# FIRST YEAR ACHIEVEMENTS OF GABARDINE PROJECT IN PORTUGAL

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## ABSTRACT

This paper describes the first year achievements of Gabardine project in Portugal. The major objectives of GABARDINE "Groundwater Artificial Recharge Based On Alternative Sources Of Water: Advanced Integrated Technologies And Management" project are: (1) explore the viability of supplementing existing water resources in semi-arid areas with alternative sources of water that could be exploited in the context of an integrated water resources management approach, (2) investigate the feasibility of using aquifers as the primal facility for the large scale storage of these alternative water sources and investigate techniques for their artificial recharge (AR) and injection of the produced alternative water, including a monitoring of water quality and purification by natural attenuation and filtration processes, (3) evaluate and quantify the potential impact of degrading factors, such as climate change, changes in the quality of water, salt water etc. on the global quality and usability of the resource, by developing tools for risk mapping, for modelling and for monitoring, and to propose measures for preventing or minimizing, and mitigating their impact. The alternative water sources are surface water surpluses generated during rainy seasons, treated effluent, surpluses of desalinated water, that are expected in periods of low water demand or high water availability (from natural resources) and exploitation of saline water bodies that could be used for adequate agricultural practices or used as raw material for low-cost desalination..

Key-words: Artificial groundwater recharge, infiltration test sites, alternative sources of water, Campina de Faro

## 1. INTRODUCTION

Laboratório Nacional de Engenharia Civil, Departamento de Hidráulica e Ambiente, Núcleo de Águas Subterrâneas, is Partner 3 of Gabardine Project sponsored by the 6th Framework Programme for Research Technological Development and Demonstration, being a Specific Targeted Research Project under Contract Number 518118. In Gabardine, LNEC team (Portugal) is formed by Dr. J.P. Lobo-Ferreira, MSc. Catarina Diamantino, Dr. Manuel Oliveira, Dr. Teresa Leitão, MSc. Maria João Moinante, Mrs. Maria José Henriques (DHA/LNEC), MSc. Albino Medeiros (in cooperation with LNEC on Gabardine test site assessment), MSc. Nuno Charneca (DHA/LNEC), MSc. Rogério Mota and Dr. Marília Oliveira (DG/LNEC).

LNEC tasks included coordination towards a coherent gathering of all data relevant for the characterization of four Gabardine test sites. The data was collected, compiled and organized into computerized database layers and integrated into GIS systems (for each test site). In all sites severe water supply problems exist, due to over-exploitation, and therefore, Artificial Recharge (AR) may prove to be a viable solution. Four test sites have been selected, each representing a different aspect of the problem: (1) the aquifer of Thessaloniki area, in which AR is being considered for controlling seawater intrusion and storage of treated effluent (Greece); (2) the Lower valley of the Llobregat river, where the objective is to mitigate the aquifer from seawater intrusion by means of AR of effluent and or runoff water (Barcelona-Spain); (3) the Campina de Faro aquifer, in Algarve region where the objective is achieving groundwater quality improvement by injecting surface-water (Portugal); (4) the Coastal aquifer

shared by Israel and Palestine (Gaza). In Israel most of the recharge technologies are implemented but the quality and mixing aspects need to be investigated and quantified.

In Portugal small-infiltration ponds have been built in two test sites. One of the aims of the AR in this test site will be the rehabilitation of groundwater polluted by the excess of fertilizers in Campina de Faro agricultural area by using surplus flash flood water with better quality. The following tasks are being developed: (1) Selection of the AR technique and full design of the project; (2) Monitoring the aquifer system in terms of piezometric level distribution and groundwater composition, performed before and after the AR of the aquifer; (3) Modelling tools for simulation groundwater flow and solute transport before and after the AR system is performed.

## 2. TEST SITE QUESTIONNAIRE PREPARATION AND PORTUGUESE CASE-STUDY QUESTIONNAIRE FILLING-IN

A Test Site Questionnaire was prepared during the first year of the project. Gabardine case-study areas parameters and specificities have been addressed and filled-in by the case-study leader institutions (*cf.* Lobo-Ferreira et al., 2006a). The team included Lobo Ferreira, Diamantino, Moinante, Oliveira, Leitão, Henriques, Medeiros (LNEC, Portugal), Dimitriadis and Styllas (Geoservice, Greece), Soupilas, (EYATH, Greece), Maheras, Anagnostopoulou, Tolika, Vafiadis, Machairas, (Aristotle University Thessalonica, Greece), Sanchez-Vila and Barbieri (Universitat Politecnica de Catalunya), Bensabat (EWRE, Israel), Hadad (HIS, Israel), and Rabi and Tamimi (Palestinian Hydrology Group). The Portuguese case-study questionnaire was prepared by LNEC, regarding the aquifer of Campina de Faro (Fig. 1).

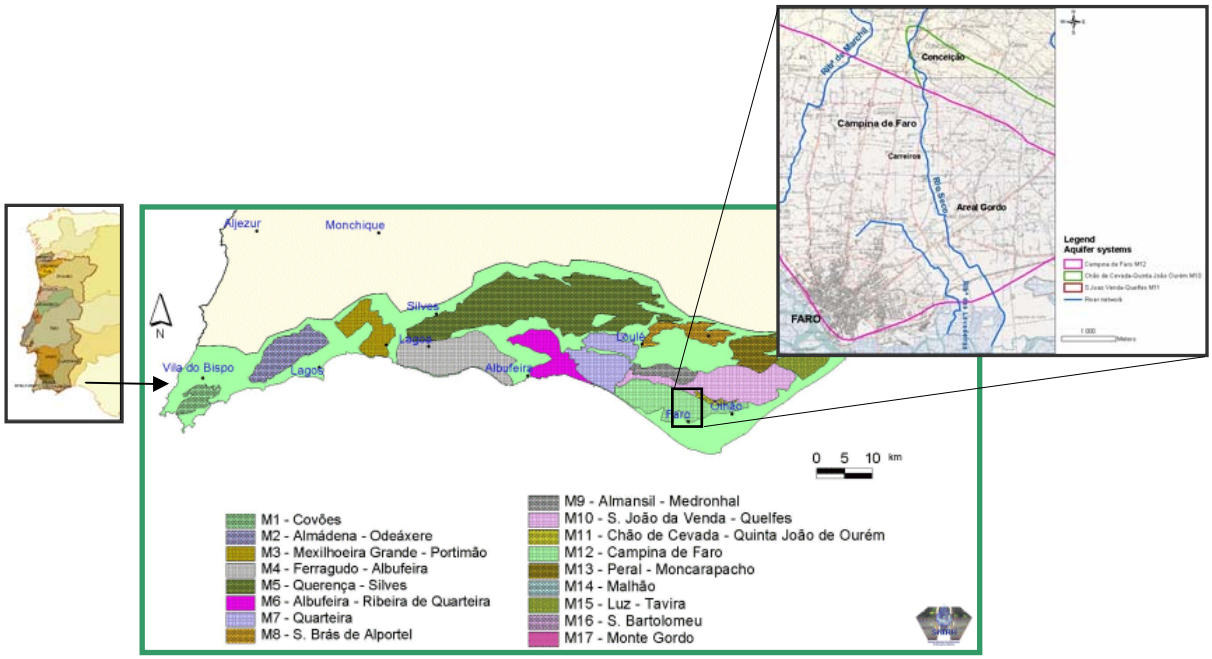



Fig. 1 – Location of the Campina de Faro case-study aquifer (M12) area in South Portugal and the test site area

## 3. GEOPHYSICAL ASSESSMENT OF THE CAMPINA DE FARO CASE STUDY AREA IN PORTUGAL

This task has been developed by MSc. Albino Medeiros (in cooperation with LNEC on Gabardine test site assessment), MSc. Rogério Mota and Dr. Marília Oliveira (DG/LNEC).

The test sites in Portugal are located in a section of the Aquifer System of ***Campina de Faro***, located in the Southern Algarve region (Fig. 1). This section is located in the central part of Campina de Faro and encompasses an area of approximately 9 km$^2$. The total area of this aquifer system is 86.4 km$^2$.

This section of the aquifer is bordered by the Atlantic Ocean in the south, two aquifer systems in the North (M10 and M11 – Fig. 1), the river "Ribeira de Marchil" in the west, and 2 km to east from the river Rio Seco. In this region it is well known that agricultural practices have a large impact on groundwater chemical composition. This aquifer needs groundwater rehabilitation, and AR is envisaged to reach this goal.

Additional geophysical and other hydrogeological data has been obtained during the 1$^{st}$ year towards complementing the assessment required for a sound aquifer mathematical modelling at three different scales, *i.e.* the regional aquifer scale (Fig. 2), the local/intermediate scale (Fig. 3) and the test site scale (Fig. 4).

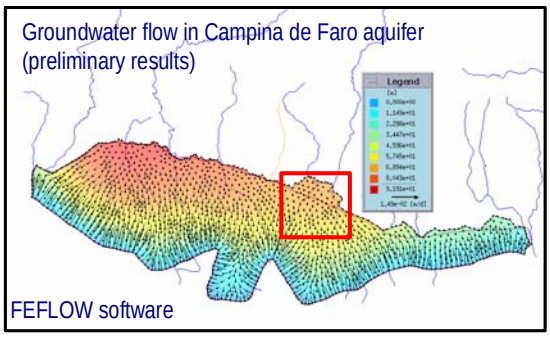



Fig. 2 - Campina de Faro aquifer scale

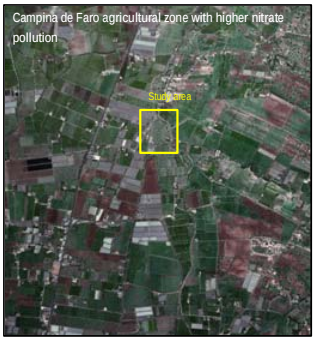



Fig. 3 - Aerial view of the local scale study area


Fig. 4 - Test site scale (Conceição)

Four different geophysical methods have been applied to the Campina de Faro study-area, namely:

- Ground Penetration Radar (GPR) (Fig. 5)

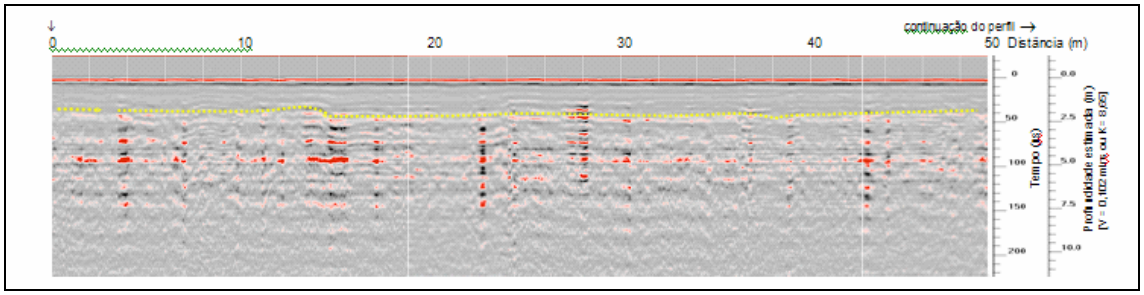



Fig. 5 - Example of Ground Penetration Radar results (Profile P3) performed in Conceição test site

- Electrical Resistivity method (Fig. 6)

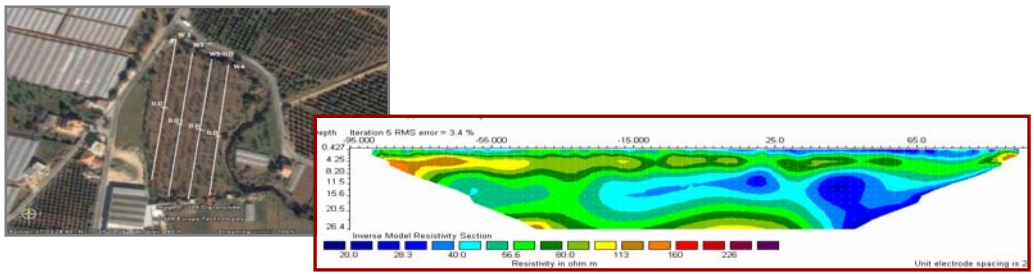


Fig. 6 - Location of the profiles and one of electrical resistivity profile results (Conceição test site)

- Electromagnetic methods (Equipment used: EM31 and EM34 from Geonics) (Fig. 7)

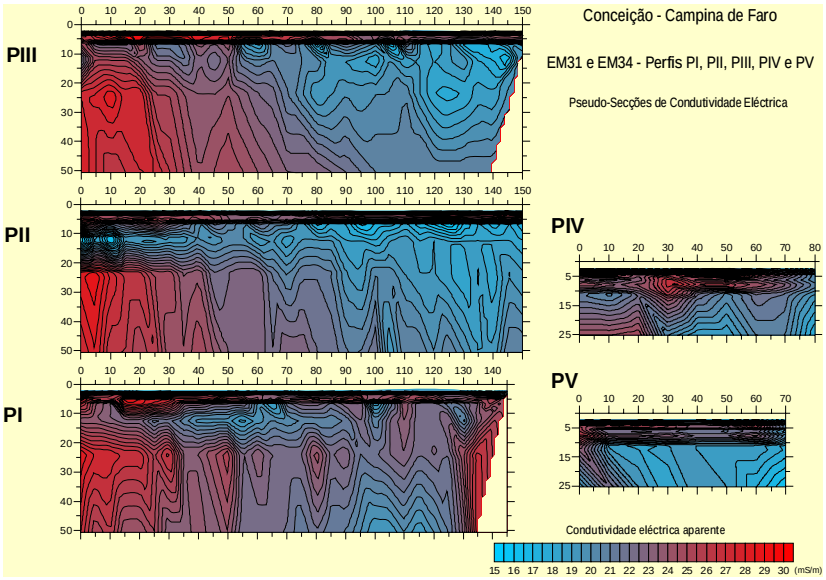



Fig. 7 – Results obtained with the electromagnetic methods in 5 profiles performed in Conceição test site

- Vertical Electrical Sounding (VES) – the location of the 7 VES performed in Campina de Faro case study area is presented in Fig. 8 and also the available software for results interpretation showing the layers distribution in VES number 2.

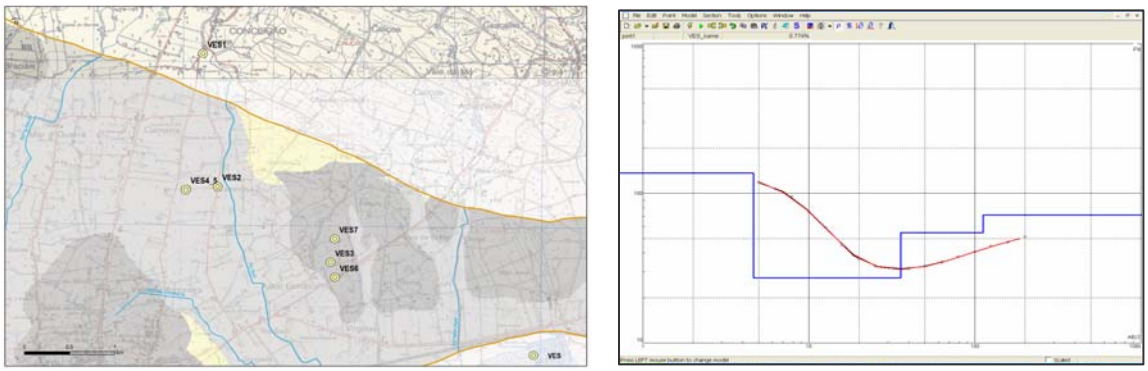


Fig. 8 - Location of Vertical Electrical Soundings (VES) performed in Campina de Faro and interpretation of the results obtained

The objective of using different geophysical methods is the need of testing the applicability of each one for the geological and hydrogeological characterization of the study area and to define also its applicability for monitoring the AR experiments (*i.e.* water content evolution in time and in space in the unsaturated and saturated zones). This comparison would allow defining the type of equipment more appropriated for our objectives.

## 4. MATHEMATICAL MODELLING

This task has been developed by MSc. Catarina Diamantino, MSc. João Moinante and Dr. Manuel Oliveira (LNEC). In Fig. 9 a first approach towards a finite element mathematical modelling of the regional case-study area is presented, *i.e.* FEFLOW mathematical groundwater flow model grid, layers and piezometric levels results. This is a first attempt to model the main paths of the flow in the aquifer for a further incorporation of the artificial water injection in the aquifer.

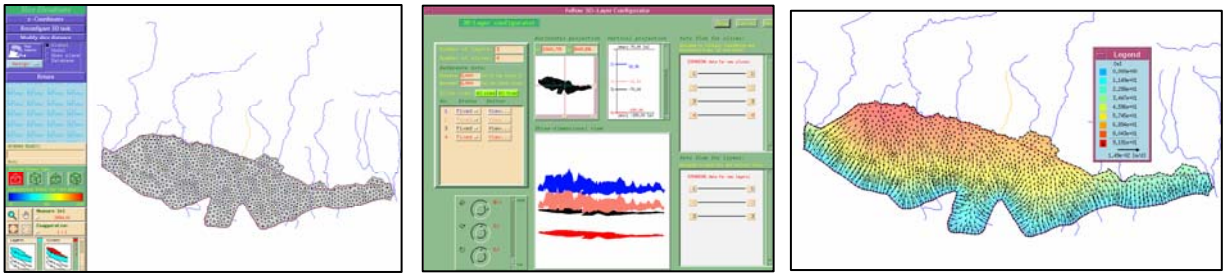


Fig. 9 – FEFLOW first results of Campina de Faro groundwater flow model

Latter, an approach towards a finite difference element mathematical modelling of the regional and local scale was performed using Visual MODFLOW. Fig. 10 shows a few results obtained for the groundwater flow in the study area.

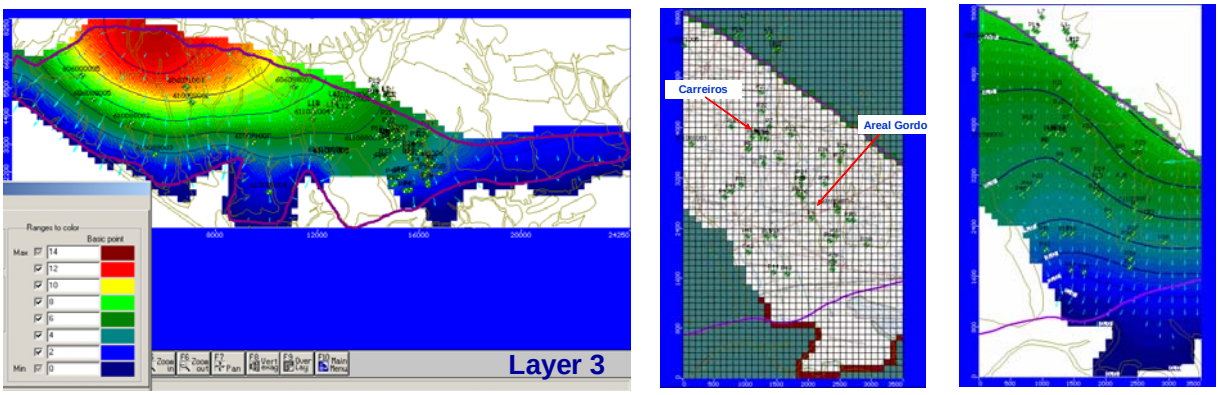



Fig. 10 - Visual MODFLOW first results of Campina de Faro groundwater flow model

## 5. SELECTION OF AREAS FOR ARTIFICIAL RECHARGE EXPERIMENTS DEVELOPMENT

A selection of potentially appropriate areas was performed for the development of the AR experiments in Campina de Faro region. The first area selected was at Conceição but geological and geophysical assessments revealed important lithologic constrains. The two other areas, named Carreiros and Areal Gordo were selected for the development of the AR

experiments using different AR technologies and water sources. The location of these 3 areas is presented in Fig. 11. Fig. 12 shows the aerial photo with the location of Carreiros Test Site where 3 piezometers for quality and quantity monitoring and 2 AR structures were constructed (during September/October, 2006) in the Rio Seco river bed, with 20 metres length and 7 meters depth, each one filled with clean gravels. The source of water for AR should be surface water from the river during floods. Fig. 13 shows also the location of the Areal Gordo Test Site and a vertical profile with the different lithologic formations in this area. The planned AR experiments for this area include the construction of 3 infiltration basins, with depths accordingly with 3 different local sandy layers depth; the water for AR will be extracted from the underneath confined aquifer. In Areal Gordo 2 piezometers have been drilled for quality and quantity monitoring during October and November, 2006.

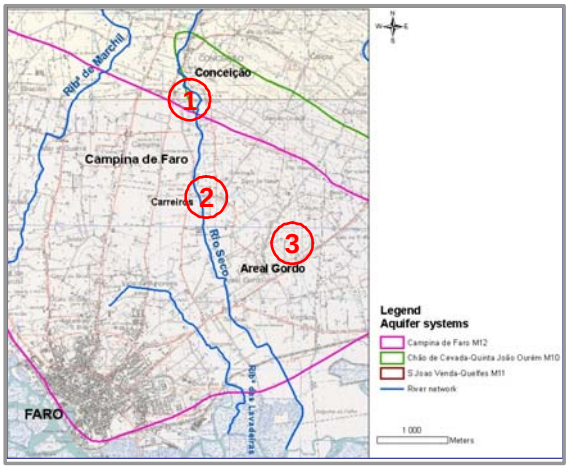



Fig. 11 - Location of the areas for the development of the artificial recharge water experiments in Campina de Faro.

## 6. QUALITY AND QUANTITY MONITORING CAMPAIGNS (SEPTEMBER/2006)

This task has been developed by Dr. Teresa Leitão, MSc. Catarina Diamantino, MSc. João Moinante and Mrs. Maria José Henriques (LNEC). For the groundwater quantity and quality analysis, an inventory of the existing information was performed and a database was built to store this information. The data available include several sources of information and correspond to around 300 points, with quality data from 625 analyses, ranging from 1961 to 2006.

Complementary information on other locations, and also the existing ones, was done in the field campaigns performed in September, 2006 in the test site areas. The results were interpolated by the kriging method in ARCVIEW (cf. Fig. 14 for piezometric assessment). Available nitrates concentration in the aquifer system of Campina de Faro (1994 – 2004) is shown in Fig. 15.

## 7. PRECIPITATION, AQUIFER REPLENISHMENT AND WATER BUDGET

Groundwater recharge estimation and mapping using the daily sequential water balance model BALSEQ has been computed for the hydrologic years from Oct/1995 until Sept/1999, in the first chosen area (Conceição). These results are included in the Questionnaire for Portuguese case study area.

A new estimation of natural groundwater recharge was carried out for the whole Campina de Faro aquifer system using a sequential daily water balance model. The model was run for a 10 year-series from Oct/1981 until Sept/1991. Average natural recharge obtained values are presented in Fig. 16.

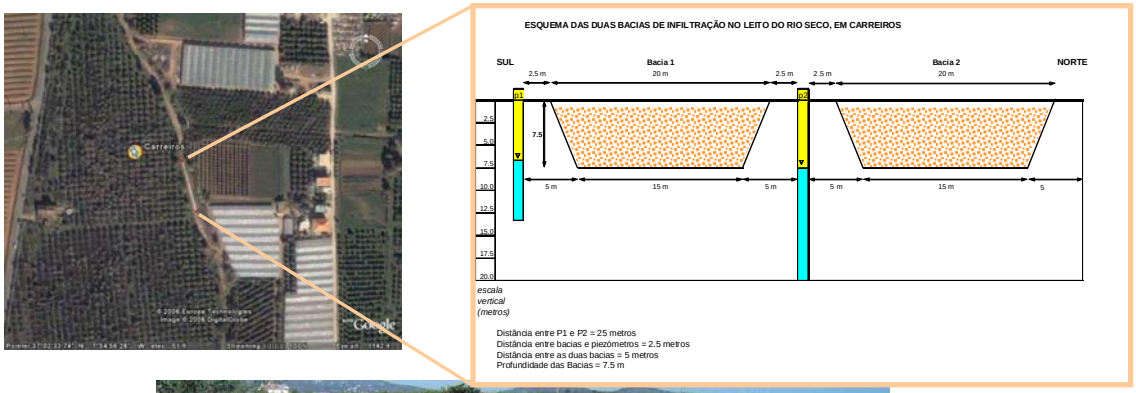



Fig. 12 - Carreiros test site and artificial recharge project.


Fig. 13 - Areal Gordo test site and sandy layers vertical profile.

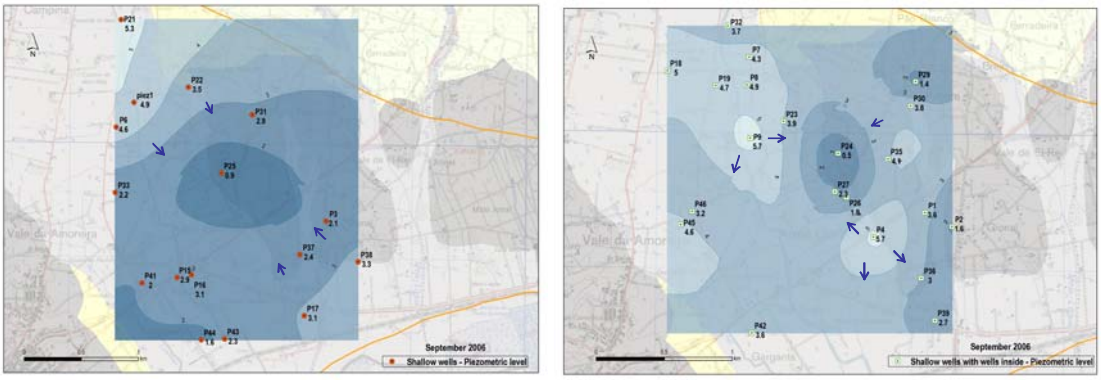



Fig. 14 - Piezometric levels in the phreatic and confined aquifers in Campina de Faro (September, 2006 quantity campaign).

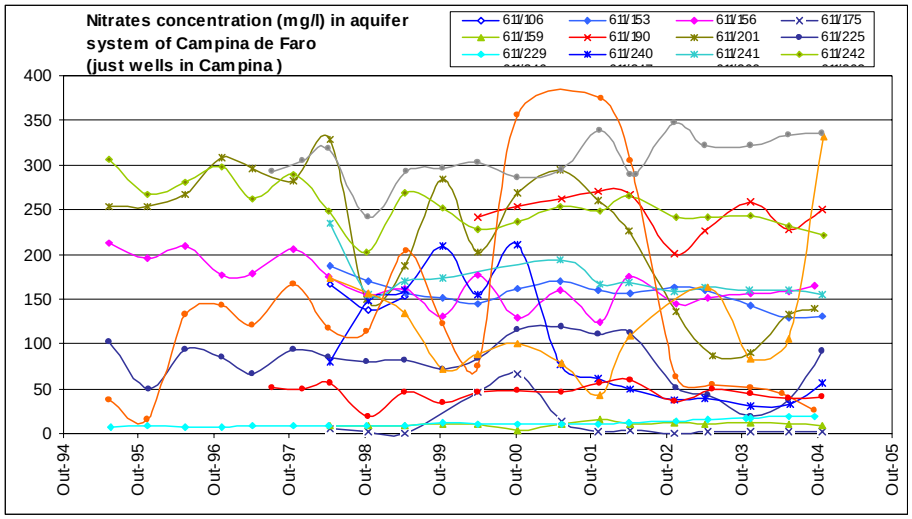



Fig. 15 - Nitrates concentration in the aquifer system of Campina de Faro (1994 – 2004)

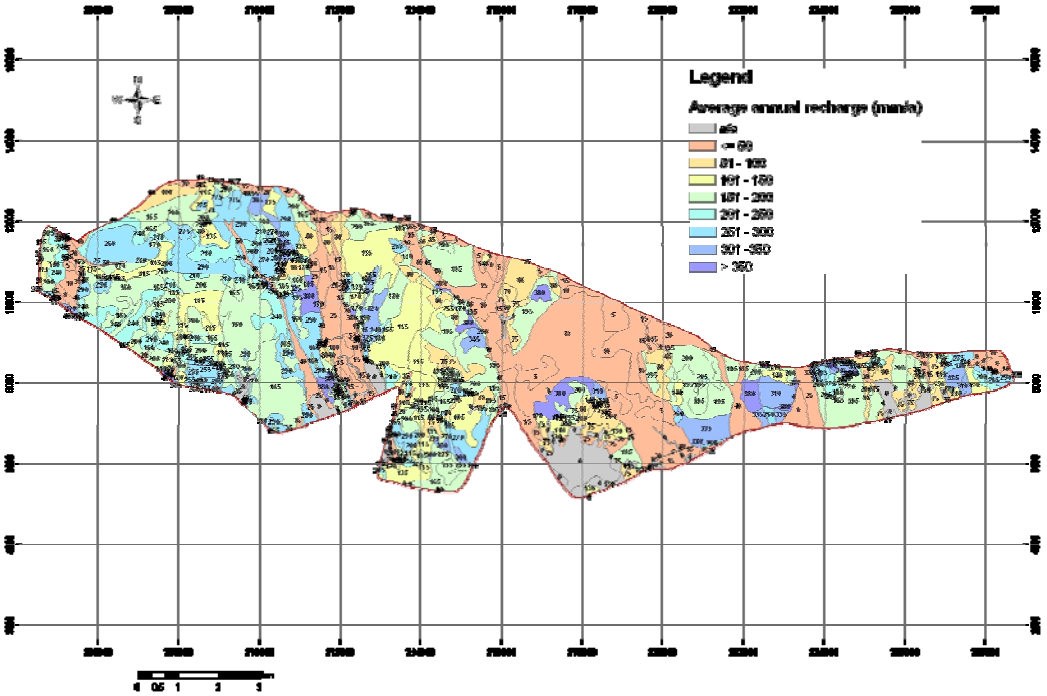
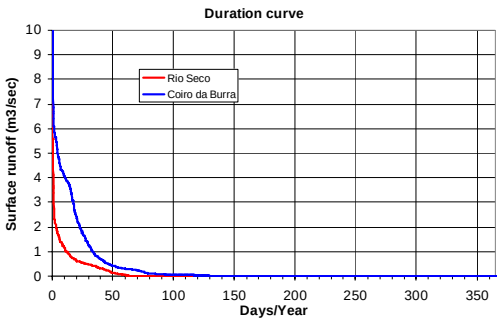



Fig. 16 - Average annual natural groundwater recharge estimated for the Campina de Faro aquifer system.

## 8. ALTERNATIVE WATER SOURCES AND ARTIFICIAL RECHARGE

(Lobo-Ferreira *et al.,* 2006b) identified potential alternative sources of water for each test site. Preliminary calculations of the Water Budget in Campina de Faro Test site have been made by Dr. Manuel Oliveira. Surface runoff (average, median maximum, minimum and maximum characteristic - exceeded 10 days/yr, exceeded 1 month/yr and exceeded 3 month/yr) and annual volume runoff were determined in Rio Seco using the available daily data in two stream flow stations upstream and downstream of the study area of Carreiros (Coiro da Burra and Rio Seco) – Fig. 17. The infiltration surface water losses in Rio Seco were calculated using the previous data between the two stream stations. These values were also compared with literature values determined also for the same section of Rio Seco. These water budget preliminary results were presented during the WP3 discussion section occurred in the Third Meting of the Project Gabardine, held in LNEC, from November 6-10, 2006.




| Surface runoff (m3/s) | Coiro da Burra | Rio Seco |
|---|---|---|
| Maximum | 20.42 | 57.08 |
| Maximum characteristic (overpassed 10 days/yr) | 4.07 | 1.17 |
| Median | 0.00 | 0.00 |
| Exceeded 1 month/yr | 1.26 | 0.46 |
| Exceeded 3 month/yr | 0.08 | 0.00 |
| Minimum | 0.00 | 0.00 |
| Average | 0.36 | 0.14 |

Fig. 17 - Streamflow characteristics in two stream flow gauge stations in Rio Seco River.

## 9. OPERATIONAL TOOLS

A rating methodology for the definition of areas of maximum infiltration for a preliminary identification of candidate areas for artificial recharge (IFI) was preliminary calculated for the aquifer system of Campina de Faro. This task has been developed by Dr. Manuel Oliveira. This rating methodology was presented during the WP4 discussion section occurred in the Third Meeting of the Project Gabardine, held in LNEC, from November 6-10, 2006. (Fig. 18)

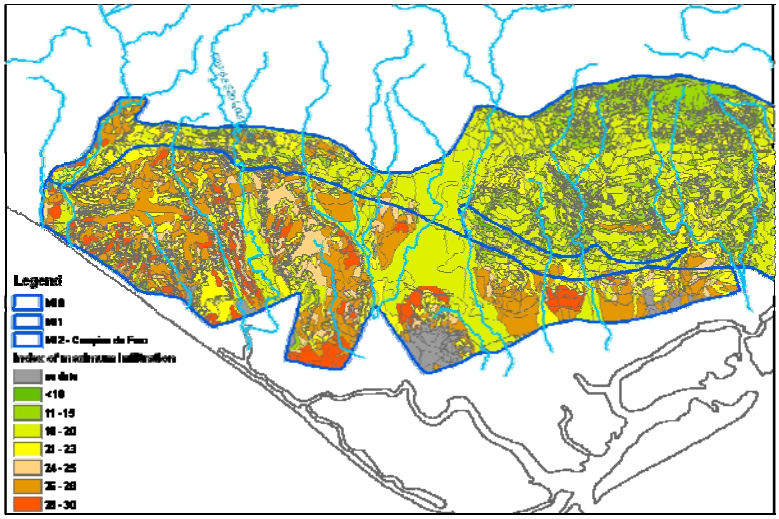



Fig. 18 - Index of infiltration (IFI) in the Campina de Faro and confining aquifer systems.

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