GEOMORPHOLOGICAL CHANGES OBSERVED BETWEEN 2006 AND 2009 IN A FRESHWATER SUBMARINE GROUNDWATER DISCHARGE (SGD), KALOGRIA BAY, SW PELOPONNISSOS, GREECE

Aristomenis P Karageorgis [1]*, Kostas Katsaros [1], Theodore D Kanellopoulos [1] and Evangelos Papathanassiou [1]
[1] Hellenic Centre for Marine Research, Institute of Oceanography, 19013, Anavyssos, Greece - ak@ath.hcmr.gr

Abstract
An impressive SGD in Kalogria Bay (SW Peloponnissos) was surveyed for the first time in 2006, revealing the existence of 2 major and 2 minor point sources of freshwater (salinity ~1-2); the discharge was ~1000 m^3 h^{-1}. The major point source was located inside a karstic cavity at 25 m depth. In July 2009, the site was revisited and divers reported that only the largest point source was active, whereas the roof of the cave had collapsed. The underwater discharge was not very strong, the water was flowing from many dispersed points, and salinity range was 20-36. Following visits will show if the SGD has turned to a diffused type and if changes in salinity are permanent, thus hampering the possibilities of water exploitation.
Keywords: Geomorphology, Hydrology, Coastal Processes, Salinity, Eastern Mediterranean

Introduction
Knowledge concerning submarine groundwater discharges (SGDs) has existed for many centuries [1]. However, SGDs were neglected scientifically for many years because of the difficulty in assessment and the perception that the process was unimportant [2]. Within the last two decades, that notion has changed, and now there is growing agreement that groundwater inputs can be chemically and ecological important to coastal waters [2]. Here we present new data regarding a large karstic freshwater SGD situated in Kalogria Bay, near Stoupa town, in SW Peloponnissos (Fig. 1). We focus on the geomorphological changes that were observed between 2006 and 2009, which may have consequences on the salinity of the discharged water.

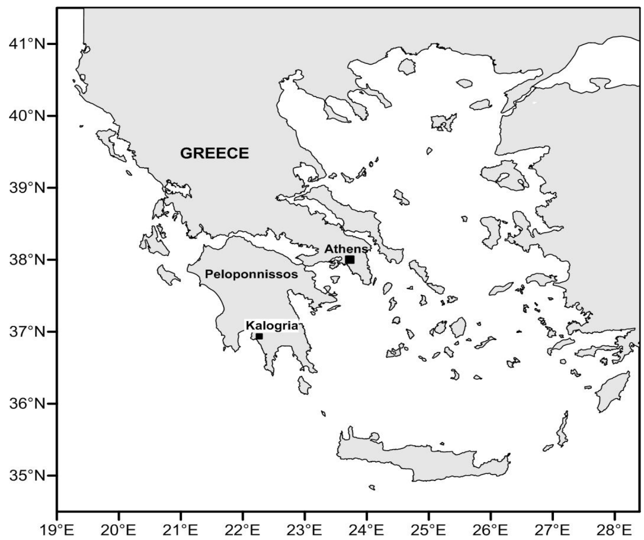

Fig. 1. Study area location map

Materials and Methods
The site was first visited in November and December 2006. During the latter visit, a multifaceted operation with divers, a remote operated vehicle, a portable CTD, and other equipment was implemented, which provided ample samples, videos, and other data from the site. Another visit was conducted in February 2008, and then in July, September, and October 2009. During 2009, apart from sampling with divers, a lander equipped with conductivity, temperature, current velocity, and g-ray spectrometer sensors was deployed permanently.

Results and Discussion
In 2006, the entire submarine spring feature formed an ellipsis with dimensions approximately 60 m x 40 m. Two major point sources discharged from Pleistocene conglomerates; the strongest, in terms of discharge, underwater spring emanated from the bottom (diameter ~2 m) of a cave, at 25 m depth. Salinity was ~1-2. Two minor SGDs discharged from the sandy seabed. Using ^{222}Rn measurements [3], the discharge was estimated at ~1000 m^3 h^{-1} at the second point source (water depth ~26 m). This morphology was maintained unaltered between 11-2006 and 2-2008. In July 2009, the underwater morphology appeared completely changed, as the roof of the cave, where the strongest SGD emanated, had collapsed almost entirely. The second SGD was completely filled with sand, and similarly, as the two smaller ones, they were inactive. The behavior of the major point source was also different, because the water was not any more concentrated as a single jet flowing from the bottom of the cave towards the surface, but it was scattered and emanated under rocks, from little cracks, and was generally rather diffused. Salinity measured in various spots was high (20-36). Elevated salinity can be attributed to the altered morphology of the submarine spring and particularly to the much more diffused character of the flow. However, it should not be disregarded that all measurements conducted in 2009 reflect summer and early autumn conditions, where rainfalls are practically absent in this territory, and therefore freshwater supply from the land should be at the lowest levels. In this perspective, the entire SGD represents minimum freshwater outflow allowing faster mixing with the sea water and brackish character of the outflowing water.
Measured flow velocity was on average 0.25 m s^{-1}, which corresponds to 900 m^3 h^{-1} if we assume that all small discharges cover a surface of just 1 m^2. This is a very conservative assumption, and the discharge can be many times higher. A possible explanation for the collapse of the conglomerates could be related to the extremely high rainfall that occurred during the winter and spring of 2009. Residents of Kalogria stated that during March 2009, after an intense rainfall, the SGD was 'boiling' at the sea surface, other smaller SGDs in the bay were also very active, and the sea was colored red. The red color is probably attributed to 'terra rossa', which is the final product of limestone dissolution during karst formation, and was transported to the sea.
In September and October 2009, a small freshwater spring (salinity ~3-4, temperature 12-13 °C) was spotted in Kalogria beach discharging exactly at the coast. According to geological observations conducted by the Agricultural University of Athens, this freshwater springs from the mountains and is hydrologically connected to the studied SGD. Most likely, freshwater reaches the SGD, but due to low discharge, it gets rapidly mixed with seawater between the impermeable marble bedrock and the sea bottom, where permeable formations prevail (sand, gravel, etc.). The available geological evidence suggests that a fault line or an impermeable rock formation (e.g. schist) blocks the freshwater flow on the marble bedrock and creates the SGD at this site.

Conclusions
Significant geomorphological changes have occurred in the studied SGD, which may have consequences on the type of the flow (from point to diffused), and possibly to the salinity of the water. Winter observations will reveal if elevated salinity is due to the sampling period (summer, low terrestrial water supply) or due to the changes of the rocky structure. Potential water exploitation will depend on a full year of observations.

References
1 - UNESCO, 2004. Submarine groundwater discharge. Management implications, measurements and effects. *IHP-VI, Series on Groundwater No. 5, IOC Manuals and Guides No. 44*, United Nations, Paris, 35p.
2 - Burnett W.C., Bokuniewicz H., Huettel M., Moore W.S. and Taniguchi M., 2003. Groundwater and pore water inputs to the coastal zone. *Biogeochem*., 66: 3-33.
3 - Tsabaris C., Scholten J., Karageorgis A.P., Commanducci J-F., Georgopoulos D., Kwong L-L.W. and Papathanassiou E., 2009. Application of an in situ underwater gamma spectrometer as a marine radon progeny monitor: continuous monitoring of groundwater discharges into the coastal zone. *J. Environ. Radioactiv.,* submitted