Using Integrated 3D Geological Modelling for Planning Artificial Recharge of Karstic Groundwater. Case Study in the Enipefs River Basin, Thessaly, Greece

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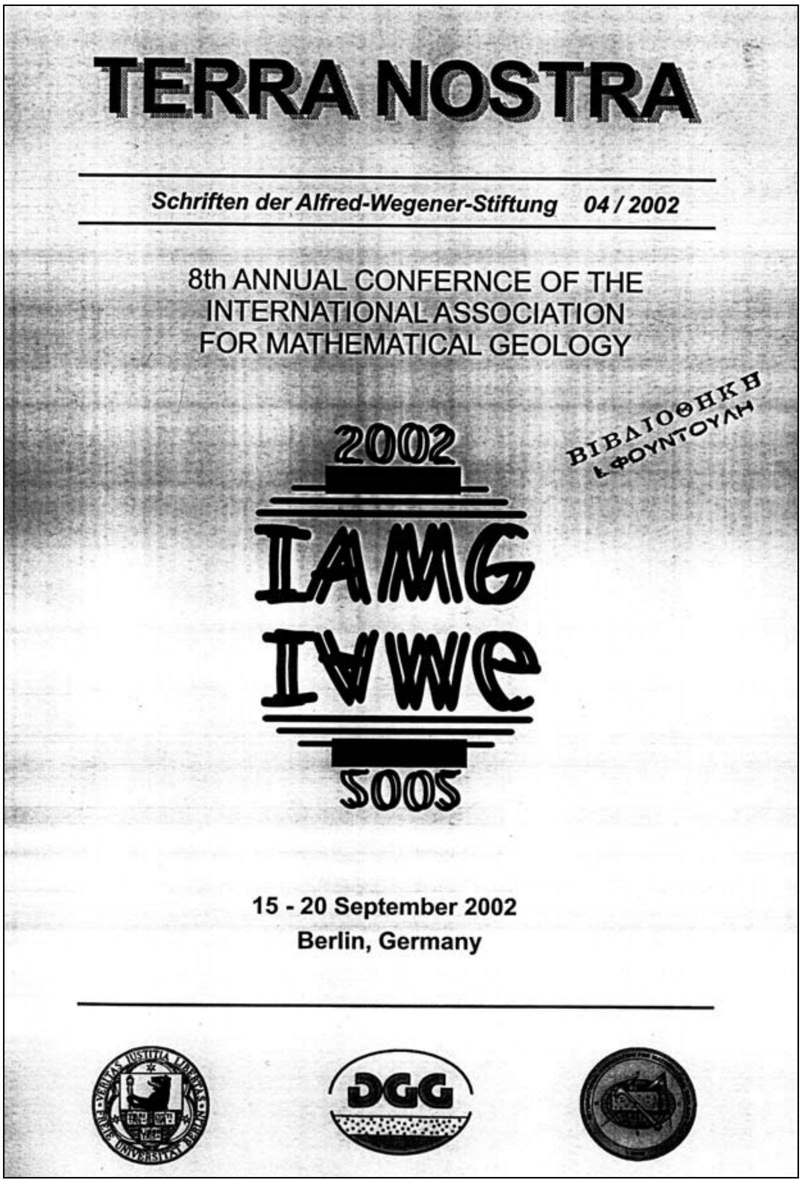

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Using Integrated 3D Geological Modelling for Planning Artificial Recharge of Karstic Groundwater. Case Study in the Enipefs River Basin, Thessaly, Greece

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1. Abstract
A pilot study for the artificial recharge of karstic aquifers in the basin of the Enipefs river in Thessaly (Central Greece) is presented in this paper. The method of artificial recharge, based on the storage of surplus water of the winter months in aquifers for consumption during the dry summer months is especially suited for karstic aquifers, due to their large water storage capacity. The critical step in planning such measures is the delineation of the aquifer geometry, so that accurate estimates of the water volumes needed can be calculated. This was accomplished by employing 3D CAD techniques. Working with an integrated software package allowed us to combine all available information acquired before the start and during the project. The resulting geological model is the basis for the development of a groundwater model describing the interaction between the karstic and the adjacent porous aquifers.

2. Introduction
Water shortage is one of the main problems modern human society is facing. In the Mediterranean climate, the term shortage is not an absolute one, but it has a spatial and temporal meaning. Although the annual overall budget shows a water surplus, there is a deficit between water availability and water demand in the dry period of the year. To overcome these shortages, suitable groundwater management techniques have to be developed. One promising technique is artificial recharge. It is based on the storage of surplus water of the wet winter months in aquifers for consumption during the dry summer months.

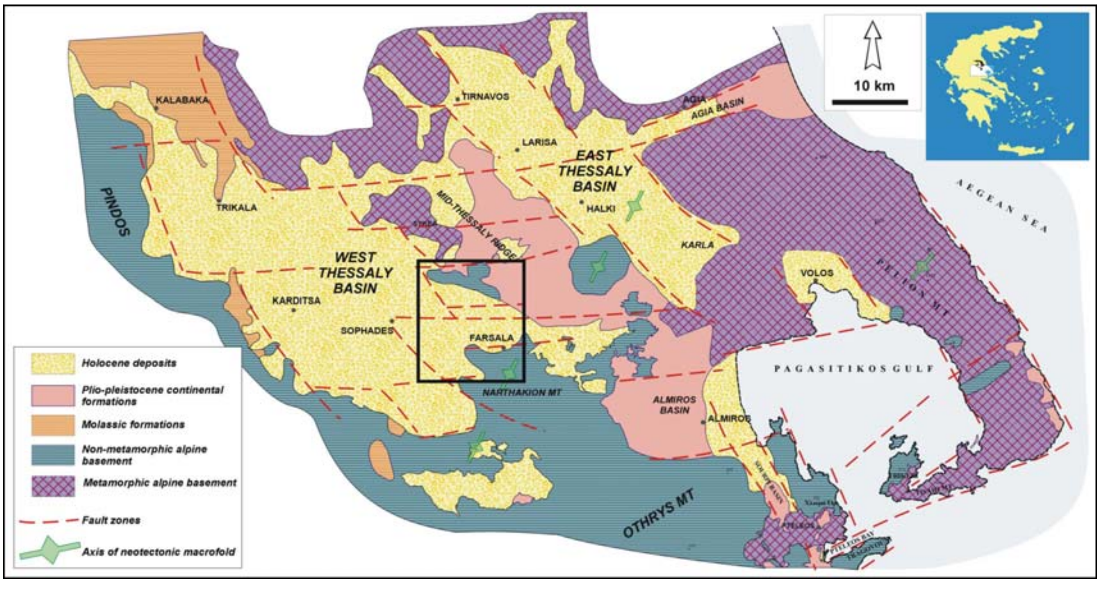

Fig. 1. Location of the study area and geological map of Thessaly.

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In this paper, a pilot study on the artificial recharge of karstic aquifers in the basin of the Enipefs river in Thessaly (Central Greece) is presented. The study area is located northwest of Farsala (Fig. 1), around the villages of Orfana and Ypereia (Fig. 3). The area was selected due to the special interest of the Hellenic Ministry of Agriculture to evaluate possibilities to replenish water resources that are presently going to be exhausted. This critical condition is highlighted by irrigation wells, in which the water level is continually falling with a rate of 3-6 meters per year since the beginning of the last decade. In this situation, it was decided that the applicability and the benefits of artificial recharge of karstic aquifers should be investigated. One of the objectives of the pilot study was to estimate the volume of the depleted water and to compare it with the available water from the Enipefs river in the winter months.

3. Regional Geological Setting

The investigated Farsala basin is part of the Western Thessaly basin (Fig. 1). The sediments filling the basin are mainly Holocene alluvial sands and Pleistocene terrestrial sediments. The alpine basement is formed by Flysch and Cretaceous Limestones (Figs. 2, 3). The morphology of the top of the basement is controlled by the neotectonic activity, expressed by large folds with axis direction NE-SW as well as by E-W and NW-SE striking faults (Fig. 4).

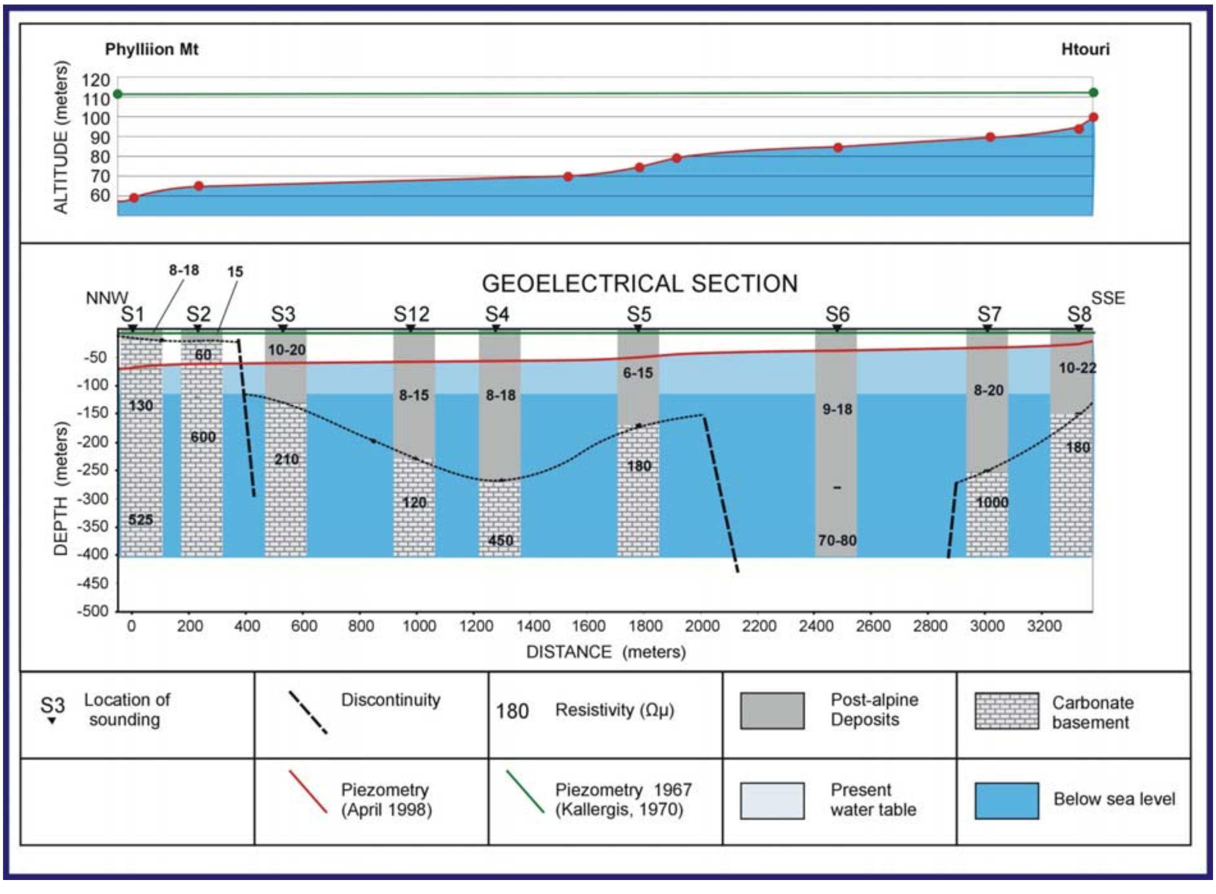

Fig. 2. Cross section of the Farsala basin between the hills Phylliion and Htouri, where the main carbonate mass outcrops in the area.

4. Use of integrated Modelling Software

The use of integrated software packages allows modellers to put together all available information acquired before the start and during the project. In this case, drill hole data (down to a depth of 150 m) was combined with geoelectrical sounding results (down to 300 m depth) (Figs. 2, 4), surface geology and tectonic analysis data to reconstruct the geometry of the contact between carbonate basement and overlying sedimentary formations. This structure proved to play a determining role in the hydrogeological conditions of the area (Mariolakos et al., 2000). The geological modelling exercise was accomplished using the integrated 3D-CAD

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modelling system SurpacVision whose database and cartographic modules will also be employed as pre- and post processor for the groundwater modelling part.

5. Hydrogeological conditions - Volume calculations

The hydrogeological conditions in the study area are characterised by an unconsolidated aquifer in hydraulic contact with two karstic aquifers. The unconsolidated aquifer is charged by rainfall and infiltration of water from the Enipefs River. The present groundwater level in the karstic aquifer of the Phylliion Mt. area is fluctuating at depths several tens of meters below the level of the (now dry) Mikro Vouno springs (see NW part of the map), where the aquifer used to discharge before overexploitation.

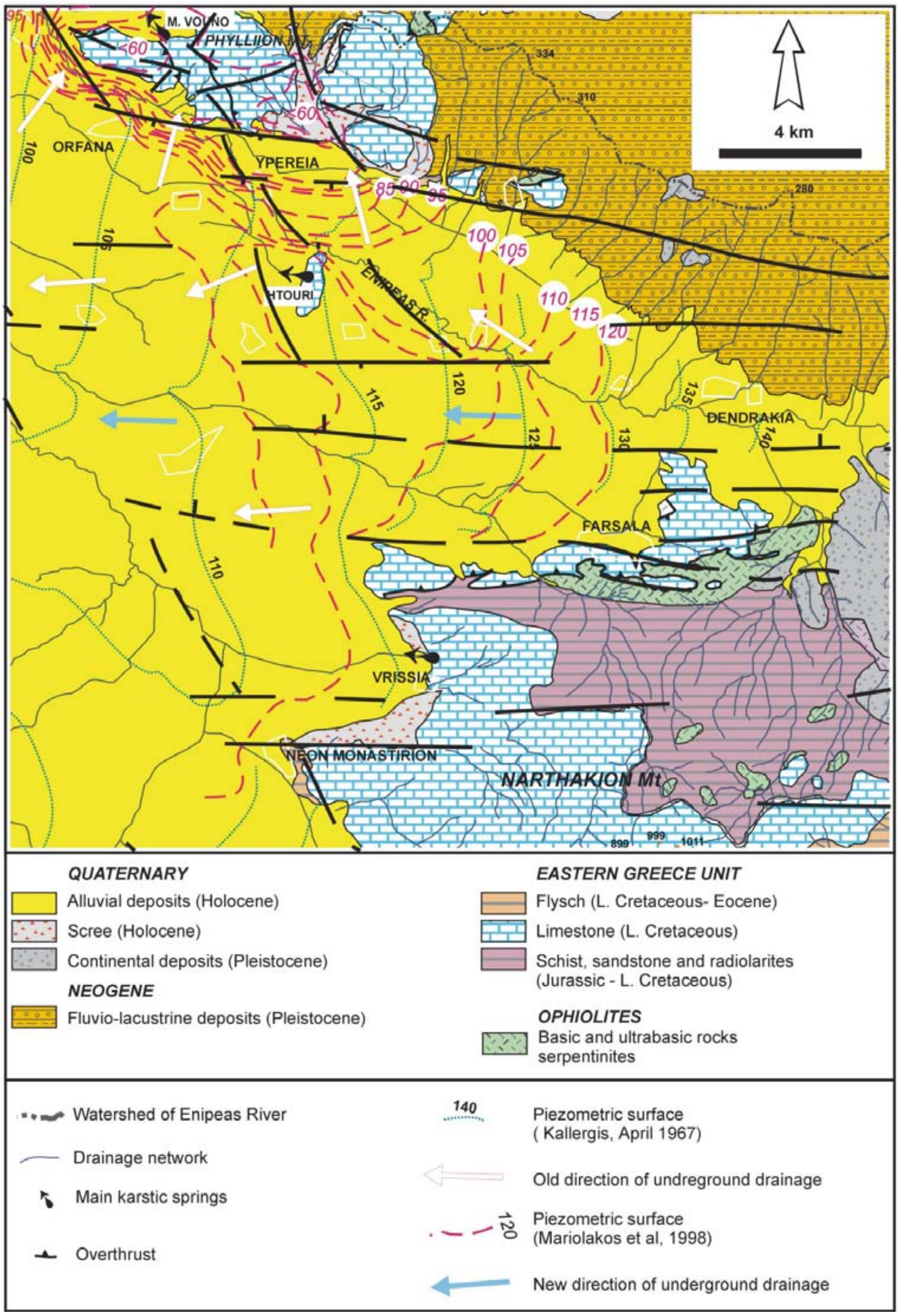

Fig. 3: Hydrogeological map of the study area.

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The available information about this hydrogeological system can be summarised as follows:

- The Htouri springs lie at an altitude of 116m asl; the Mikro Vouno springs are situated on the northern flank of Phylliion Mt. at a height of 102m asl. In the Orfano area, the gradient of Enipefs River is negligible small. The average elevation of the banks of is 110m asl. Assuming an uniform aquifer, these water table measurements would indicate the existence of a mean hydraulic gradient of 1.6% towards north, i.e., towards Mikro Vouno springs.
- The Htouri springs have been strongly influenced by overexploitation since 1989. In 1980, they had a mean yield of 0.3 m^3/s, i.e. a mean discharge of 9.3 million m^3 per year.
- The Mikro Vouno springs had fallen dry due to overexploitation of the aquifer since 1985. In 1980, they provided an average supply of 0.2 m^3/s, i.e. a mean yearly discharge of 6.2 million m^3.
- It seems that the Htouri springs were discharging a local "tank" with increased permeability and storability intercalating an unconsolidated aquifer. The karstic tank must have been supplied form the east. It discharged towards the west through the unconsolidated aquifer. This hypothesis is based on the fact that the supply by precipitation is too small to explain the yield of the springs. In addition to that, the regime was permanent and did exhibit seasonal fluctuations like the karstic aquifer in the Phylliion Mt. area.

The facts listed above show that the unconsolidated aquifer is the main source of water for the karstic aquifers in this area. This is possibly the only reason that the aquifers in the Htouri area were not depleted during the years of overexploitation.

Regarding the hydrogeological system at Phylliion Mt., the following conclusions have been drawn:

- The limestone mass of Phylliion Mt. and the smaller mass of Htouri represent two isolated karstic tanks which - under normal conditions - are hydraulically connected to the aquifer that develops in the unconsolidated post-alpine material (Mariolakos et al. 2001).
- The development of the springs west of Htouri and north of Phylliion Mt. (Mikro Vouno) is the result of the altitudinal difference of the free surface in the unconsolidated material surrounding the limestone bodies, in combination with a sudden drop in velocity when the water from the karstic aquifers re-enters the porous medium.
- At Htouri, water flows, under normal conditions, from the east through the unconsolidated aquifer and discharges to the west. The same phenomenon can be observed at Phylliion Mt., but in this case with a groundwater flow in south-north direction.
- Charging of the karstic aquifer is controlled mainly by inflow from the unconsolidated aquifer and to a lesser degree by atmospheric precipitation.

Before overexploitation, seasonal differences in hydraulic head between the unconsolidated and the karstic aquifer lead to a cyclic water exchange between both aquifers. During the dry period, the unconsolidated aquifer was exploited to for water supply purposes. The drawdown of the water table triggered a recharge by inflow from the karstic aquifer. During the subsequent wet period the karstic aquifer was replenished by the unconsolidated aquifer.

Today, the water surplus in the wet period is not even sufficient to replenish the unconsolidated aquifer. Due to the disturbance of the balance of this intricate system the water deficit in the karstic aquifer is increasing. By restoring the water reserve in the Phylliion karstic tank the system of mutual water exchange between the aquifers can be re-started. The reverse flow towards the unconsolidated aquifer is expected to begin as soon as the water table in the limestones rises above the water table in the unconsolidated aquifer and the Mikro Vouno springs are back in operation.

The assessment of the feasibility of an artificial recharge requires a calculation of the amount of water necessary to replenish the karstic aquifers. The water deficit can be estimated from the difference in the piezometric levels of 1967 and 1998. To carry out this task as accurately as possible, modern 3D CAD techniques are indispensable. Three models were set up:

- The geometry of the tectonic block that contains the karstic aquifer of Phylliion Mt. as a whole (Mariolakos et al., 2000), and the basement morphology of the post alpine deposits that represents the upper limit of the carbonates (Mariolakos et al., 2001) (Fig. 4).
- The piezometric surface of the aquifers on 1967 (Kallergis et al., 1973) (Fig. 3).
- The 'actual' piezometric surface (1998) determined during the last project (Mariolakos, 1999) (Fig. 3).

Afterwards, the volumes between the two piezometric surfaces in the porous aquifer in the Farsala basin (approx. 100 km^2) were determined. The volume of water was obtained by multiplication with the average storability of the sediments (10%, after Kallergis et al., 1973).

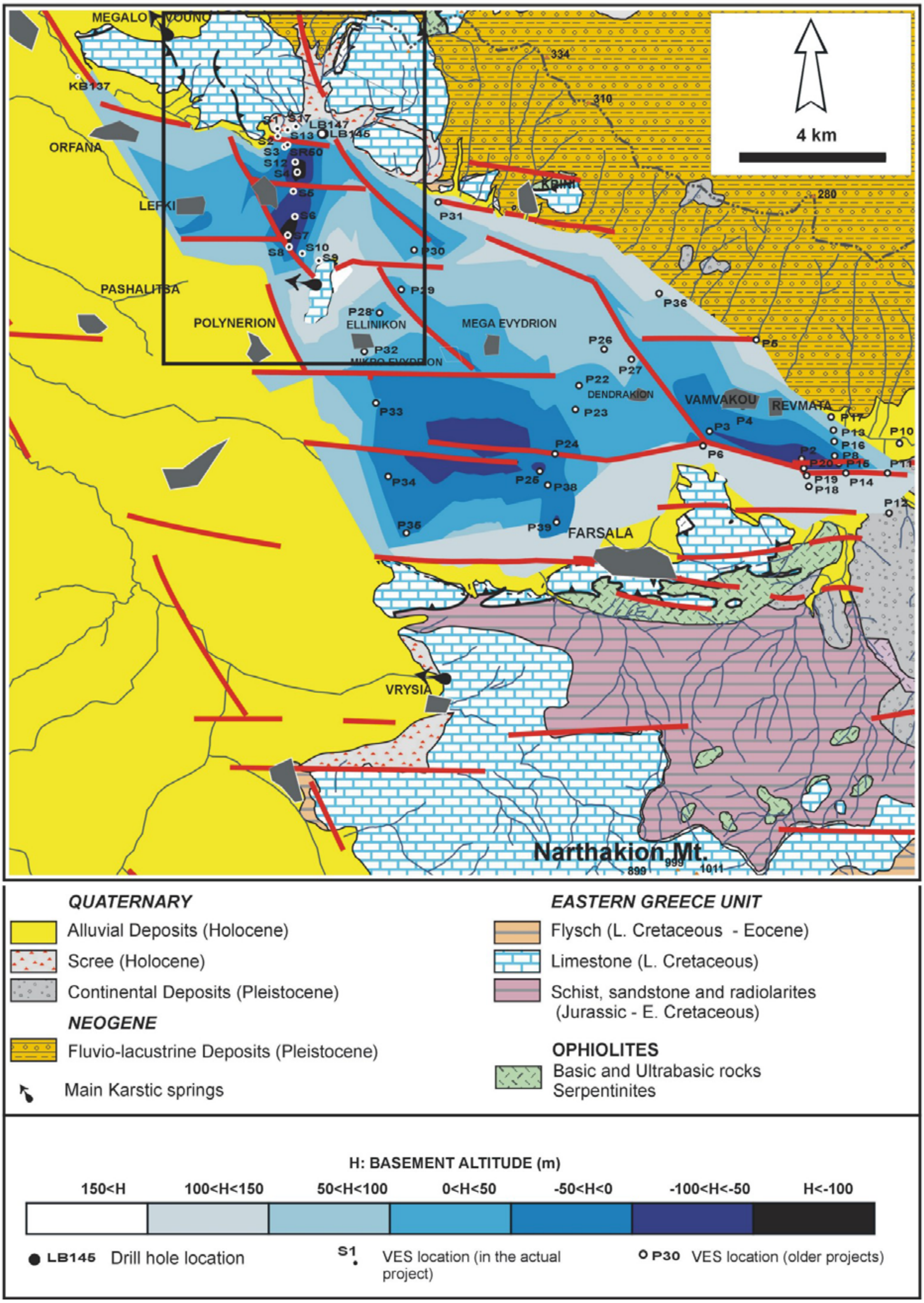

Fig 4. Structure map of the alpine basement of the Farsala basin

6. Results - Conclusions

The calculation results for the volumes between the modelled piezometric surfaces and the basement morphology, as well as the expected available annual water quantity from the Enipefs River are listed in table 1. Although the mean available water for recharge is estimated to be 16.7×10^6 m^3, planning of artificial recharge works has been done on the basis of the minimum measured value, 6.0×10^6 m^3, in order to safeguard the ecological conditions downstream.

Table 1: Volume Calculation for the water deficit and available water quantities from Enipefs River

Storability (%)	Water Volume between boundary levels (millions m^3)		Mean annual increase of deficiency (millions m^3)	Average annual water flow of the Enipefs River (millions m^3)	Average annually available water quantity for Artificial Recharge (millions m^3)
	1967 to 1998	Basement to 1998			
10.0	160	608	2.1	61.51	16.7

In the following stages of the project, a stochastic rainfall – runoff model can be set-up to simulate the behaviour of the karstic aquifers. Measurements of the water table elevation in these aquifers can be used to calibrate the model. Finally, a groundwater model for the porous aquifers adjacent to the karstic ones can be set up. In this case, the water table elevation in the karstic aquifers can be used as a boundary condition for the porous aquifers model.

7. Acknowledgments

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