

Interactive comment on “Hydrologic and geochemical modeling of a karstic Mediterranean watershed” by N. P. Nikolaidis et al.

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The reviewer thought that the application of the "SWAT model to simulate the hydrologic variability and nitrate levels of a karst aquifer system on the island of Crete, Greece and is potentially interesting and presents some relevant conclusions", however it requires substantial improvement based on the comments provided. The reviewer had three interrelated general comments dealing with the determination of the extended karst area, its description and the presentation of the hydrogeologic setting of the study, in addition to a series of specific comments. We want to thank the reviewer for the constructive criticism of the manuscript, whose readability will improve substantially by the revision. Detailed response to both general and specific comments follows. Each comment is also presented before the response in order to facilitate the reader.

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General comments

* The hydrologic behavior of karst aquifer systems can only be understood on the basis of a thorough hydrogeological analysis and a valid conceptual model. However, this article only presents some verbal description of geology, but no geological or hydrogeological maps and sections, and no conceptual hydrogeological model of the aquifer system.

A significant discussion of the hydrogeologic setting of the area has been presented in a previous publication (Moraetis et al., 2010) in the *Journal of Hydrology*. A brief review of the system has been presented in the manuscript on page 5 and the conceptual model (as implemented in the SWAT model) is presented in section 3. We agree with the reviewer that a brief review presentation of the setting, functioning and structure of the karst will improve the overall readability of the manuscript. The geologic map with the faults and a cross section can also be presented. The manuscript will be revised as follows:

The Stylos Spring Karst System

The karstic system of the White Mountains is comprised of an autochthonous geotectonic unit, Plattenkalk and two allochthonous units. the Trypali limestones and the metamorphic schists (Figure 1). The Plattenkalk nappe consists of layers of dolomites, limestones and marbles and limestone and cherts with intense bedding (in the lower boundary of metamorphism). The Trypali nappe is highly karstified and has overthrust the Plattenkalk nappe. The metamorphic schists overthrust both the Plattenkalk and Trypali units mainly in the western part of the White Mountains. Neogene sediments (marls and marly limestones) have been deposited at the lower elevations of the basin over the autochthonous formation. Finally, alluvial sediments are found near the river corridor mostly in lower elevations. Figure 1 presents the geology of the area of Koiliaris River watershed and Figure 2 presents two geologic cross sections depicting the stacking of the nappes and the existing faults.

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The stratigraphy of Crete has been formed by one dipping north and one south that meet at the north-south divide (approximately at 2000 m elevation) as well as east-west trending zones (Papanikolaou and Vassilakis, 2010). The Plattenkalk autochthonous formation in the watershed has significant east-west normal faults dipping north. At the eastern part of the White Mountains there is increased exhumation of the autochthonous nappes, while in the western part, there is stacking of allochthonous nappes that overthrust the north-west dipping of Plattenkalk. Along the Plattenkalk dipping a series of normal faults influence the creation of neogene sedimentary basins (Fassoulas, 1999).

The karst system is characterized by very fast infiltration and direct connection to the conduits below. There is a significant number of sinkholes with long downward shafts, caves and a deep conduit system (Gourgouthakas cave -1205m, Liantari cave -1100m-Moraetis et al. 2010). The karst system discharges in a series of permanent springs, Stylos springs at elevation +17 m AMSL and an intermittent spring, Anavreti at elevation +24 m AMSL. Both springs then feed Koiliaris River. The springs have an average discharge of 154 million m³/yr (2007-2010) with very intense fluctuation between winter and summer flows. The total recharge area of the springs extend beyond the boundaries of Koiliaris River Basin to the south-east of the watershed boundary (Moraetis et al., 2010). The area of the extended karst is depicted in Figure 1 and was determined based on geologic and fault analysis (Figure 2). The cross sections of the extended karst area identify a major fault in a northeast-southwest direction (located at the boundary of the karst and neogene deposits) which together with dipping of the nappes direct the water towards the Koiliaris River Basin. Considering the dipping of Plattenkalk nappes towards north-west in relation to normal faulting, the dolomites (lower part of the stacking sequence) which are less karstified come in contact with the Plattenkalk nappes (upper part - more karstified limestones with cherts) at lower elevation (Figure 2) directing the water to the springs.

* The authors determined the "extended karst contributing area" by trial and error using

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SWAT and playing with different HRUs. This is a serious mistake. Karst catchments can only be delineated based on hydrogeological considerations and by means of tracer tests.

In the manuscript, we presented a methodology for quantifying the extended karst contributing area using a hydrologic model, after taking into consideration the hydrogeology and detailed analysis of the karst structure (see description of karst that will be presented in the revised version of the manuscript). As mentioned earlier the approximate location of the extended karst of Stylos springs (the main spring in Koiliaris River Basin) was presented in Moraetis et al. (2010) and there have been a series of published (i.e. Papanikolaou and Vassilakis, 2010 in Tectonophysics) and unpublished studies (i.e. tracer studies conducted by Institute of Geological and Metallurgical Research, Knithakis, 1993 and bore log sections from speleological exhibitions in the main/large caves and sinkholes) that describe the setting of the karst in the area. One of the problems of using tracer studies in a geologic setting such as Stylos Karst in order to delineate the extended karst area the high degree of dilution due to the large volume of discharge water (80-150 Mm³/yr) as well as the large permanent volume that according to our study is 4.5 times larger than the discharged volume. The Knithakis tracer study introduced two types of tracers up-gradient from the springs (about 1-2 Km) in wells and observed the appearance of the tracers in the springs and nearby dug wells. The results were of limited value for the delineating the extend of contributing karst.

In fact our methodology quantified the extent of the karst (as determined by geologic analysis) by using mass balance modeling. The quantification was determined by what we called "trial and error", which in practice was assigning areas from the extended karst to contribute to Stylos spring discharge. This is an additional evidence that is consistent with the theoretically determined extended karst area (by contributing the appropriate amount of water to Stylos spring). The above information combined with modeling of nitrate concentrations in the karst provides additional consistent evidence with the determination of the extended karst. This is an important point in our anal-

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ysis since independent chemical data and nitrate loads were used in the modeling of nitrates and the resulting simulation was consistent with other determinations of the extended karst.

Part of the objective of this manuscript was to provide a modeling methodology for the study of hydrologic and chemical response of karstic systems. We believe that the results of this study have been consistent with previous studies and advance our methods and tools of studying such systems.

The manuscript will be edited to better account for these issues and clarify/ justify better the methodology used.

* Figures 1, which is supposed to present the test site, does not indicate the location of the test site; it also has no scale, no north arrow, no legend, etc. Where are all the springs and gorges that you are talking about? What is the structure and geometry of the aquifer system, etc.?

Figure 1 will be revised to present the watershed and extended karst area on a geologic map with the faults included. Scale, direction and legend will also be included. The structure of the aquifer system is discussed in general comment #1.

Specific comments

* Introduction, first paragraph: This is a poor general description of karst systems. Please refer to some relevant international papers and textbooks dealing with karst hydrogeology and consider the terminology and concepts used in these international standard references.

A separate section that would describe the setting, functioning and structure of the karst will be included in the manuscript. See reply to general comment #1.

* P. 3, line 21: You state that 75 % of the Mediterranean is irrigated? This is obviously nonsense. Do you mean 75 % of the agricultural land in the Mediterranean?

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Yes, the reviewer is right, it is 75% of the total agricultural land in the Mediterranean. The manuscript will be corrected.

* P. 3-4: This is a simple recital of who did what, but not a thorough discussion of the state of science in karst hydrogeology and karst modeling.

See reply in general comment #1.

* P. 5, first paragraph: This is not only true for Mediterranean karst. It is commonly known that topographic divides often do not match with groundwater drainage divides in karst. See first specific comment: Please refer to international papers and textbooks.

We agree with the reviewer that this statement also applies to other karst areas and not only in Mediterranean. Corrections will be made in the manuscript to address this issue.

* P. 5, line 8: What is a karstic system under pressure? Do you mean a confined /artesian aquifer? Please use terms and concepts commonly used in hydrogeology.

Yes it is an artesian aquifer.

* Line 15: In a dynamic system, like an aquifer, dilution is not only a function of water volume, but also and mainly a function of flow rate.

The manuscript will be changed to better describe the phenomena.

* Section 2, page 6: This is a poor and incomplete description of the geological setting. What is missing here is a geological map, geological cross sections and/or block diagrams, etc. What means "has an intense geomorphology"? Did you do tracer tests to delineate the catchment?

See reply in general comment #1.

* P. 9, line 22: Dispersion is not (not only) a result of fluctuations of the water table. You can get dispersion even without any fluctuations.

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Here we wanted to make the point that changes in barometric pressure in the sinkhole induces water table fluctuations and thus dispersion. this issue was examined in detail and data and calculations were presented in Moraetis et al., 2010.

* P. 10, lines 10-11: This is a serious and fundamental scientific mistake: You cannot determine the extended karst contributing area in this way! This can only be done based on hydrogeological considerations and tracer tests, but not by trial and error using SWAT and playing with HRUs. Reference list: The reference list misses most relevant papers and textbooks in karst hydrogeology.

See reply in general comment #2.

* Figure 1 is unacceptable: No location, no scale, no north arrow, no legend, no information on geology, etc. Furthermore, your model cannot estimate the extended karst area.

See reply to general comment #3.

* Fig. 2a and b: The model simulated three peaks, but only one peak has been observed?

Unfortunately flow data at the entrance and the exit of the gorge were available for one year only.

* Fig. 2 and the following figures: This is very poor Excel design but not compatible with international standards of how to prepare nice graphics! Please check figures from other papers and take them as an example. Almost everything about your graphics is poor: Lines are too fat, the scales of the X-axes (time axes) is inappropriate, there should be no heading inside the figures, etc.

All figures will be redrawn.

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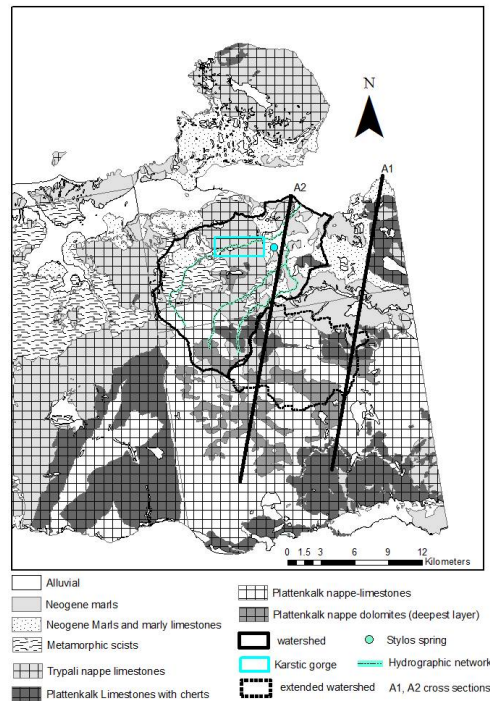


Fig. 1. Geology of Koiliaris River Basin.

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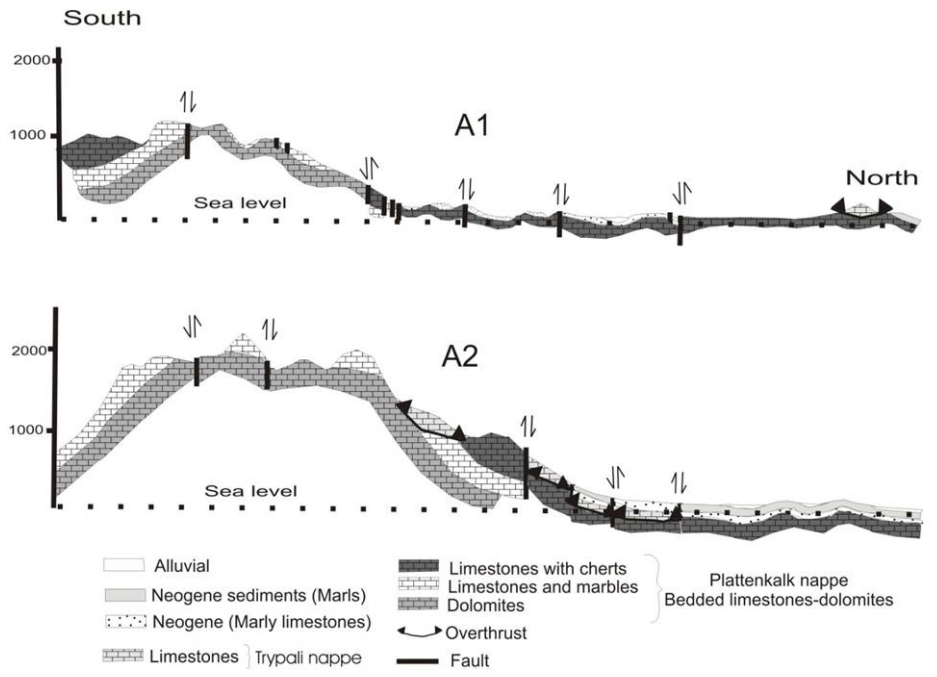


Fig. 2. Geologic cross sections of Koiliaris River Basin.