HYDRO-GEOCHEMICAL ASPECTS OF A TYPICAL MEDITERRANEAN TEMPORARY POND IN WESTERN CRETE (OMALOS PLATEAU)

F. Stamati (1), N. Nikolaidis (1), E. Dimitriou (2), N. Skoulikidis (2), T. Koussouris (2)
(1) Technical University of Crete (TUC), Department of Environmental Engineering, 73100 Chania, Greece, fstamati@enveng.tuc.gr, nnikolai@mred.tuc.gr, (2) Hellenic Centre for Marine Research, Institute of Inland Waters, 19013 Anavyssos, Attiki, Greece, elias@ath.hcmr.gr, nskoul@ncmr.gr, tkouss@ncmr.gr

ABSTRACT

The Mediterranean temporary ponds (MTPs) are "priority habitats for conservation" (Natura code: 3170*), according to the Habitat Directive of the European Union (92/43/EC) and they are considered as ecological ornaments of the environment. They possess peculiar hydroperiods that provide habitat to many rare and endangered species. The geochemical conditions that prevail in MTPs, create an unique environment, for each one, of high geochemical value, which has not been studied up to now in Greece. The objective of this work is the study of hydrology and geochemistry of a characteristic MTP at Omalos plateau.

1. INTRODUCTION

The MTPs are small and shallow temporary water bodies that occur in depressions with an impermeable ground and have a relatively small catchment area. They usually flood in winter and drain, mainly due to evaporation, in the summer. Some temporary ponds may hold water for more than one year, whereas others may remain dry for more than one season, depending on the amount of rainfall. They vary in size, shape, depth, diversity among organisms (flora and fauna) and duration of flooding. [1,2,3,4,5,6,7,8,9,10,11]

Mediterranean temporary ponds are of major conservation importance, because, despite their small size, they possess peculiar hydroperiods that provide habitat to many rare and endangered species. Therefore, they are considered as a priority habitat according to the EU Habitat Directive (92/43/EC). Priority habitats are those habitat-types or elements with a unique or important significance to a diverse group of species. They consist of a unique flora composition, succession stage and/or structural factor. Another important reason why they have to be protected is that these ponds have an alarming rate of elimination and degradation, while they are important environments. [12,13] since they support a diversity of various species including plants, amphibians and their tadpoles, insects, many microorganisms and macro invertebrates. Some of the species are endemic and some are rare. Endemic species are likely to disappear when these ponds are degraded due to the prevailing threats. The temporary ponds are isolated habitats and important environments for many migratory birds. They also provide a perfect spot for many birds to rest during their journey.

[6,14] The flora and fauna are uniquely adapted and as a result they can cope in very different ways with their environment. In some cases species are even dependent on the hydrological changes of these ponds for their reproduction or for the completion of their life-cycle. For example, a range of flooding patterns is important in these ponds to establish not only a diversity of plant species but also to allow these species to reproduce. Alteration of the hydrological regime will therefore cause a declination of those uniquely-adapted species. There is also a strong probability that temporary ponds contribute to maximizing the gene pool of species which occur in temporary as well as in permanent waters. This increased diversity may be crucial to the survival of species facing possible future changes of global environments. [1,6,14,15,16] Moreover, the geochemical conditions that prevail in MTPs, create an individual environment, for each one, of high geochemical value, which has not been studied up to now in Greece.

Twenty three appearances of MTPs, have been recently (2002) recorded in Greece. Five of them are located in Western Crete (Gavdos, Falasarna, Elafonisi, Georgjoupoli, Omalos) and are included in the LIFE-Nature project: ‘Actions for the conservation of Mediterranean Temporary Ponds in Crete’. The MTP at Omalos-Samaria plateau can be considered as one of the most typical according to its hydrology, geomorphology and geochemistry.

The objective of this work is to study the hydrology and geochemistry of a characteristic MTP at Omalos plateau. The study was conducted in four levels. The first level included the determination of sediment’s physicochemical characteristics (soil moisture, pH, dry bulk density, porosity, particle size distribution, XRF, XRD). The second level included in-situ studies, such as infiltration tests. A conceptual site model and a mathematical model, for the estimation of the MTP hydroperiod, has been developed. Finally, the predominant processes in the nitrogen and phosphorous cycles were studied in the laboratory**.** Batch experiments were conducted, using as master variables soil moisture and pH, to evaluate the capacity of the sediment for mineralization, leaching and adsorption of nutrients.

2. SITE DESCRIPTION

The MTP at Omalos-Samaria plateau is situated near the southwest margin of the Omalos Plain, in the prefecture of Chania, Crete, Greece. It is about 2.5 km from the settlement of Omalos. The altitude is 1060 m above sea-level. The coordinates are N35°1’35’’, E23°53’25’’. The Omalos pond has an almost circular shape and an area of about 1600 m^2. The catchment area is about 3000 m^2. The area is part of the Natura 2000 site “Lefka Ori” (code GR4340008). The main pressure in the area of the pond is livestock breeding (~10,000 sheep in the region – Figure 1).

Figure 1. Views of the Mediterranean temporary pond at Omalos-Samaria plateau.

3. METHODOLOGY

Pond sediments were collected from the central and the outer circle of the MTP area and were characterized for typical physico-chemical parameters. The following parameters were analyzed: particle size distribution, pH, soil moisture, porosity and dry bulk density, mineralogical and chemical composition (XRD, XRF). The soil pH was measured using an Orion, 9107 pH meter. When the soil sample was extremely fine Laser Diffraction Size Analysis was conducted.

Observations of lake's stage and ground water level were taken on monthly basis. Infiltration experiments were conducted to determine the infiltration rate. Regular infiltrometers were used to estimate the rate of infiltration of the sediment. The infiltrometers consist of a 50 cm cylinder that is inserted into the sediment. The cylinder is filled with water and the time it takes for the water to drain into the sediment was measured. Horton's equation $f = f_c + (f_{co} - f_c) * e^{(-kt)}$, was used to model the infiltration rate, where f_{co} and f_c are the initial and final infiltration rates and k is an empirical constant,. Water deficit was estimated, by the abstraction of evaporation from precipitation. A conceptual site model and a mathematical model, for the estimation of the MTP's hydroperiod were developed.

Batch leaching experiments, under 20 ^{0}C and three different pH values 6, 7 and 8, were conducted to evaluate the potential of sediments to release inorganic-N species and DIP. The experiment was carried out in 100 ml flasks using 5-gr sediment and 100 ml 0.1 M $NaNO_3$ (for DIP) or 0.01 M KCl (for inorganic-N species). The samples were placed on a shaking table for 4 days. After the end of the experiment the flasks were left in order to settle the sediment and the supernatants were collected. The leachate was filtered through a 0.45 μm Nylon filter and analyzed using a Hack 2010 spectrophotometer for DIP (PhosVer3 Method, 8048), NO_3-N (Cadmium Reduction Method, 8039), NO_2-N (Diazotization Method, 8507) and NH_4-N (Salicylicate Method, 10023). Ammonium-nitrogen production under waterlogged conditions was used for the short-term mineralization capacity test [17]. Slight modifications were made to account for the varying soil moisture conditions (oversaturated sample and saturated 40%) [18]. The amount of ammonium present before incubation was determined on separate triplicate samples and the mineralizable N was calculated as the difference between incubated and non-incubated samples. Adsorption experiments were carried out in order to study the sorption of phosphate in Omalos pond sediment. Adsorption isotherm at 20 ^{0}C and pH 7 was conducted by filling the 100 ml flasks with 5-gr sediment and 100 ml 0.1 M $NaNO_3$ solution with concentrations of phosphate 0.1, 0.3, 0.6, 0.8, 1, 3, 5 mg/l PO_4-P. Moreover, phosphate sorption experiments under three different pH values 6, 7 and 8, also in 20 ^{0}C were carried out by filling 100 ml flasks with 5-gr sediment and 100 ml 0.1 M $NaNO_3$ with concentration of phosphate 1 mg/l PO_4-P. The samples were placed on a shaking table for 4 days. After the end of the experiment the supernatants were analyzed for PO_4-P.

4. RESULTS

4.1 Soil characterization

The soil characterization conducted for the central radius less than 20m from the center and the outer radius geater than 20m from the center- circles of the sediment. The upper soil layer was estimated to be acidic (5.83), but below 50 cm depth is calcareous and basic. The humus (6.45 %) [measurements by MAICH] content is high in the uppermost soil layer. The dry bulk density was 0.98 g/mL and the porosity 41 %. From the grain size analysis in the < 2 mm fraction and the USDA Soil Textural Triangle, the sediment of the central circle is characterized as sandy loam and of the outer circle as silt loam. The major element of the sediment is Si (86.41 % SiO_2 - quartz

~100 %). These sediments originate from the erosion of calcareous-schists (mountain above the pond).

TABLE 1. Physicochemical properties of the sediment.

Soil properties		**Value**	
		core area *(radius < 20 m)*	***outer area*** *(radius > 20m)*
Soil moisture (%)		12.4	3.8
Porosity (%)		40	42
Dry bulk density (%)		93.2	103.6
pH		5.83	
Particle size distribution (< 2 mm) (%)			
Sand		51	32
Silt		46	64
Clay		3	4
	d10 (μm)	9,59	6,01
	d50 (μm)	70	37.1
	Uniformity coefficient	89	8.79

Metal concentration (XRF)

Major (%)	**Value**	**Trace (ppm)**	**Value**
Na_2O	0.00	V	69.7
MgO	0.82	Cr	37.5
K_2O	1.15	Mn	464.4
CaO	0.25	Co	10.4
TiO_2	0.31	Ni	32.8
MgO	0.04	Cu	37.2
Fe_2O_3	2.42	Zn	79.5
Al_2O_3	6.52	As	8.5
SiO_2	86.41	Br	12.5
P_2O_5	1.34	Rb	52.7
		Sr	26.9
		Zr	93.7
Trace (%)	**Value**	Mo	2.8
S	0.071	Ba	261.0
Cl	0.013	Pb	34.4

4.2 Hydrologic Processes

Figure 2 represents precipitation and evaporation in Omalos plateau region (Rainfall data from Ksiloskalo rainfall station-Ministry of Rural Development and Food), on a monthly basis for the year 2000. The evaporation was calculated using Hamon's equation. The results indicate that water deficiency period lasts from May to September. However, the cumulative diagram shows that there is no deficiency on annual basis because of evaporation. The monthly measurements of lake's stage and ground water level (Figure 3) indicate that there is no significant interaction between surface and ground water even during winter, when ground water level is 16 m under the surface of ground. Due to small catchment area ($3000m^2$) and the topography of the region, the overland flow is considered rather small. Two infiltration tests were conducted at the pond's area in order to estimate the infiltration capacity of the sediment. The first one conducted in the area of the outer circle. The results of the experiment are presented in the diagram below (figure 4). The second one conducted in the area of the central circle and infiltration rate was negligible (duration of the test 4.5 h).

Initially, the infiltration rate in the outer circle was rather high and when the sediment acquired steady state regarding moisture the rate was constant at 0.014 cm/min. The constant k was estimated 0,597 and RMSE was very small. Horton's infiltration model for the sediment is $f = 0.014 + (2.305 - 0.014) * e^{(-0.597t)}$. Although the porosity of the sediment is rather high 40 % (Table 1), as the sediment is very fine with high percentages of medium and coarse silt and is characterized as clay sandy silt, the particles of the sediment tend to stick to one another and the permeability is restricted. Moreover, soil compaction, caused by livestock breeding on the site results in a loss of soil structure and aggregate stability, and therefore reduction in soil porosity. Compaction reduces the movement of water, air, nutrients and soil microbes through the soil. Finally, the sediment's high percentage of organic matter 6 % has as a result the enhancement of the sediment's capacity to hold water. So, the small infiltration capacity of the sediment leads to the overland storage of water even after small events of precipitation. Consequently, rainfall and evaporation are the main hydrologic processes. The conceptual model of hydrologic cycle in Omalos pond is represented at Figure 5, where P is Precipitation, ETa aquatic evapotranspiration, ETs terrestrial evapotranspiration, Ia aquatic infiltration and It terrestrial infiltration. A mathematical model for the simulation of pond hydroperiod has been developed. Balance for terrestrial soil is $dV_{ts} / dt = P - ET_{ts} - O$, for pond water $dV / dt = P + O - ET_a - I_a$ and for aquatic soil $dV_{as} / dt = I_a - ET_{as}$.

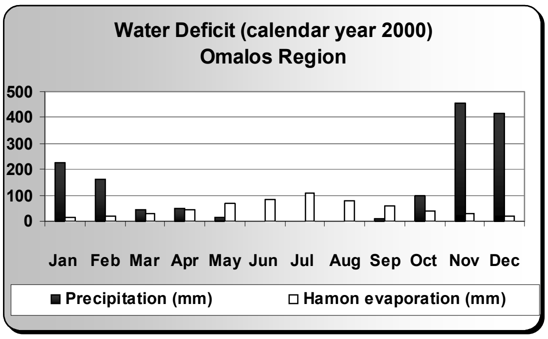

Figure 2. Monthly precipitation and evaporation in Omalos plateau region.

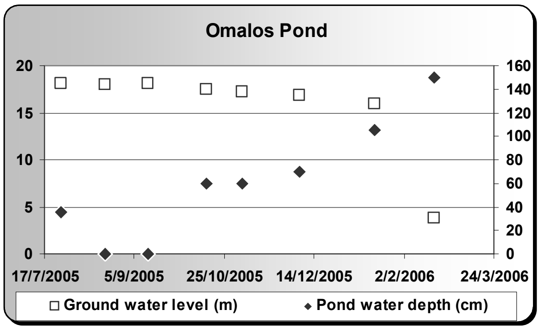

Figure 3. Pond water stage and ground water level in monthly observations.

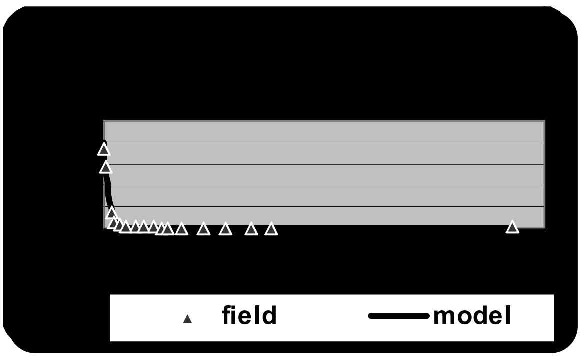

Figure 4. Modeling of infiltration rate at Omalos pond sediment.

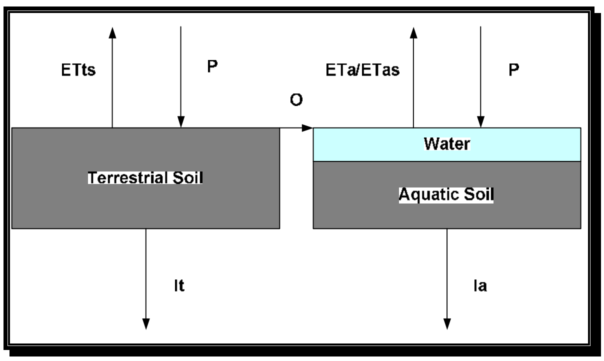

Figure 5. Conceptual model of the hydrologic cycle at Omalos pond.

4.3 Geochemical Processes

The inorganic nutrient concentrations estimated through the experiments of leaching and mineralization capacity, as well as adsorption at different pHs for Omalos pond sediment are presented in Figures 6(a) - 6(d) and TABLE 2.

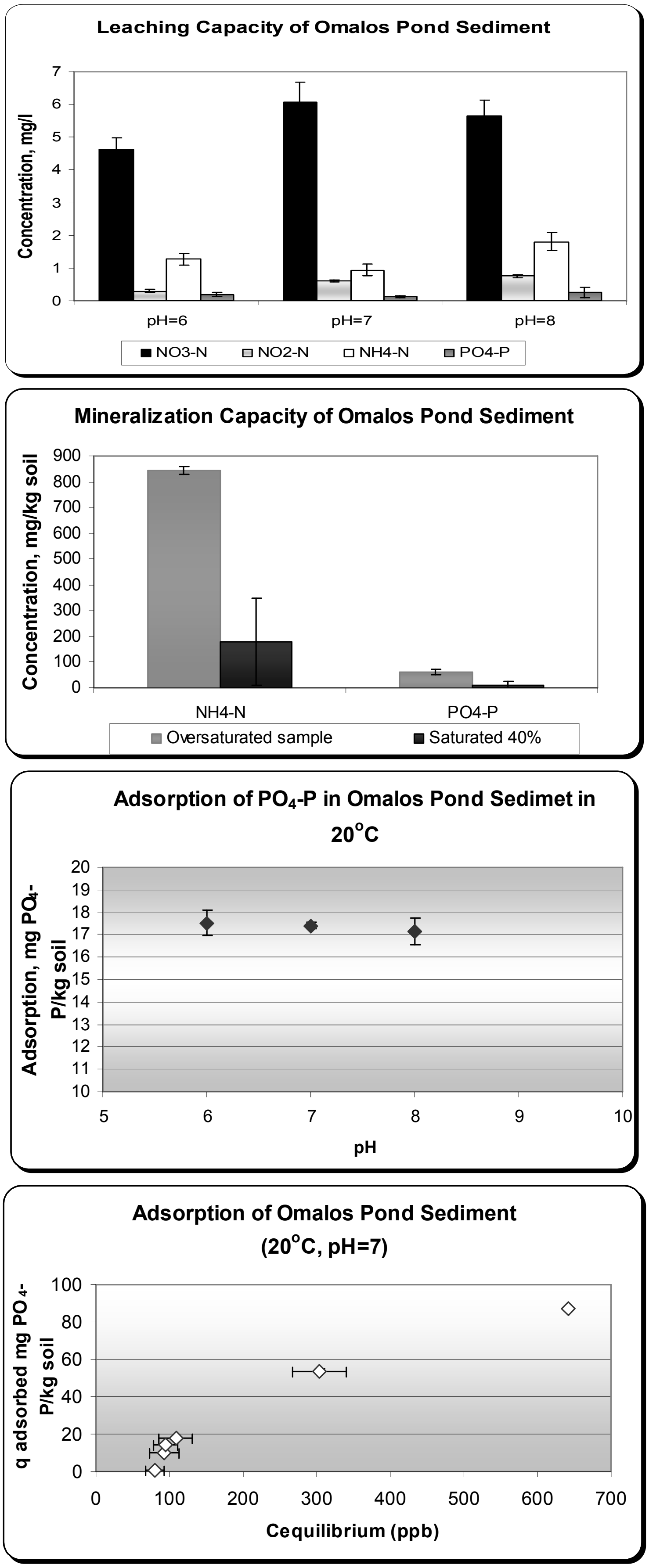

Figure 6. Leaching and mineralization capacity as well as adsorption at different pHs for Omalos pond sediment.

The capacity of Omalos pond sediment to leach out nitrogen and phosphorous species was larger than the dissolved concentrations of these species in the pond's water indicating the propensity of the sediment to enhance the chemical composition of pond water that recharges the groundwater. Figure 6a presents the equilibrium leaching concentrations of the sediment as a function of pH. The leaching concentrations of the sediment was 11 times higher for ammonia and 5 times for nitrite than the respective dissolved nutrient concentration in the pond (0.12 ppm NH_4-N, 0.15 ppm NO_2-N measurements by MAICH) and at the same levels for nitrate (< 10 ppm NO_3-N-measurements by MAICH). The total dissolved inorganic nitrogen leaching out of the sediment is increasing with pH (TABLE 2).

TABLE 2. The leachate concentrations at Omalos pond sediment in ppm.

	pH=6	std	pH=7	std	pH=8	std
NO_3-N	4.624	0.344	6.072	0.609	5.644	0.494
NO_2-N	0.300	0.052	0.606	0.036	0.767	0.052
NH_4-N	1.279	0.181	0.935	0.179	1.814	0.267
PO_4-P	0.183	0.071	0.138	0.030	0.268	0.158

Mineralization studies were conducted in order to estimate the variability of the mineralization capacity under different soil moisture conditions. The aim was to estimate mineralization capacities corresponding to the wetting and drying phases of the sediments in the field. Sediment of Omalos pond appeared to have higher mineralization capacity for nitrogen (11-857 mg NH_4-N/kg soil) in comparison with phosphorous (0-72 mg PO_4-P/kg soil). In general the mineralization capacity is strongly sensitive concerning the soil moisture of the sediments. Highest mineralization capacity was observed in the oversaturated samples (Figure 6b). The sorption experiment at different pHs (Figure 6c) revealed that the sediment has a large capacity to adsorb phosphorous, that is not affected significantly by pH. The results of the sorption isotherm at 20 ^{0}C indicated that at low P concentrations, the isotherm was linear (Figure 6d). However, there was not any net sorption of phosphorous by the sediment at the concentration of 0.1 mg/L PO_4-P (equilibrium P concentration). This value is consistent with value (EPC_0 = 0.08 mg/L PO_4-P) obtained from the empirical equation EPC_0 = 0.0000577*(Clay + Silt) + 0.0763 [19], where (Clay + Silt) is the fraction of clay and silt for sediment (58.5 %). Furthermore, the isotherm indicated surface precipitation at high P concentrations. In general, the sediment have a large capacity to adsorb phosphorous, however, the levels of phosphorous in the aqueous phase are below the EPC_0 level which makes the process inactive.

5. CONCLUSIONS

The Omalos pond presents a simple hydrology; rainfall and evaporation are the main hydrologic processes. Pond's hydroperiod is extensive (from Nov. to Aug.) and steady. The monthly observations of pond's stage will be used to calibrate a mathematical model that has been developed for the simulation of pond hydroperiod. The capacity of sediment for mineralization was influenced by soil moisture, exhibiting significant capacity even at moisture levels of 40 %. The sediment enhances the chemical composition of pond water that recharges the groundwater and finally the springs of the region. Finally, the sediment has a large capacity to adsorb phosphorous, however, the low levels of phosphorous in the aqueous phase makes the process inactive.

ACKNOWLEDGEMENTS

This study was financially supported by the E.U. LIFE-Nature project LIFE04NAT/GR/000105: 'Actions for the conservation of Mediterranean Temporary Ponds in Crete'.

6. REFERENCES

1. Beja P, Alcazar R (2003) 'Conservation of Mediterranean temporary ponds under agricultural intensification: an evaluation using amphibians'. Pages **Biological Conservation** 114 3: 317-326.
2. Boix D, Sala J, Quintana XD, Moreno-Amich R (2004). Succession of animal community in a Mediterranean temporary pond. **North American Benthological Society** 23 1: 29-49.
3. Boix D, Sala J, Moreno-Amich R. 2001. The faunal composition of Espolla Pond (NE Iberian Peninsula): the neglected biodiversity of temporary waters. **Wetlands** 21 4: 577-592.
4. European Commission DG Environment (2003) Interpretation manual of European Union habitats- directive. Natura 2000, Nature and biodiversity EUR 25: 32-3.
5. Fahd K, Serrano L, Toja J (2000) Crustacean and rotifer composition of temporary ponds in theDoñana National Park (SW Spain) during floods. **Hydrobiologia** 436 (1-3): 41-49.
6. Grillas P, Gauthier P, Yavercovski N, Perennou C (2004b) Mediterranean Temporary Pools, 2 - Species information sheets. Station biologique de Tour du Valat.
7. Jakob C, Poizat G, Veith M, Seitz A, Crivelli AJ (2003) Breeding phenology and larval distribution of amphibians in a Mediterranean pond network with unpredictable hydrology. **Hydrobiologia** 499: 51-61.
8. Lahr J. (1997) Ecotoxicology of organisms adapted to life in temporary freshwater ponds in arid and semi-arid regions. **Archives Of Environmental Contamination And Toxicology** 32 1: 50-57.
9. Rhazi M, Grillas P, Charpentier A, Médail F (2004) Experimental management of Mediterranean temporary pools for conservation of the rare quillwort "Isoetes setacea". **Biological Conservation** 118 5: 675-684.
10. Rhazi M, Grillas P, Tan Ham L, Khyari El D (2001) The seed bank and the between years dynamics of the vegetation of a Mediterranean temporary pool (NW Morocco). **Ecologia mediterranea** 27 1: 69-88.
11. Rhazi M, Grillas P, Mounirou Toure A, Tan Ham L (2001b) Impact of land use in catchment and human activities on water, sediment and vegetation of Mediterranean temporary pools. **Life Sciences** 324: 165-177.
12. Blaustein L, Schwartz S.S (2001) Why study ecology in temporary pools? **Journal of Zoology** 47 4: 303-312.
13. Collinson NH, Biggs J, Corfield A, Hodson MJ, Walker D, Whitfield M, Williams PJ (1995) Temporary and permanent ponds: an assessment of the effects of drying out on the conservation value of aquatic macroinvertebrate communities. **Biological Conservation** 74: 125–133.
14. Madhyastha MN, Shashikumar KC, Rekha PD (2000) Temporary ponds – a neglected ecosystem. Section 6 Limnology, **Watershed Hydrology and Monitoring 6**.
15. Warwick NWM, Brock MA (2003) Plant reproduction in temporary wetlands: the effects of seasonal timing, depth, and duration of flooding. **Aquatic Botany** 77: 153–167.
16. Williams DD (1997) Temporary ponds and their invertebrate communities. Aquatic conservation: **Marine and freshwater ecosystems** 7: 105-117.
17. Bundy L.G. and Meisinger J.J. (1994). "**Nitrogen Availability Indices, in Methods of Soil Analysis: Part 2-Microbiological and Biochemical Properties**." Chapter 41, in the Soil Science Society of America Book Series, Soil Science Society America, Number 5, Madison, Wisconsin, USA.R.W., Weaver, Scott Angle, Peter Bottomley, David Bezdicek, Scott Smith, Ali Tabatabai, and Art Wollum (ed.)
18. Tzoraki O., Nikolaidis N., Skoulikidis N (2005) "Evaluation of In-Stream Processes of Four Temporary Rivers" Abstracts of the Contributions of the **EGU General Assembly Vienna**, Austria, 24-29 April 2005.
19. Smith, D.R.; Haggard, B.E.; Warnemuende E.A.; Huang C., (2005) Sediment phosphorus dynamics for three tile fed drainage ditches in Northeast Indiana. **Agricultural Water Management, 2005**, 71, 19-32.