Separation of karstic thermal springs discharge components as based on the analysis of discharge and temperature variations measured at exsurgence

by

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Determination of the existing relation between deep karstic circulation and infiltration waters taking a more direct and rapid course represents a current concern in karstic hydrology. Karstic spring component separation may be approached as based on correlative analysis of discharge and temperature variations recorded at exsurgence, by reading continuity equations of liquid and caloric discharge.

Possibilities and restrictions required in using this method are exemplified in the case of Hercule thermo-mineral spring.

The hydrological regime of karstic exsurgence reflects the conditions of water flow from the aquifer corresponding to the karst type and the evolution stage reached in the karst drainage development.

Accordingly, water circulation in karst systems may have either deep routes, when water flows under pressure and the transit of water mass is slow, or routes situated in the vicinity of piezometric surface, a zone in which a rapid drainage system develops. At the level of these drains there is a continuous supply of water provided by infiltration, and whose characteristics may be strongly different from those specific of waters in the profound zone of the aquifer.

When deep circulation water is the main source in exurgent discharge, karstic springs are often characterized by an extremely stable regime with regard both to discharges and temperatures. An extensive share of infiltration waters, whose temperatures do not immediately arrive at an equilibrium with the rock's and whose discharges strongly vary in terms of hydrometeorological conditions of the zone, causes important variations both in the discharge regime and in water temperature at exurgence.

These variations become extremely sensible when temperatures of infiltration and depth waters are significantly contrastive, such as in the extreme case of the thermo-mineral springs in "Băile Herculane" (The Herculane Spas).

The "Băile Herculane" resort situated in the South-West part of Romania is exploiting a thermo-mineral aquifer with its great bulk in the Titonic-Neocomian limestones of the Cerna graben. The ascent of thermal-mineral waters takes place via transverse faults to the graben. Temperature variations of thermo-mineral springs and existing drillings are rather small, ranging between the limits of 2—5°C, except for two springs : Apollo and Hercule. Both springs come out of a limestone strap in display along the Cerna river and above it, enclosing a separate deposit compartment. The aquifer of Hercule is limited by waterproof deposits on three sides, being open from a hydrogeological point of view only to the South, i. e. the zone where the above mentioned springs

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come out. The mixture of ascending thermo-mineral and cold waters occurs into the aquifer, the latter being provided by infiltration descending through the limestone strap directly by rainfalls or brooks crossing the limestone. It was clearly pointed out that underground circulation of cold waters follows a definite karst route at an average speed of 20 m/h. They arrive on the slope in 1.7 day in terms of the distance to exurgence. Cold and thermo-mineral water mixture is performed in the karst drain which crosses thermo-mineral ascending route, the resultant of this mixture appearing on the slope.

Discharge and temperature records of Hercule spring showed in the period October—December temperature variations between 48.4°C and 19.9°C while discharges varied from 18 l/s to 98 l/s.

The decrease in spring temperature and the mixture between thermal and infiltration waters is detrimental to proper exploitation of the source. In finding out the adequate provisions to avoid thermal and infiltration water mixture, it is necessary to know the value of thermal source discharge and temperature.

Separation of karstic spring components as based on the analysis of discharge and temperature recorded at exsurgence is faced with two major difficulties :

a) Infiltration waters penetrating into the underground get into thermic interaction with the rock, the temperature of mixing water being different from the one water had at the surface. During periods of increased infiltration discharge (following rainfalls) thermic exchange between rock and water becomes nonlineary, water acting as cooling fluid for the rock in the infiltration zone with the continuous decrease in the initial temperature of infiltration water.

While stationary (constant infiltration discharge) thermal exchange between rock and water becomes stable, but, although the temperature of infiltration mixing water keeps constant now, its value cannot be directly determined.

b) By recording water discharge and temperature at exsurgence, continuity equations may be written for liquid and caloric discharge :

$$Q = q + q_i$$

$$QT = qt + q_i t_i$$

where notations have the same significance as in Fig. 1.

It comes out that we have a system of two equations with four unknowns, the only known element being Q and T. Thus formulated the problem can not be solved, the system remaining undetermined. However, if the actual situation to which we are referring makes it possible to formulate some additional restrictions there appears that we can determine the two components, both for temperature and discharge.

As for the Hercule spring whose termal component comes from very deep, it is possible to assume for periods of the order of the week, the hypothesis of thermal component temperature and discharge constancy, this hypothesis being satisfactorily confirmed by analysis results.

By assuming q = constant and t = constant, a correlative analysis of QT and Q values has been performed for those periods in which significant variations of QT and T values have been recorded (Fig. 2).

A loop shape of QT and Q relation is to be seen, showing that following a period of lineary growth, caloric discharge (QT) is growing slower than Q. This because at large discharges, water cools the contact crack walls and arrives in the mixing zone with a lower temperature

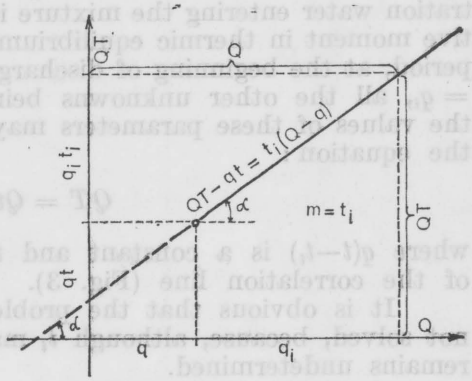

Fig. 1. — Caloric discharge variation (QT) in terms of liquid discharge (Q), for q. t and t_i constants (the general case).

Q = exsurgence discharge; q=component thermal discharge; q_i = infiltration discharge; QT = caloric discharge of exsurgence; qt = caloric discharge of thermal component $q_i t_i$ = caloric discharge of infiltration.

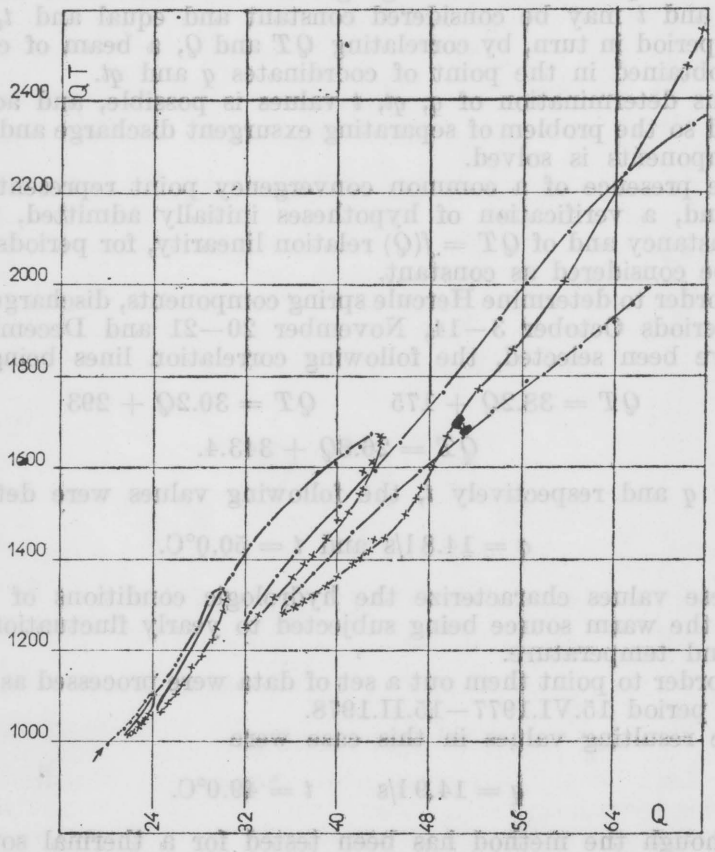

Fig. 2.—Caloric discharge variation graph in terms of liquid discharge $QT = f(Q)$ for the Hercule spring (period October—December 1976).

than at the beginning of the discharge growth. That is why variations of $QT = f(Q)$ were not recorded on the whole range of discharge and temperature variation. Only those periods have been approached in which discharge growth occurs after a period of stability. In these cases infiltration water entering the mixture is the one to be found at the respective moment in thermic equilibrium, with the rock, so that, for a short period, at the beginning of discharge growth, there is only one variable $= q_i$, all the other unknowns being constants. The relation between the values of these parameters may be considered a straight line, with the equation :

$$QT = Qt_i + q(t-t_i)$$

where $q(t-t_i)$ is a constant and t_i represents the angular coefficient of the correlation line (Fig. 3).

It is obvious that the problem of component separation is still not solved, because, although t_i may be deduced, the constant $q(t-t_i)$ remains undetermined.

If more periods of discharge growth are taken into account for which q and t may be considered constant and equal and t_i constant for each period in turn, by correlating QT and Q, a beam of concurrent lines is obtained in the point of coordinates q and qt.

Thus determination of q, qt, t values is possible, and accordingly of q_i, and so the problem of separating exsurgent discharge and temperature components is solved.

The presence of a common convergency point represents, on the other hand, a verification of hypotheses initially admitted, i. e. of q and t constancy and of $QT = f(Q)$ relation linearity, for periods in which t_i may be considered as constant.

In order to determine Hercule spring components, discharge growths in the periods October 3—14, November 20—21 and December 1—3, 1976 have been selected, the following correlation lines being drawn :

$$QT = 38.2Q + 175 \qquad QT = 30.2Q + 293$$

$$QT = 26.8Q + 343.4.$$

For q and respectively t, the following values were determined :

$$q = 14.8\ \text{l/s} \text{ and } t = 50.0°\text{C}.$$

These values characterize the hydrologic conditions of the 1976 autumn, the warm source being subjected to yearly fluctuations of discharge and temperature.

In order to point them out a set of data were processed as recorded over the period 15.VI.1977—15.II.1978.

The resulting values in this case were

$$q = 14.9\ \text{l/s} \qquad t = 49.0°\text{C}.$$

Although the method has been tested for a thermal source characterized by strong thermic contrasts ($\Delta t = 28.5°\text{C}$), its application is theoretically possible in all situations under the mentioned restrictions.

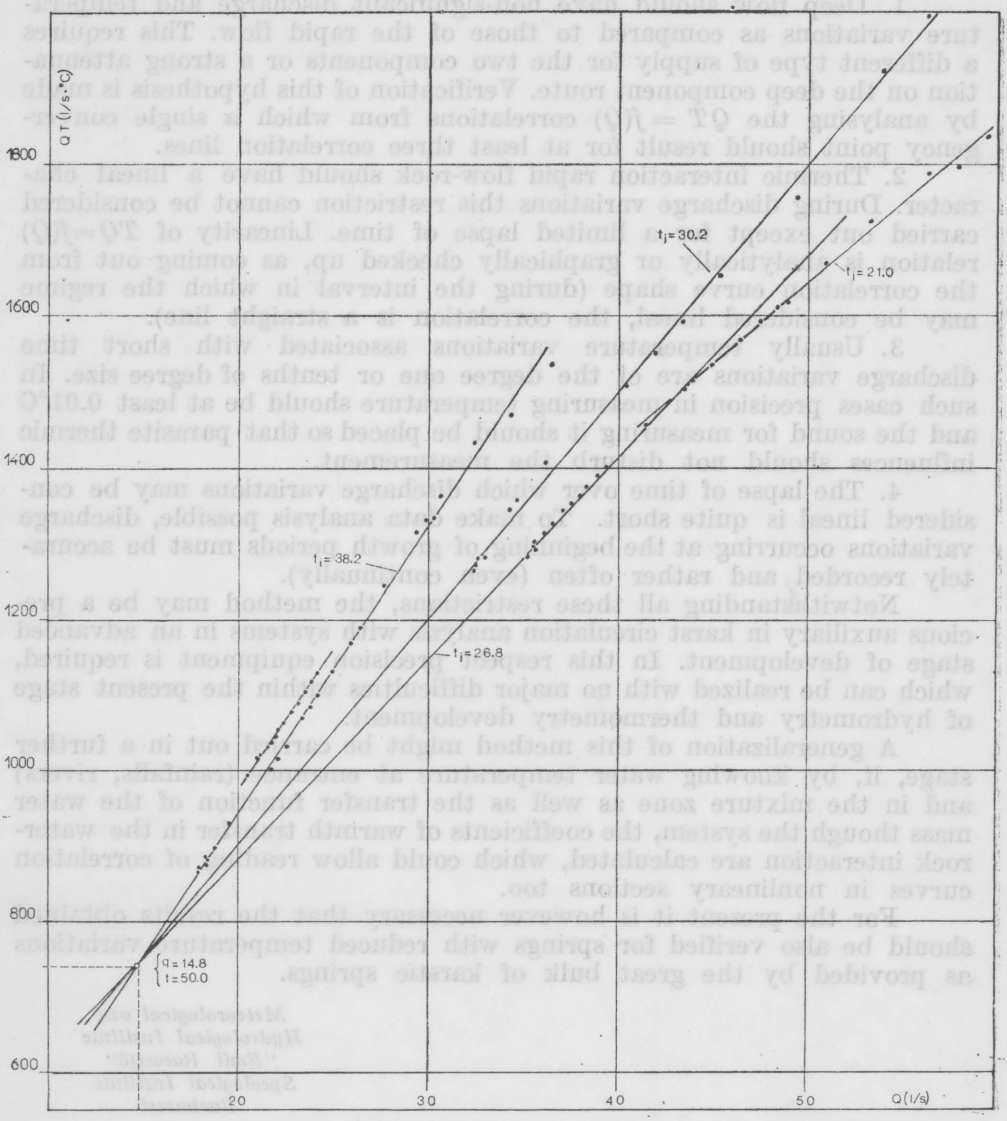

Fig. 3. — Caloric and liquid discharge while observing the condition of linearity (q = constant, t = constant, t_i = constant).

Separation of karstic springs components, as based on correlative analysis of discharge and temperature records at exsurgence, is possible in situations when a deep flow with constant discharge and temperature, and a rapid flow with discharge and temperature strongly different, from the former are to be found.

In order to calculate component discharge and temperature of the entire exsurgent flow, the following restrictions have to be taken into account :

1. Deep flow should have non-significant discharge and temperature variations as compared to those of the rapid flow. This requires a different type of supply for the two components or a strong attenuation on the deep component route. Verification of this hypothesis is made by analysing the $QT = f(Q)$ correlations from which a single convergency point should result for at least three correlation lines.

2. Thermic interaction rapid flow-rock should have a lineal character. During discharge variations this restriction cannot be considered carried out except for a limited lapse of time. Linearity of $TQ = f(Q)$ relation is analytically or graphically checked up, as coming out from the correlation curve shape (during the interval in which the regime may be considered lineal, the correlation is a straight line).

3. Usually temperature variations associated with short time discharge variations are of the degree one or tenths of degree size. In such cases precision in measuring temperature should be at least 0.01°C and the sound for measuring it should be placed so that parasite thermic influences should not disturb the measurement.

4. The lapse of time over which discharge variations may be considered lineal is quite short. To make data analysis possible, discharge variations occurring at the beginning of growth periods must be accurately recorded and rather often (even continually).

Notwithstanding all these restrictions, the method may be a precious auxiliary in karst circulation analysis with systems in an advanced stage of development. In this respect precision equipment is required, which can be realized with no major difficulties within the present stage of hydrometry and thermometry development.

A generalization of this method might be carried out in a further stage, if, by knowing water temperature at entrance (rainfalls, rivers) and in the mixture zone as well as the transfer function of the water mass though the system, the coefficients of warmth transfer in the water-rock interaction are calculated, which could allow reading of correlation curves in nonlineary sections too.

For the present it is however necessary that the results obtained should be also verified for springs with reduced temperature variations as provided by the great bulk of karstic springs.

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