ASSESSMENT OF OPEN THERMODYNAMIC SYSTEM CONCEPTS FOR FLUVIOKARST TEMPERATURE CALCULATIONS – AN EXAMPLE, THE CENT-FONTS RESURGENCE (HÉRAULT, FRANCE)

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Answers to Dr. M. Bakalowicz interactive comment

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Answer to Dr. M. Bakalowicz

Dear Colleague,

We thank you for your comments that you will find partly recalled below in italic font followed by our answers.

Hydrogeologist and especially …. To … The equilibrium is not reached.

From a physical point of view, the dynamic equilibrium of temperature in an open system cannot be reached without a steady situation. This condition does not imply a slow velocity (that remains a subjective or questionable notion) for the moving fluid. The stabilization of aircraft engines temperature is a clear and daily proof. However it is obvious, as mentioned by Schoeller (1962), half a century ago, that slow velocities favor heat transfer equilibria. Nevertheless, even like this heat transfers and dissipations exist for underground flows notably in karstic systems that present very different flow properties between the conduit system and the porous fractured matrix.

He then considered the thermal variability of a spring as a very interesting information…. As all tracers, it is not perfect and allow only an approach of flow conditions. In that sense the approach proposed by the authors is not really new.

This is precisely because these heat transfers exist that temperature cannot be a-priori considered as a conservative tracer. You are perfectly right mentioning that temperature is not a perfect tracer and allows only an approach of flow conditions. We all know that perfection don't exist in sciences and that measures, assumptions and theories are justified by their approximation levels. It is therefore always useful (and also unavoidable to test the pertinence of methods and results). Our study is a step in that direction. It cannot be resumed to a simple statement that temperature is an interesting but sometime unreliable tracer for underground flow. Our study aims to go beyond by assessing the first order accuracy (and therefore gives a tools for decision) of the conservative tracer assumption for temperature. To our knowledge, this has never been published in fluid mechanic or hydrology scientific journals.

According to the encyclopedia of caves (W.B. White et D.C. Culver, 2012) , fluviokarst is the name applied to many landscapes where exposed karstic rocks make up part but not all of the drainage basins.

We don't understand the signification of the semantic point that is risen by this comment. The Cent-Fonts watershed answers precisely to the morphological requirements of fluviokarst with quaternary plateaus deeply incised by Buèges Stream and Hérault River. This kind of morphology corresponds to the one given in:

"A Lexicon of Cave and Karst, Terminology with Special, Reference to Environmental
Karst Hydrology, The Karst Waters Institute, EPA/600/R-02/003, National Center for Environmental Assessment, U.S. Environmental Protection Agency, Washington, February 2002.", which full definition given page 77 and 78 is recalled below :

Fluviokarst

1. A karst landscape where the dominant landforms are valleys cut by surface rivers. Such original surface flow may relate either to low initial permeability before caves (and hence underground drains) had developed, or to reduced permeability due to ground freezing in a periglacial environment. In both cases the valleys become dry as karst development improves underground drainage.

2. Mixed terranes characterized by both shallow karst and erosional landscape.

3. A predominantly karst landscape in which there is much evidence of past or present fluvial activity. Synonyms: (French.) fluviokarst; (German.) Fluviokarst; (Greek.) fluviokarst; (Italian.) fluviocarsimo; (Spanish.) fluviokarst; (Turkish.) akarsu karst2; (Yugoslavian.) fluviokrš, fluviokras, fluviokarst.

This word was never used for characterizing the functioning of a KS, especially by the team who studied the Cent-Fonts KS…. In White's paper cited by the authors, the conceptual models never refer to fluviokarst. So Figure 1(a) is partly inspired from White.

We respect the choice done by this scientific team. It seems to us that it is perfectly correct to describe the Cent-Fonts karstic system as a binary karst or a fluviokarst.

However, it is clearly wrong to say that White don't use the word fluviokarst for his model. You will find below an extract of his 2002 paper we used for the present work (and that is cited in Figure 1 caption and reference list):

Most investigators are in essential agreement on the components of the karst surface water/ground water system in regions of fluviokarst and doline karst. The majority of the karst regions of central and eastern United States are fluviokarst with some limited areas of doline karst. The conceptual model can be drawn in various ways but the essential features are those shown in Fig. 2. This model provides the basis for the discussion that follows.

gauges placed just upstream from the swallets. Placement of the gauges requires care because at many locations, water loss will occur at a sequence of sink points distributed along the streambed. In broad-brush terms, however, allogenic recharge is determined by the areas of the allogenic catchments and the annual precipitation at the location.

The underground drainage system is not equally well developed in all regions. We can define a

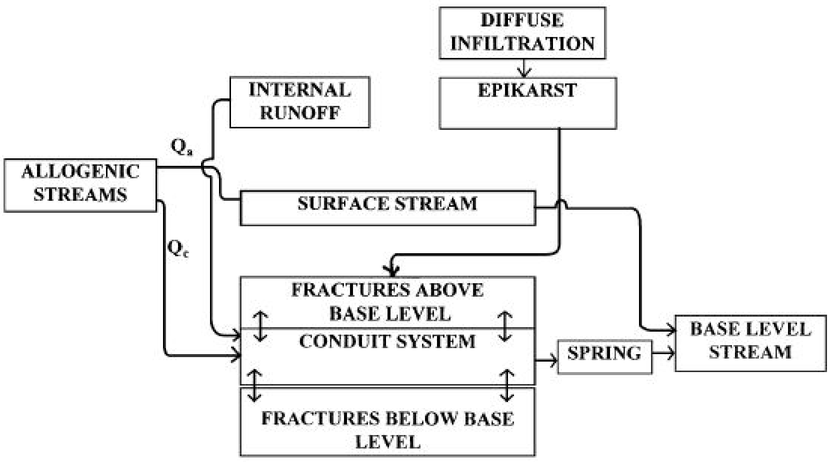

Fig. 2. Conceptual model for the carbonate aquifer.

From: White, W. B.: Karst hydrology: recent developments and open questions, Eng. Geol., 65, 85–105, 2002.

In the same way Figure 5 caption contains some inaccuracies: (epikarstic basic flow, intrusive underground recharge). Figure 6 is not a map, but an unrolled cross section.

The Cent-Fonts resurgence is the only output of the Cent-Fonts karstic system. This simple fact implies that all the rainfall that finally cross the epikarstic layer is finally drained by the resurgence…

For the same reason the recharge collected at the Buèges swallow zone is also drained by the Cent-Fonts resurgence…

We do not see what inaccuracy is contained in Figure 5's caption.

The caption of Fig. 6 mentions that it is an unrolled map… The map projection changes the drawing but does not change the fact this is a map…

The authors make several more or less implicit about the functioning… Some of them are necessary for modeling…. The conduit system is very simple… The infiltration from the carbonate outcrop recharge only the rock matrix…. The exchanges between the conduit and the matrix occurs homogeneously all along the conduit… No boundary layer is considered between the flow and the conduit wall. In fact the surface stream is not a point recharge… but apparently not considered here.

Indeed, since years, numerous works have tried to describe the thermal and hydrologic behavior of particular karstic structures by recording and modeling external data as recession curves and/or temperature. This approach does not deny the internal heat propagation processes but renounce to assess their local consequences. From a fluid mechanic point of view, the mass and energy conservative principles that drive the physical exchanges involved in the heart of these black boxes are well known. The existence of such internal processes prevent from using temperature as a conservative tracer, at least without caution.

In this work, we aim to quantify the first order of the error done considering temperature as a conservative tracer. The benefit that could be obtained of such an assessment and the deciphering of conditions for which it could be applied is obvious because of the low cost and easiness of such measurements. However, conversely to the feeling of the reviewer (who did not mention any reference to support this point) we do not know any precise article that treats this objective and that could have been added to the reference list as a precursor.

We will explain below that our approach aims for preserving as far as possible the generality of the problem against the hydrological and geometrical local particularities. If we had such purpose, and with the knowledge of detailed internal boundary conditions we would have developed numerical models including particular boundary conditions and local hydrologic values; and solved the equations on the basis of existing scientific works and methods. Doing this we would have definitively lost the generality which is aimed in the present work. Conversely, we have chosen to describe à more sophisticated fluid mechanics physic in the simplest geometry adapted to describe the problem. This allows cautious extrapolation of the work results to most of the karstic configurations.

The annex describing the Cent-Fonts compiles data from scientific reports by BRGM …. The authors were never associated to these studies.

What a strange comment! Again this paper is not a work done to describe the Cent-Font karstic system but has been conducted to develop a theoretical model for which the Cent-Fonts karstic system is an appropriate example because it has been well studied as fluviokarstic (or binary system). The reference list of the paper mentions the main reports of BRGM as well as several other studies published by various authors in various scientific journals.

The recording and interpretation of hydrologic data have been done under contract by the BRGM. The authors do not contest that. These are public studies, which data have been officially requested by us and that have been transmitted to us by the data owner -Conseil Général de l'Hérault-, which is mentioned in the acknowledgments of the paper (as well as BRGM). The authors can give the covering letter from Conseil Général de l'Hérault if necessary.

What is exactly the point risen by the comment?

This annex is not really useful….hydrogeology….
The errors and inaccuracies are not given in the comment. Just lines numbers

L23P186 : "Then, a surface stream joins the Hérault River a few kilometers upstream from the confluence with the Lamalou stream. The relationship between the Buèges stream swallow zone and the Cent Fonts resurgence was established by tracer experiments (Dubois, 1964; Schoen et al., 1999)."

We confirm these tracer experiments results and references.

L3-6P187:"The basic matrix-conduit flow recharge of the aquifer percolates through Oxfordian and Kimmeridgian late jurassic epikarstic layers or directly, by continuous water seepage, from the Buèges riverbed into the Bathonian calcareous dolomite layer (Pételet-Giraud et al., 2000)."

We confirm these morphological properties and references.

L14-17P187 : "Most of the time, the resurgence outlets flow into Hérault River through a shallow network of springs that gush out a few tens of centimeters above the karstic base level but also directly through the bottom of the Hérault riverbed (Schoen et al., 1999).

We confirm these morphological properties that are easy to check in the mentioned reference and in the BRGM reports (Ladouche et al, 2005).

Montpellier, march 1st 201
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