

Blocking Sea Intrusion in Brackish Karstic Springs

The Case of Almiros Spring at Heraklion Crete, Greece

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Abstract: A mathematical model for brackish karstic springs has been proposed and used to simulate the periodically brackish karstic spring of Almiros at Heraklion Crete, Greece. The model was constructed by considering the mass and mechanical energy balance on a hydrodynamic analog, which incorporates effective reservoirs and tubes. Spring simulation showed that the seawater intrusion could be prevented through an artificial upraising of the spring water outlet, effected by the construction of a dam. The exact upraising of the water outlet of the spring, which must be realized in order to prevent sea intrusion in the spring's reservoir has been estimated. Fresh-water loss to the sea, because of this upraising, has been also calculated.

Key words: Karstic, spring, brackish, model, Almiros

1. INTRODUCTION

The karstic springs development is of great importance for regions like many areas around the Mediterranean Sea where, due to the warm and dry climate, there is a great need for water. Unfortunately, many of them are brackish or periodically brackish, as the limestone of their basin is adjacent to the sea. For example, all the major karstic springs of eastern Crete are brackish or periodically brackish.

Getting fresh water from a brackish karstic spring is a difficult problem, sometimes solved by the construction of development drills uphill of the water outlet point. The difficulty with this, is that the site of the "red line" uphill of which the drills could give fresh water is unknown. Thus, during the first stages, the development must proceed by trial and error. On the other hand, it is very difficult to determine the water quantity that could be taken by the water reservoir every year, without sea intrusion going further inland. Besides that, this method is an expensive one, as very often in strongly karstic areas, where the water follows preferential dimensions through a network of tubes, it is hard to find it through the construction of a drill. Alternatively, in some cases it is possible, when the topography permits it, sea intrusion to be blocked by the construction of a dam in front of the water outlet point as, in this way, the fresh water level in the spring reservoir will be upraised and the corresponding increase in pressure will prevent sea intrusion. This is an old but not popular method since there are two basic difficult problems, which must be solved. These problems are, first the determination of the dam height, and second the elimination of the possibility of fresh water being lost to the sea, after its level is upraised.

The objective of this presentation is to determine the sufficient height of the dam and to evaluate the fresh water loss for the periodically brackish karstic spring at Heraklion Crete, Greece. This determination has been realized by the use of a mathematical model (Maramathas, Maroulis, Marinos 2001), which simulates the brackish karstic springs hydrograph and the chlorine ions variation against time. Input information of the model is the rainfall data of the recharge area. It uses parameters, which represent the properties of the karstic system, estimated by fitting to the available field measurements. Actually, this model transforms the rainfall data of the recharge area to the hydrographs of the spring (Fig.1).

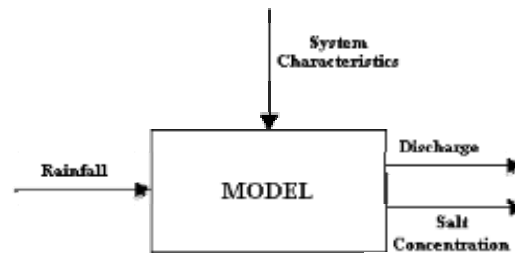


Figure 1. Schematic of the suggested model

2. A BRIEF DESCRIPTION OF THE MODEL

During the initial phase of karstic systems depletion, two emptying rates can be identified. A fast one, that corresponds to a section of karst, which is emptied quickly, and a slow one that corresponds to another section of karst, which is emptied slowly. The first part of karst consists of a few tubes of large diameter while the second, of many tubes of small diameter (Maramathas, Maroulis, Marinos 2002). Thus, it can be argued that two different karstic subsystems, according to hydrogeologic behavior, feed the karstic springs. If the later happens to be brackish, they are also fed by the sea. In Fig.2 a hydrodynamic model, which is constructed according to these ideas is presented. The reservoirs “karst1” and “karst2” represent the karstic subsystems while the other one represents the sea. The sea reservoir has infinite size. The discharge of the spring is given by the sum of the discharges of the reservoirs. The chlorine ions concentration of the spring water is the result of the mixing of fresh water of the karstic reservoirs with the salty water of the sea. This mixing happens in the tube, which brings the water to the spring.

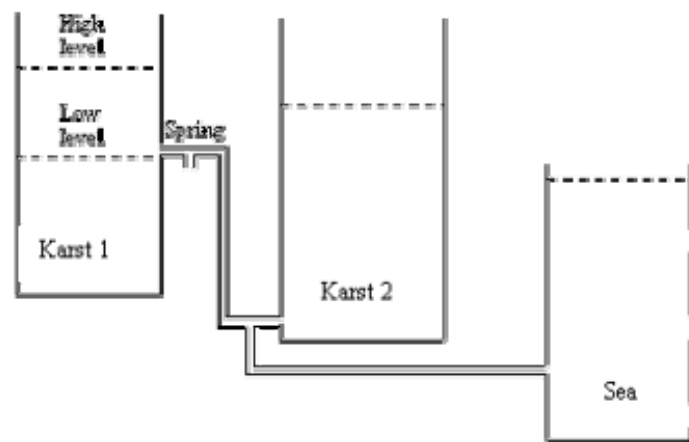


Figure 2. Hydrodynamic model of the karstic springs.

In order to develop a mathematical model based on the above-mentioned karstic springs hydrodynamic model, the mass and energy balances were considered in the reservoirs, which emulate the two karstic subsystems and the sea. The macroscopic mass balance equation (continuity equation) and the macroscopic mechanical energy balance equation in a control volume and the corresponding control surface have been used. The flow has been taken to be transient in the reservoirs of the karstic subsystems and steady in the sea. Thus, a system of non-linear differential and algebraic equations must be solved. All the parameters are effective and can be estimated by fitting the proposed model to available field measurements.

3. ALMIROS SPRING AT HERAKLION CRETE

The Almiros spring is located 10 km west of the city of Heraklion, at an elevation of about 4m and at a distance of 1km from the sea. It is a periodically brackish karstic spring. Its discharge fluctuates between 4m³/sec in the summer and 70-80 m³/sec in the winter following heavy rainfalls on the Psiloritis Mountain. The annual water spring quantity approaches 250x10⁶ m³. At low discharge, the spring water is brackish because of seawater entering in the spring reservoir.

The hydrogeologic basin of the spring is structured by three geologic formations (Fitrolakis 1980, Vidakis 1983). These formations, from top to bottom, are:

Limestone of the geotectonic zone of Tripolis (upper Triassic – upper Jurassic, Vidakis 1983). This rock has preferential permeability and small porosity.

Phylites (Permian – upper Triassic, Vidakis 1983). It is an impermeable rock, which is impeded not everywhere but at certain points between the two other rocks.

Platen limestone of the Ionian geotectonic zone (middle Jurassic – Eocene) (Vidakis 1983). It is a rock with less preferential permeability and larger porosity than the Tripolis zone limestone (Fig.3).

Phylites is overthrust on the Ionian limestone and Tripolis limestone is overthrust on the phylites. However, in some places, Tripolis limestone is overthrust directly on the Ionian limestone (Fitrolakis 1980, Vidakis 1983). In the area there are more or less vertical faults of N-S and E-W general direction that cut all the above formations. The spring is on the meeting point of two faults, one on the direction of N-S and the other on the direction of E-W (Vidakis 1983).

The spring's recharge area is almost the entire Psiloritis Mountain area with the exception of a rather small region in the south, the water of which feeds the Zaros spring next to Zaros village. Because of contact of the spring reservoir with the sea, its water becomes brackish in the summer when fresh water pressure is low as there is no rainfall.

With regard to the problem of the spring water becoming brackish, it has been assumed by most geologists, following Breznic (1973) that the water becomes brackish at the point where the fresh water tube meets another tube that comes from the sea. During periods of low freshwater pressure (low spring discharge) seawater enters the fresh water tube through the sea tube and causes the spring water to become brackish.

4. THE DEVELOPMENT OF THE SPRING

Because of the importance of this spring, many efforts have been made until now to improve the quality of the spring water, but with limited success.

Twenty-five years ago, a small dam with a height of six meters was constructed in front of the spring to prevent sea intrusion, but its height is not sufficient. During an experiment of upraising the elevation of the water outlet from the actual point to 10 meters above sea level, the quality of the spring water was improved by a magnitude of about 500ppm Cl⁻.

On the other hand, many drills have been constructed uphill of the spring without finding substantial quantities of water, as the water in the karstic reservoir follows a network of tubes and is very difficult to locate.

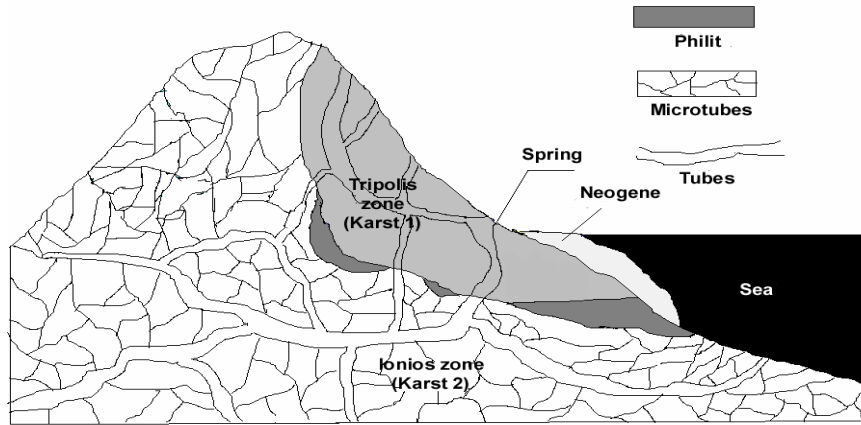


Figure 3. Conceptual representation of the Almiros karstic spring reservoir

5. ALMIROS SPRING SIMULATION

The proposed model has been used to simulate the Almiros spring. The simulation period covers the years between 1989 and 1997. Time interval for the model calculations was one-day. In Fig.4 the model calculated discharges are compared with the actual ones, while in Fig. 5 the model calculated chlorine ions variations are compared to the measured ones.

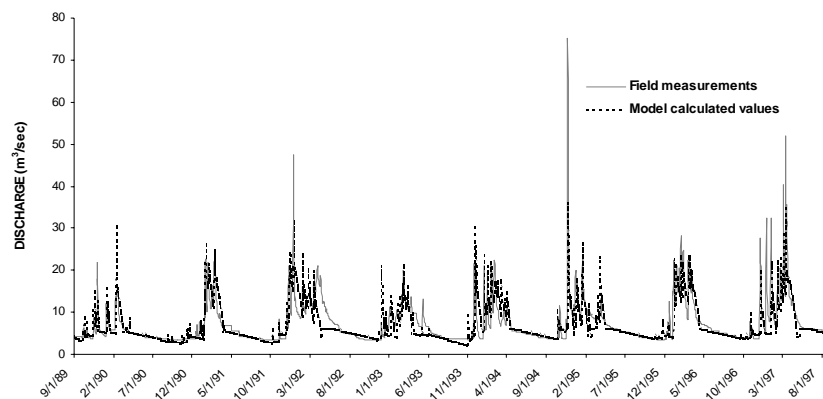


Figure 4. Comparison between models calculated discharge values and field measurements

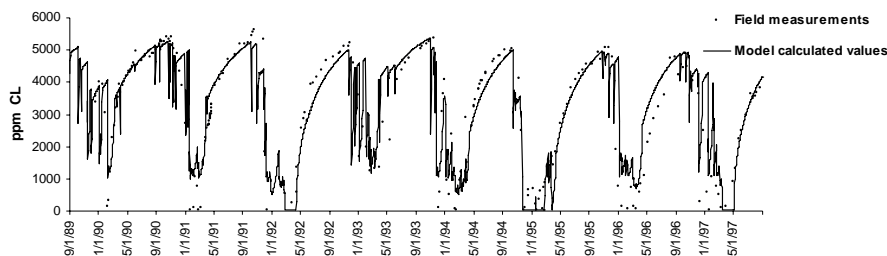


Figure 5. Comparison between models calculated water chlorine ions concentration values and field measurements

6. RESULTS AND DISCUSSION

One of the parameters of the model is the spring elevation. Thus, we can predict the discharges and the chlorine ions concentration of the spring water in connection with it. We have used the

model for different spring elevations and the results are presented in Figures 6, 7, 8, 9 and 10. In figures 6, and 7 the model calculated discharges and chlorine ions variations versus time for the 20meters spring elevation are compared to the real ones. In Fig.8 the percentage of the days with fresh water against the spring elevation for the hydrologic years 1989-90 till 1996-97, is presented while in Fig.9 and 10 the fresh water loss versus the spring elevation for the entire period and the depletion period respectively, during the same years, is shown. On Table 1 the fresh water loss in connection with the elevation of the spring water outlet during the above time period, is reported.

The conclusion is that when we upraise the water outlet point of the spring, the quality of its water improves and the time intervals with fresh water become longer while, with an upraising of this point up to the elevation of 26m, the sea intrusion is almost totally blocked.

The fresh water loss for the upraising up to the elevation of 26m, is of the order of 24% for the whole hydrologic period and 37% for the depletion period. However, if we don't necessarily need to get from the spring totally fresh water but can tolerate higher chlorine ion concentrations instead, the water loss can be substantially lower. With the proposed model we can estimate the spring elevation so that, the water quality and the implicit water loss to have the desired values.

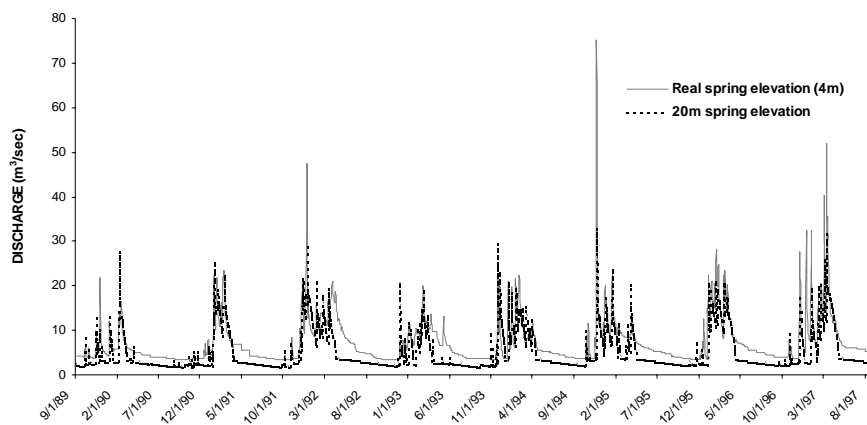


Figure 6. Comparison between discharges at the real spring elevation and at 20m spring elevation

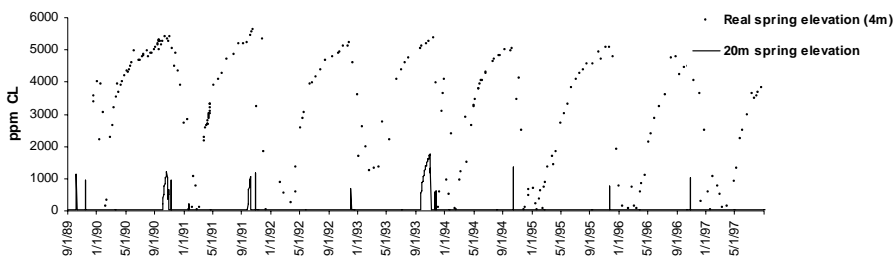


Figure 7. Comparison between chlorine ions concentration at the real spring elevation and at 20m spring elevation

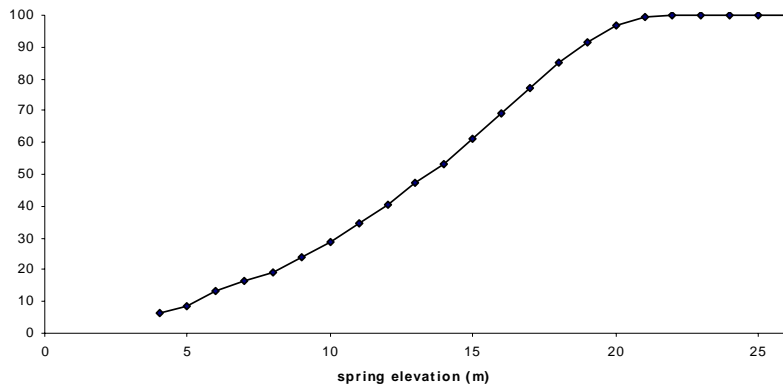


Figure 8. (%) Days with fresh water versus the spring elevation

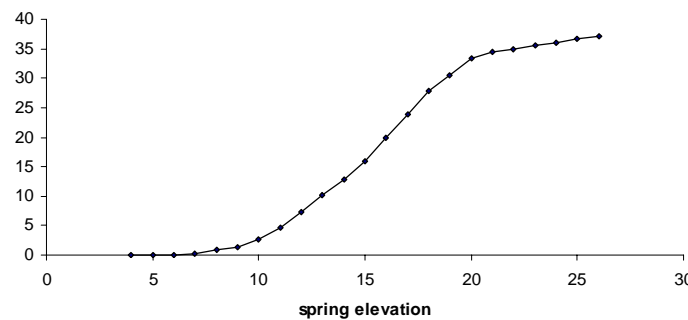


Figure 9. (%) Loss of fresh water versus the spring elevation (depletion period)

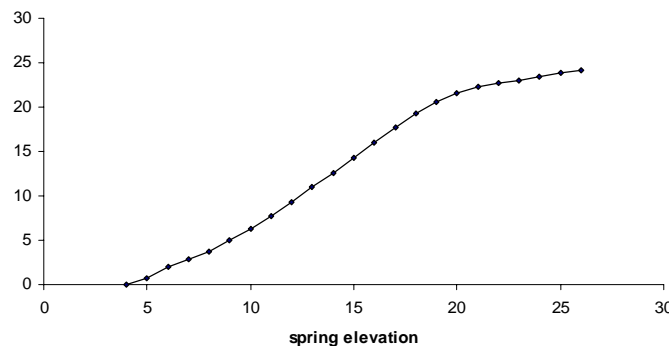


Figure 10. (%) Loss of fresh water versus the spring elevation (whole period)

7. CONCLUSIONS

The suitable development method for some brackish karstic springs is the artificial upraising of the water outlet point. This method is applied on the condition that, the necessary lifting of the water outlet and the implicit fresh-water loss to the sea could be estimated.

The Almiros spring simulation showed that the upraising of its water outlet, through the construction of a small dam, could prevent sea intrusion. The dam must be constructed up to the elevation of 26m. In this elevation the sea intrusion will be totally blocked. The fresh-water loss will be about 37% during the depletion period.

Table 1. Spring fresh water loss (%)

| Elevation | Whole period | Depletion period |
|-----------|--------------|------------------|
| 4 | 0.00 | 0.00 |
| 5 | 0.66 | 0.00 |
| 6 | 1.95 | 0.00 |
| 7 | 2.86 | 0.23 |
| 8 | 3.76 | 0.79 |
| 9 | 4.95 | 1.34 |
| 10 | 6.35 | 2.65 |
| 11 | 7.78 | 4.60 |
| 12 | 9.35 | 7.27 |
| 13 | 11.04 | 10.15 |
| 14 | 12.53 | 12.92 |
| 15 | 14.31 | 15.93 |
| 16 | 16.05 | 19.96 |
| 17 | 17.69 | 23.97 |
| 18 | 19.28 | 27.74 |
| 19 | 20.55 | 30.57 |
| 20 | 21.61 | 33.42 |
| 21 | 22.25 | 34.37 |
| 22 | 22.68 | 34.96 |
| 23 | 23.06 | 35.53 |
| 24 | 23.43 | 36.10 |
| 25 | 23.80 | 36.66 |
| 26 | 24.16 | 37.21 |

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