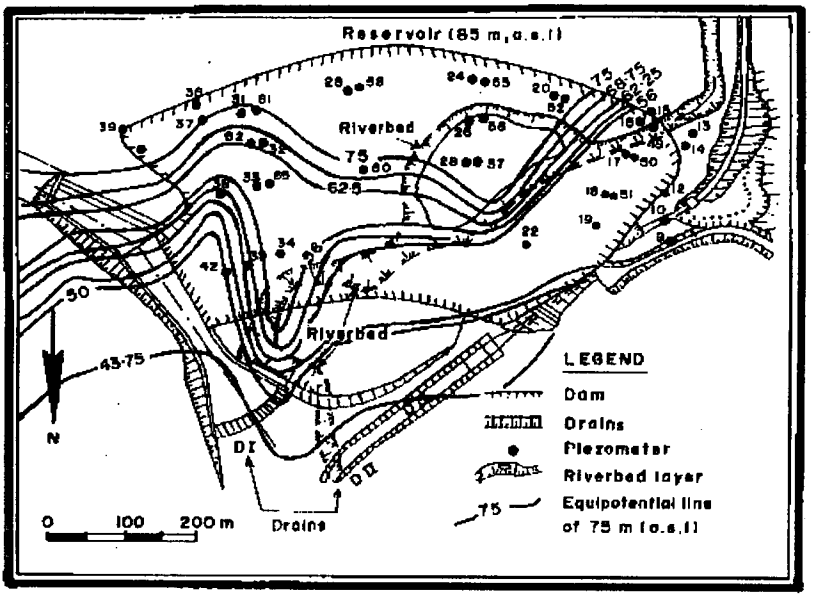


*Fig. 9.* Piezometry of local aquifer

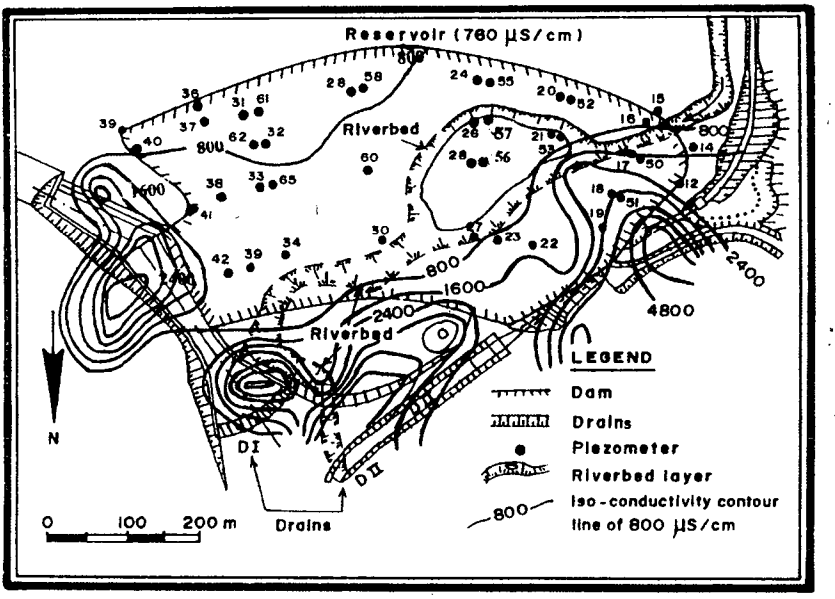


*Fig. 10.* Conductivity of local aquifer

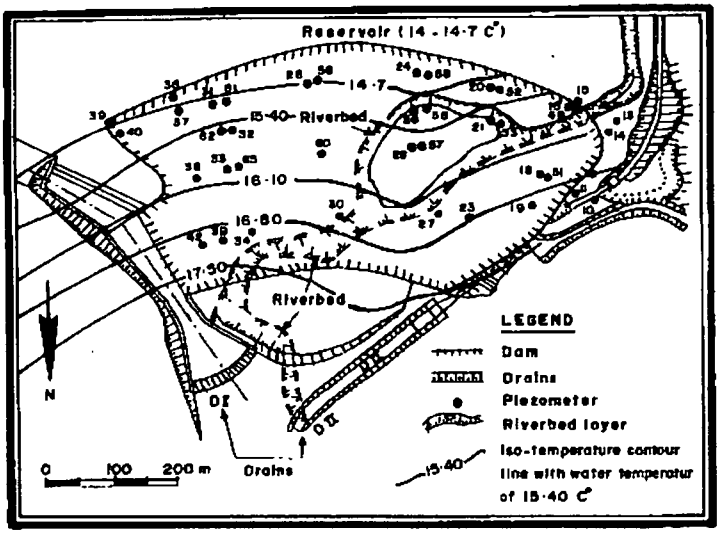


*Fig. 11.* Isotherm pattern of local aquifer

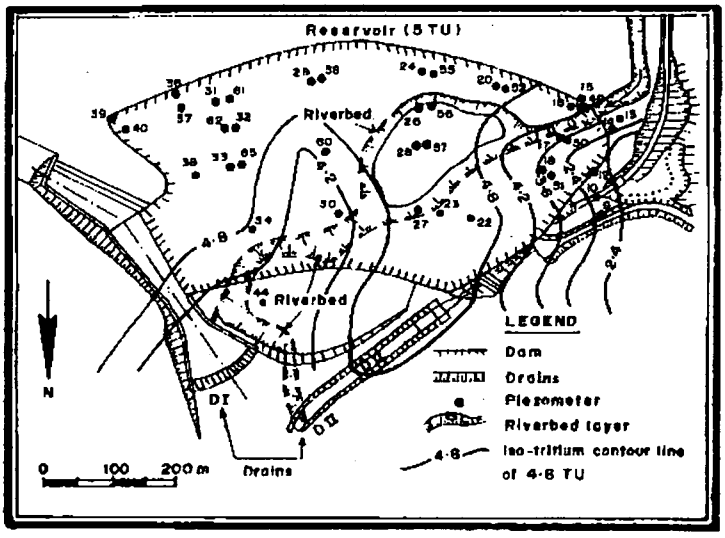


*Fig. 12.* Tritium distribution of local aquifer

## RESULTS

The injection started December 7, 1988 using rhodamine tracer in the reservoir waters (*Fig. 2 a*). The injection was carried out upstream in an attempt to detect underseepage with an average concentration of 0.73µl/m$^3$ and tracer volume of 12378 milliliter The

stable isotopes ($^{18}O$ and $^{2}H$) together with the natural tracer of $^{3}H$ were used for surface, groundwater and leaked waters .The piezometers (locations shown in *Fig.2a*) were monitored repeatedly for conductivity, temperature and water levels for seepage water and groundwater. The vertical flows in piezometer $P_{57}$, $P_{12}$ and $P_{26}$ were detected using the conventional piezometric measurements and was confirmed using the tracer and environmental isotope techniques. The main reason for selecting piezometers 57, 12 and 26 for the injection of tracer is to determine their hydraulic connection with rservoir via riverbed layer and composite fault scarp (*Figs. 2a* and *2b*). Flow rate measurements of seepage waters in both drains were carried out using both point dilution technique (HALEVY et al., 1966) and continuous injection technique (DROST et al., 1974). However, the equation of Turner solely (TURNER et al., 1990) for point dilution technique was used for estimating the flow rates in both drains.

The injection and detection time for the injected rhodamine tracer was found to be 92 hours for drain-1 and 68 hours for drain-2. However, the peak of rhodamine representing the most important fraction of tracer has reached drain 1 after about 40 hours and drain 2 after around 15 hours (*Figs 6* and *7* ) The flow rates in both drains were estimated as 45 l/s for drain-1 and 57 l/s for drain -2, applying in Turner's equation. Breakthrough curves (*Figs.6* and *7*) which define the relation between the average concentration of the injected tracers (in ppb) and detection times in both drains (in hours) were constructed in order to elucidate the mode of tracer movement and the liquid pathways followed by the tracers. The natural radioisotope tracer of H-3 was analyzed to determine the recent recharge and any groundwater pathways according to ADAR (1994). A cross plot of $^{18}O$ versus $^{2}H$ is made to determine the origin of leakage water and the gradation from surface evaporated water trough mixed with groundwater and to eventual groundwater (*Fig 8*).

A piezometric map for the local aquifer in the dam site (Eocene limestone aquifer) is constructed with contour interval of 6.25 m and a piezometric head that ranges from 75 m a.s.l. and 43.75 m a.s.l. (*Fig. 9*) .A waterfront can be seen emerging from the reservoir to the dam site.

The implication of the aforementioned interpretive steps together with the aerial distribution of: 1. Electrical Conductivity (*Fig. 10*), 2. Isotherm pattern (*Fig. 11*) and 3. Tritium distribution (*Fig. 12* ) shall be discussed in detail.

## CONCLUSION

A piezometric head of a magnitude reaching 43.75 m is noted by the inspection of *Fig. 9*. In addition, a difference of 10 m in water level at both the reservoir (85 m) and the maximum height of water at the local aquifer in dam site (75 m) suggest a hydraulic connection between the aquifer and the reservoir. This fact is supported by the dependance of flow rates in both drains on riverbed layer which in turn, has a better hydraulic connection with the reservoir (*Fig. 3*) It is shown (*Figs 10* and *11*) that the flow of seepage water (retrieved from both drains) diminishes monotonously away from the dam site. An intrusive thrust of fresh water leaking (between 38 and 45 m) from the reservoir might be inferred (*Fig. 5*) The electrical conductivity of waters, in these piezometers (which are tapping the riverbed layer), decline at a depth ranging between 38 and 45 m (*Fig. 5*).

The suggested front (*Fig. 10*) is found to be characterized by abnormally low conductivity (800µS /cm) in contrast with much higher values in both drains (2500 – 4800 µS/cm ). The graph (*Fig. 4* Cl-EC) showing the most conservative chloride ion and the electrical conductivity for the reservoir water and the two drains (particularly drain 1) as a

function of time for the interval between 1991-1998 suggest a leaked front emerging from the dam. This front was being soaked with salts driven away from the riverbed.

The isotherm pattern (*Fig. 11*) of the suggested fresh waterfront, which overlies the riverbed, is characterized by lower temperature value (14.7 C°) than those distant from the riverbed. However, the rate of temperature rise is higher towards drain 2. In contrast, the reservoir water is shown to have consistent temperatures with depth (14.1- 14.7 degree Celsius).

The plot of $\delta^{18}O‰$ versus $\delta^{2}H‰$ is shown in *Fig. 8*. An inspection of this figure reveals that ground water close to the reservoir has a stable isotopic composition which is indicative of an appreciable contribution of reservoir water (P53, P17, P52 and P55). Moving away from the reservoir the δ -values become more depleted, owing to the contribution of infiltrating precipitation which also recharges the local groundwater system of piezometers P42, P41, P34 and P39. Seepage water in D1 and D2, in addition to reservoir water (R ) with piezometer noose; P53, P17, P52 and P55 that show a similar isotopic composition and hence, reflecting the same origin. Regression line that best fit the aforementioned group has a slope of 4.36, which reflect the effect of evaporation and/or mixing on δ-values. This cluster (P53, P17, P52 and P55) represents the first end member (which is the surface water suffering from partial evaporation). The second end member (P42, P41, P34 and P39) (which is more depleted in δ -values) is the local groundwater system which shows a different isotopic composition that has ruled out the theory that the reservoir water is the only source of water in the piezometers (*Fig. 8*). This separate cluster plot to the left of Meteoric Water Line (MWL) is indicative of isotopic exchange with $CO_2$ issued from the local carbonate aquifer. The plots in between the two end members (P26, P57) represent a mixture of the reservoir water and the local groundwater with different mixing proportion (*Fig. 8*).

Tritium was used as natural tracer in order to delineate seepage flow pathways and any recent recharge to the groundwater from reservoir (JØRGENSEN et al., 2000). Aerial distribution of tritium for the local aquifer is shown in Fig 12.The prevailing tritium concentration in reservoir water amounts to 5 TU at a depth of 20m. Whereas, tritium in the ground water and in seepage water ranges between 1.24 and more than 4.8 TU. Tritiated water is emerging from the reservoir in the form of tritium front (*Fig. 12*) having tritium value of about 5 TU, following the same direction of riverbed layer and confirming the above-mentioned fact that the reservoir water is the main source of seepage water. This tritiated water when emerging from the reservoir is mixed with tritium devoid water (local ground water) and gives rise to lower tritium concentration water resulted from the mixing of the above-mentioned two end members.

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