# HEAT CONTENT OF NORTH MISSISSIPPI RESERVOIRS[1/]

by

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## ABSTRACT

The heat content of the four northern Mississippi flood control reservoirs; Arkabutla, Sardis, Enid and Grenada was analyzed. Sardis reservoir had the most complete data available, and was analyzed for a 10-yr period. The heat content for reservoirs, whose volumes vary considerably and not very predictably from year-to-year, also fluctuates unpredictably. In this study, it is shown that the heat per unit volume was quite predictable from year to year for a single reservoir and that all the flood control reservoirs in the same region, operated by the same management practices, were also represented quantitatively by the same behavior pattern.

## INTRODUCTION

The heat content of a body of water is important for several reasons. Most important is that all living organisms require an environment which contains heat energy. The measure of the energy level is expressed by the temperature, and this energy level has a fundamental control over the rate or reaction speed of the various chemical and biological processes taking place.

A second reason for examining the heat content of a body of water is that the temperature of the water affects the water viscosity which, in turn, affects the rate of sedimentation of fine sediment particles in a reservoir. Research at the Sedimentation Laboratory, Oxford, Mississippi, is concerned with sediment deposition in reservoirs and environmental variables, such as water temperature which affect the sedimentation rate.

The sediment entering and leaving a reservoir may be described by a spectral size distribution. The coarse particles settle immediately

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1/ Contribution from the USDA Sedimentation Laboratory, Southern Region, ARS, USDA, in cooperation with the Dept. of Biology, University of Mississippi.

and form deltas. The deposition process for the small sizes on the other end of the scale is the gravitational settling of very fine particles, principally clay particles in the 0.1 to 1.0 micron range. These particles originally entered the reservoir as "suspended load" and were thoroughly mixed into the water body by normal hydrodynamic dispersion processes.

In the size range being considered, the particle Reynolds number based on fall velocity and a representative particle dimension, D, is less than unity and the fall velocity, $V_f$, is controlled by Stokes law (1).

$$V_f = \frac{D^2 g\,(\rho_p - \rho_w)}{18\,\nu\,\rho_w} \qquad (1)$$

In the normal expected winter-to-summer temperature range in northern Mississippi, the relative particle and water density difference, $\rho_p - \rho_w$, is virtually unchanged while the water viscosity, $\nu$, decreases 40% in value. This means that the settling velocity of a given particle in the summer is about 2.6 times its winter settling velocity, and an increased rate of clearing during the summer can be expected. The purpose of this paper was to examine the seasonal heat contents and the average temperature, e.g., the heat per unit volume of the four large northern Mississippi flood control reservoirs; Arkabutla, Sardis, Enid and Grenada. The average temperature through the viscosity could then be related to the sedimentation rates of the suspended sediments in the reservoir.

## DISCUSSION

The heat content of a body of water at a given temperature, T, is the heat required to raise it to that temperature from some base reference temperature, $T_o$. For this reference, it is convenient to use the freezing point of fresh water as the base temperature, rather than absolute zero, where the water actually would contain no thermodynamic energy.

The heat energy contained in a body of water, thus defined and called the excess heat content, is calculated by

$$q = c\rho(T - T_o)V, \qquad (2)$$

where q = excess heat content, cal

c = specific heat, cal $g^{-1}$ °$C^{-1}$

$\rho$ = fluid density, g $cm^{-3}$

T = fluid temperature, °C

$T_o$ = reference temperature = 0°C

and V = fluid volume, $cm^3$

Since both the specific heat and the density of water are nearly unity and are very weak functions of temperature, the excess heat content of a reservoir depends on the water temperature and the water volume. In a lake where the surface level changes little throughout the season, the volume is constant and the excess heat content throughout the season is simply proportional to the lake temperature. In flood control reservoirs, like those studied, the product of the temperature and water volume is the important variable.

Heat is constantly being gained and lost by a water body through several physical mechanisms. These mechanisms, expressed as a flux of heat energy [cal sec$^{-1}$] are accounted for in the heat budget equation (2).

$$Q_w = Q_R - Q_e + Q_c + Q_a, \tag{3}$$

where $Q_w$ = heat being stored or being removed from storage in a reser voir = dq/dt, [cal sec$^{-1}$]

$Q_R$ = net transfer of heat by radiation through the air-water interface = $Q_s - Q_{sr} + Q_l - Q_{lr} - Q_b$, [cal sec$^{-1}$]

$Q_s$ = short wave solar radiation, [cal sec$^{-1}$]

$Q_{sr}$ = reflected short wave solar radiation, [cal sec$^{-1}$]

$Q_l$ = long wave solar radiation, [cal sec$^{-1}$]

$Q_{lr}$ = reflected long wave solar radiation, [cal sec$^{-1}$]

$Q_b$ = black body radiation, [cal sec$^{-1}$]

$Q_e$ = heat loss by evaporation, [cal sec$^{-1}$]

$Q_c$ = heat lost or gained by conduction-convection, [cal sec$^{-1}$]

and $Q_a$ = net heat advected to the reservoir by inflowing and out flowing streams, [cal sec$^{-1}$].

The annual heat budget for water bodies whose volumes do not change appreciably is often taken as the difference between the maximum and minimum heat contents over the years record. Because the lake serves as a good integrator of the various input energy fluxes, there is usually little change from year-to-year.

Establishing the heat budget for flood control reservoirs, whose volumes vary considerably and not very predictably from year-to-year, presents some difficulty (2). To illustrate this, the water content of Sardis reservoir over the 10 yr period 1965 to 1974 has shown drastic differences between a dry year, 1966, and a wet year, 1973 (Fig. 1).

Since the temperature records of Sardis reservoir are more complete than those of Arkabutla, Enid, or Grenada, an attempt was made to determine, as completely as possible, the excess heat content record for the 10-yr period.

To determine the excess heat content of a water body at a given time, the stage-volume relationship, the temperature profile and the stage must be known (3). By using the stage-volume relationship,

$$\frac{V}{V_{Fp}} = \left(\frac{h}{h_{Fp}}\right)^{h_{Fp}/d_{Fp}} ; \tag{4}$$

where h = stage above deepest point, m

$h_{Fp}$ = stage above deepest point at flood pool elevation, m

V = reservoir volume below stage h, $m^3$

$V_{Fp}$ = reservoir volume below flood pool stage $h_{Fp}$, $m^3$

and $d_{Fp}$ = average reservoir depth at flood pool stage, m

the lake may be layered horizontally with each layer assigned a temperature from the measured temperature profile. The excess heat for each layer can then be computed by equation 2. Summing the contributions, $q_i$, of excess heat from each layer yields the total excess heat content of the reservoir.

$$q = \sum_{i=1}^{n} q_i \tag{5}$$

From excess heat content data for Sardis reservoir determined in this manner (Fig. 2), obviously meaningful averages of maximum and minimum cannot be calculated as they can for lakes of nearly constant volume. Another means of determining a predictable form of the annual excess heat budget is required.

By integrating each term of the heat budget (eq. 3) with time for 1 month periods, T,

$$\int_T Q_w dt = \int_T Q_R dt - \int_T Q_e dt + \int_T Q_c dt + \int_T Q_a dt \tag{6}$$

the heat budget may be related to the heat content record (Fig. 2). The left hand term of equation 6 represents the difference in heat content from one month to the next.

The radiation, evaporative, and convection terms represent processes which occur through the water surface and are commonly expressed on a per unit area basis. If the thermal energy entering or leaving a across the water surface is considered a gain or loss to the entire water column, these terms could also be reduced to a per unit depth basis and equation 6 becomes

$$\int_T \frac{Q_w}{A\bar{d}}dt = \int_T \frac{Q_R}{A\bar{d}}dt - \int_T \frac{Q_e}{A\bar{d}}dt + \int_T \frac{Q_c}{A\bar{d}}dt + \int_T \frac{Q_a}{A\bar{d}}dt \qquad (7)$$

where A = reservoir surface area, $m^2$

and $\bar{d}$ = average depth, m

which converts the heat budget to a heat per unit volume basis. Since the specific heat and the density of water is very nearly unity, the heat per unit volume is equivalent to the average reservoir temperature. The 10-yr record of the heat per unit volume is shown in Fig. 3.

Whereas the maximum and minimum in the water content and the excess heat content records varied widely and unpredictably over the 10-yr period, the excess heat content per unit volume record exhibits a fairly reproducible and predictable behavior with the average maximum being 28.21 cal $cm^{-3}$ with a standard deviation of 1.38 cal $cm^{-3}$ and the average minimum 5.73 cal $cm^{-3}$ with a standard deviation of 2.44 cal $cm^{-3}$.

During the last 2 yrs of the study, sufficient data were obtained on the other three reservoirs, Arkabutla, Enid, and Grenada to compare their behavior with Sardis (Fig. 4). It is quite obvious that when reduced to this basis, the data from all four reservoirs coincides.

The advection term, $Q_a$, in the far right hand side of equation 7 is strongly related to the time scale called the residence or detention time of the reservoir. This is the time scale defined by the ratio of the reservoir volume to an average inflow rate. For Sardis the average detention time for the 10-yr record was about 4 months. The heat transfer processes through the free surface, however, are related to a time scale determined by the heat exchange coefficient and the average vertical eddy diffusivity. This time scale has been approximated to be about 1 or 2 wks (4). This indicates an expected strong dominance of the heat transfer through the water surface terms over the advected heat term in the heat budget.

The management of the reservoirs is another strong factor. Subsurface water is continually drawn from the reservoirs at the outlet spillway. Strong stratification is usually noticed only during the summer months of June through August. This means that for most of the year without stratification, the lakes are well-mixed by winds, and the entire water bodies are being controlled by the general prevailing meteorological conditions in the region.

Because of the well-mixed condition, the entire lake temperature, as well as the surface temperatures, is always tending to an equilibrium temperature. This is the temperature of the water surface when the net heat flux through the surface is zero, Edinger et al., (5). The equilibrium temperature is determined principally by meteorological conditions that are nearly the same for all four reservoirs. On this basis, the similarity of the four reservoir's behavior (Fig. 4) can be expected.

## CONCLUSION

The heat content records of the four north Mississippi flood control reservoirs exhibit remarkably predictable and similar behavior from year-to-year when reduced to an excess heat content per unit volume basis. The probable explanation for this behavior is that there is strong dominance of the heat exchange processes through the water surface over the advected heat transfer. This factor combined with a management practice, which tends to eliminate strong stratification, results in the entire lake water temperature, rather than only the surface water temperature, responding quickly to meteorological conditions and tending toward the equilibrium temperature. Since the four reservoirs studied are in close regional proximity, they have nearly the same equilibrium temperatures and nearly the same average lake water temperatures or heat per unit volume.

## ACKNOWLEDGEMENTS

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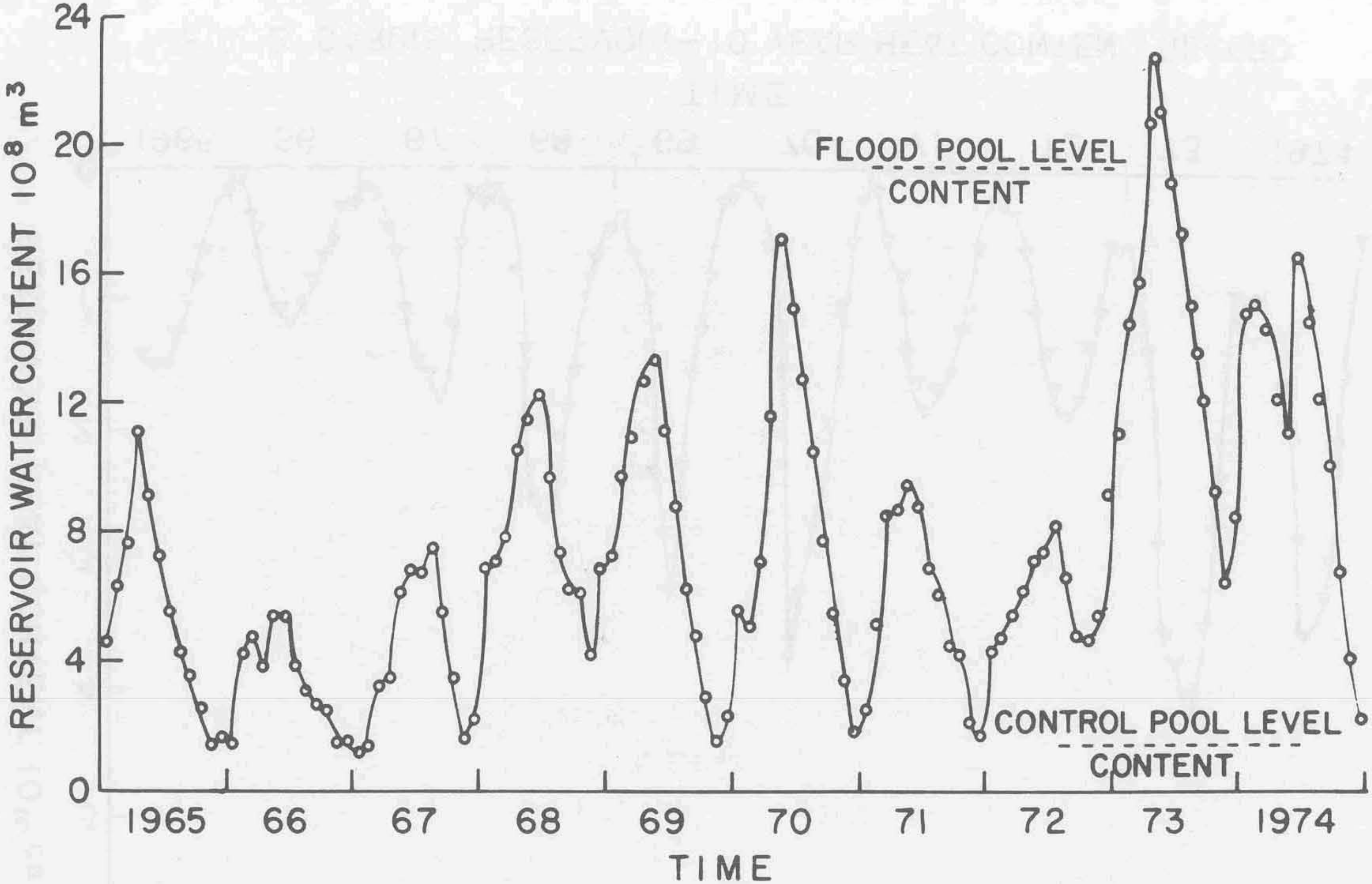

FIG. 1 SARDIS RESERVOIR—10 YEAR WATER CONTENT RECORD

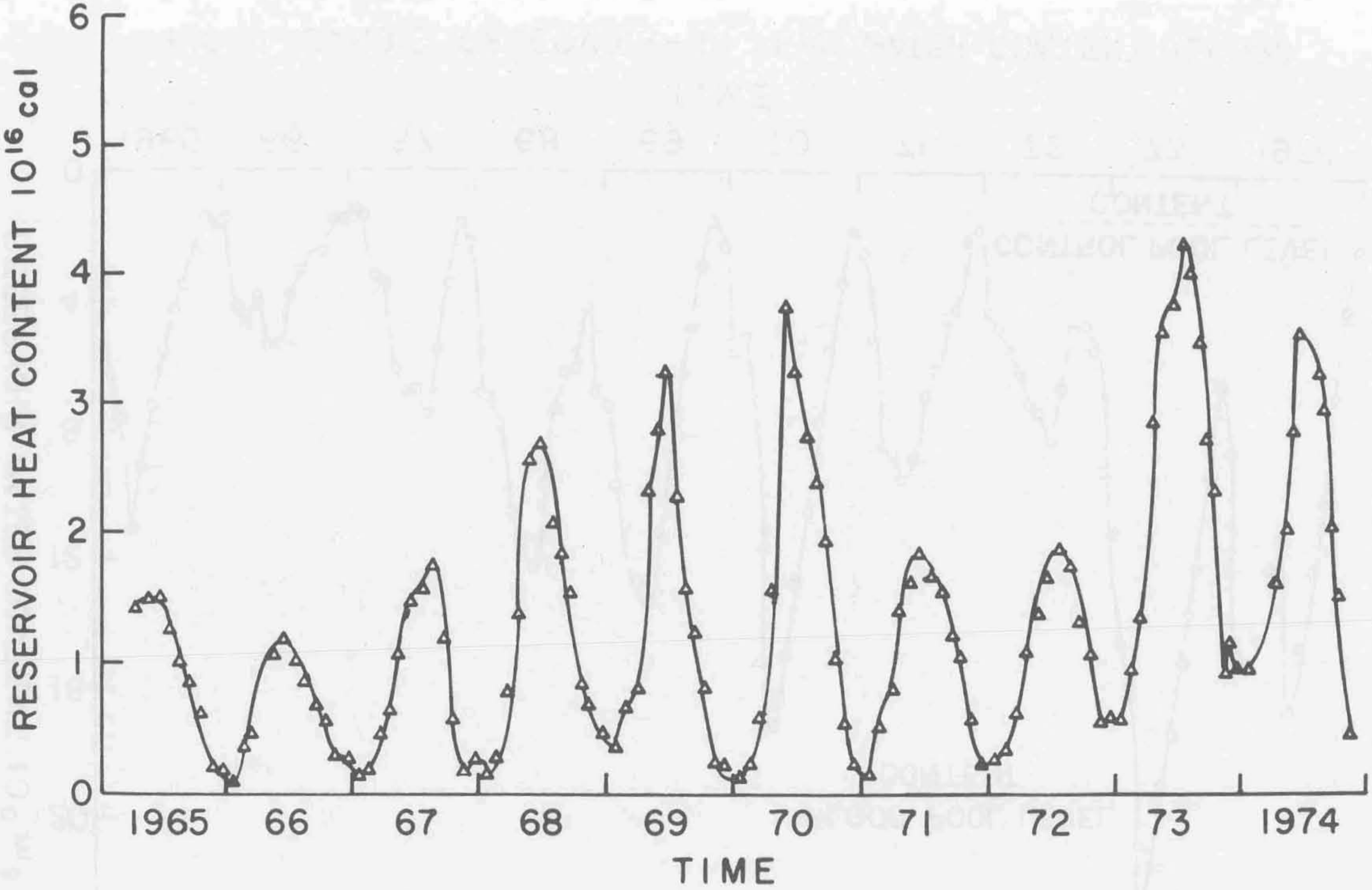


FIG. 2 SARDIS RESERVOIR-10 YEAR HEAT CONTENT RECORD

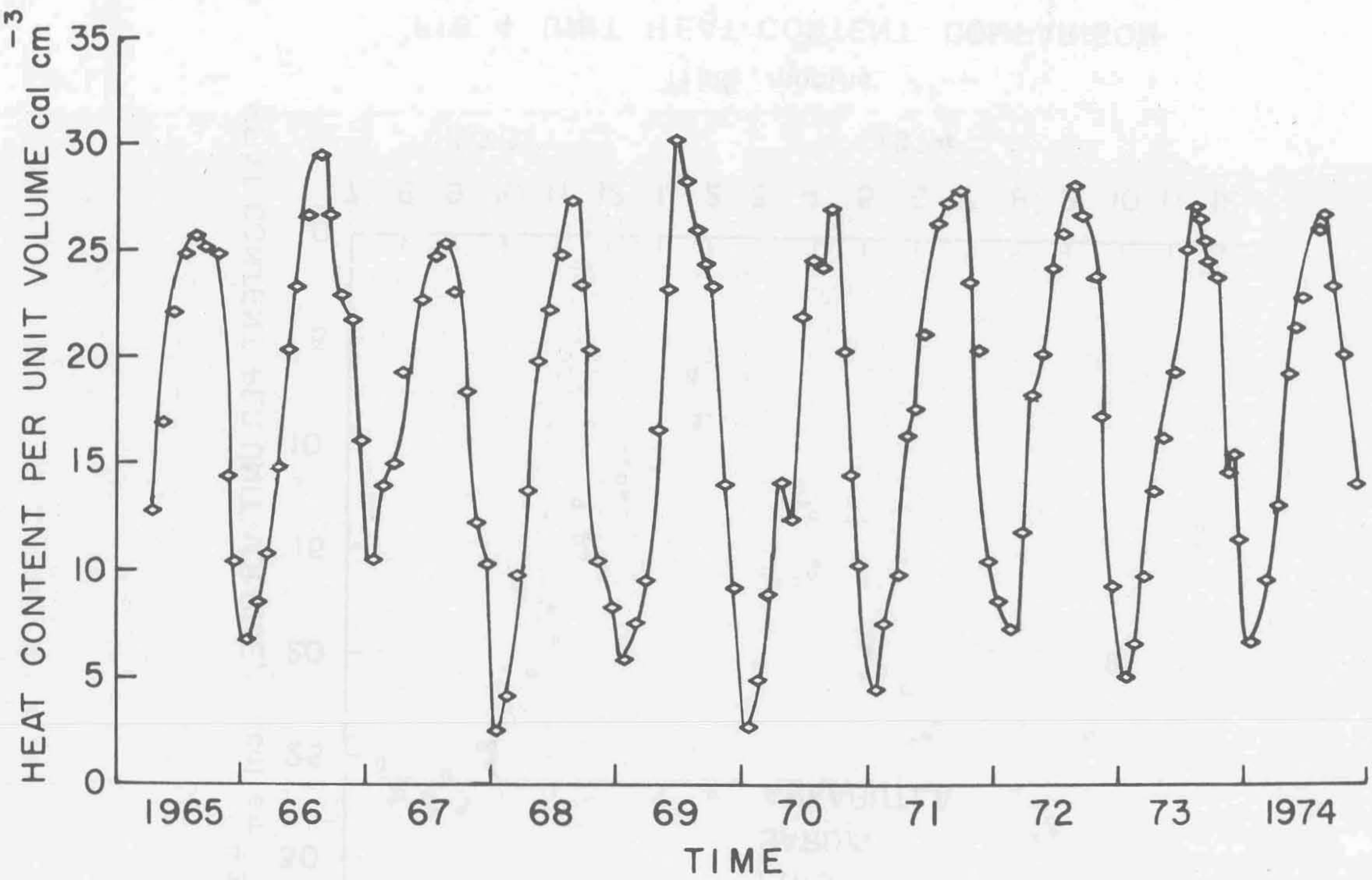


FIG. 3 SARDIS RESERVOIR - 10 YEAR HEAT CONTENT RECORD

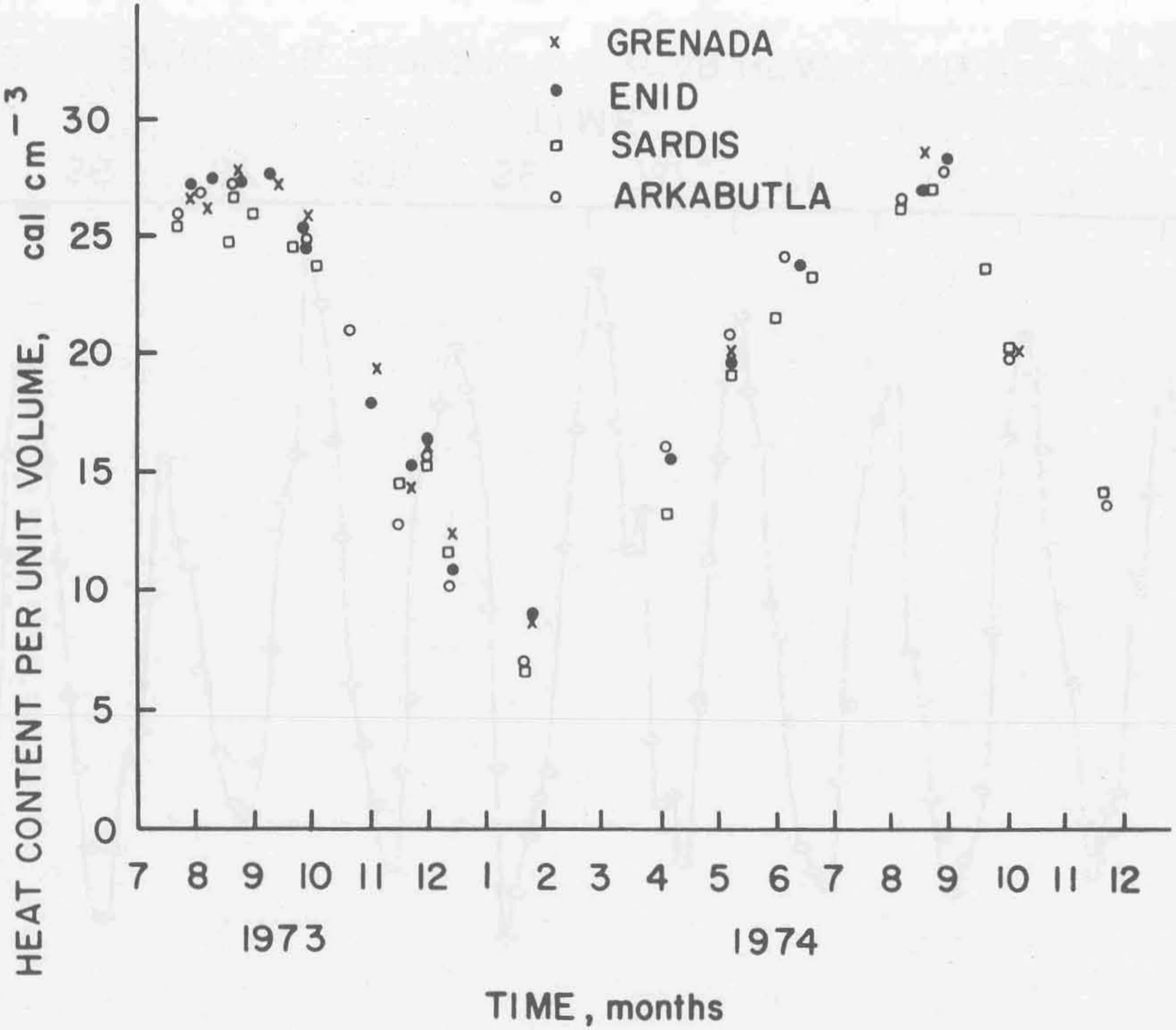


FIG. 4 UNIT HEAT CONTENT COMPARISON