ENVIRONMENTAL SITUATION IN THE SURROUNDING AREA OF LAJES FIELD AIRPORT, AZORES

João Paulo LOBO FERREIRA

Dr.-Ing. Habil in Civil Engineering, Principal Researcher and Head of the Groundwater Division (NAS) - LNEC/DHA, Av. do Brasil, 101, 1700-066 Lisboa, Tel: 218 443 609, Email: lferreira@lnec.pt

Teresa E. LEITÃO

PhD in Hydrogeology, Senior Research Officer with Habilitation, Groundwater Division (NAS) - LNEC/DHA, Av. do Brasil, 101 P-1700-066 Lisboa, Tel: 218 443 802, Email: tleitao@lnec.pt

Maria Emília NOVO

PhD in Environmental Engineering, Research Officer, Groundwater Division (NAS) - LNEC/DHA, Av. do Brasil, 101 P-1700-066 Lisboa, Tel: 218 443 538, Email: enovo@lnec.pt

Luís S. OLIVEIRA

Environmental Engineer, Trainee, Groundwater Division (NAS) - LNEC/DHA, Av. do Brasil, 101, 1700-066 Lisboa, , Tel: 218 443 786, Email: loliveira@lnec.pt

Manuel MENDES OLIVEIRA

PhD in Hydrogeology, Research Officer, Groundwater Division (NAS) - LNEC/DHA, Av. do Brasil, 101, 1700-066 Lisboa, Tel: 218 443 436, Email: moliveira@lnec.pt

Rogério MOTA

PhD in Geophysics, Research Officer, Engineering Geology and Environmental Geotechnics Division (NGEA) - LNEC/DG, Av. do Brasil, 101, 1700-066 Lisboa, Tel: 218 443 592, Email: rmota@lnec.pt

Maria José HENRIQUES

Geologist, Principal Technician, Groundwater Division (NAS) - LNEC/DHA, Av. do Brasil, 101, 1700-066 Lisboa, Tel: 218 443 443, Email: mjhenriques@lnec.pt

Tiago André MARTINS

Geologist, Trainee, Groundwater Division (NAS) - Av. do Brasil, 101, 1700-066 Lisboa,Tel: 21 844 3609, Email: tmartins@lnec.pt

ABSTRACT

A summary of the work undertaken within the study entitled "Environmental assessment of the groundwater resources quality associated with the airport infrastructures of the Lajes Air Base throughout the area of Praia da Vitória municipality" is presented. Its main objective was to characterize the environmental status of the potentially most problematic areas in order to analyse the main risk factors for groundwater abstractions, envisaging ascertaining the adequate mitigation and recovery measures.

STUDY AREA

The study area is located in the eastern sector of Terceira island, Azores (Figure 1), in a band oriented NW-SE, the Lajes graben, with about 8.5 to 10 km long and 3.5 to 4 km wide, extending from Praia da Vitória - Cabo da Praia, in the south, to Vila Nova in the north. This graben is an elongated depression of tectonic origin, bounded by two fault scarps: (1) Santiago escarpment that defines the sector of the Serra de Santiago to the west, along a NW-SE direction and (2) the escarpment Fontinhas - Pico Celeiro, which defines the northern edge of Serra do Cume.

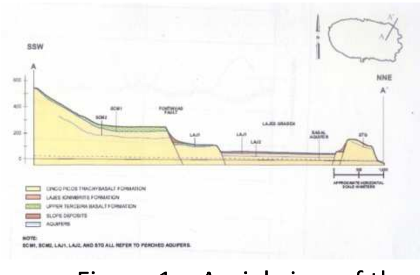

Figure 1 – Aerial view of the study area and cross section of Lajes graben (http://pt.wikipedia.org/wiki/Base_Aérea_das_Lajes and Schaller *et al.* (2005))

MATERIALS AND METHODS

The characterization of Praia da Vitória municipality environmental conditions was built upon the analysis of a wide array of new information (Figure 2), including new data from the lithological interpretation of logs (pertaining to 6 new wells in the basal aquifer), data from the geophysical prospection (40 resistivity profiles in 32 alignments), data from measurements of hydraulic characteristics (7 new pumping tests and hundreds of piezometric level measurements) and data concerning groundwater quality (11 610 chemical analysis on 54 monitoring points, spanning over one year period time). The information gathered was also integrated into a numerical groundwater flow model, and interpreted in order to understand and to validate the field data, and to evaluate possible evolution risk scenarios for the present situation.

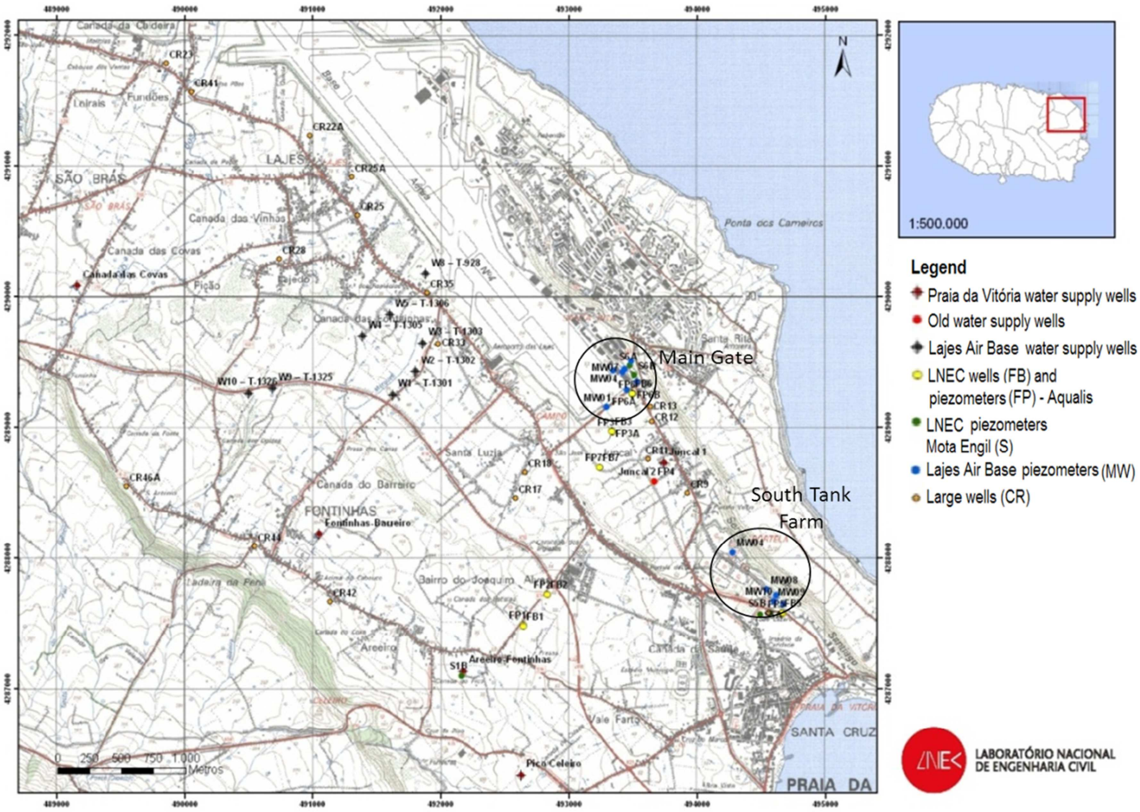

Figure 2 – Study area and groundwater infrastructures (cf. Lobo-Ferreira *et al.*, 2010)

In order to achieve this goal, the work was comprehensive, including the analysis of the main pollution sources, aquifers vulnerability to pollution, soil quality, geophysical characterization, and finally the groundwater flow modelling and quality assessment. In the References all final reports are listed. A short selection of the studies conducted is hereinafter presented.

The work carried out was based on a thorough analysis of the study area, which was developed through:

- Electrical resistivity analysis (Figure 3) performed in 40 profiles and 32 alignments with Wenner and dipole-dipole arrays, with 60 to 495 m of extension totalizing 9 557 m (Figure 3). Their goals were the (1) location of polluted zones associated with Lajes base's activities; (2) contribution to the characterisation of Fontinhas and Santiago faults; (3) identification of impervious zones that can act as a barrier to groundwater flow; and (4) helping to select zones for soil core sampling and for the installation of wells for water sampling and water pumping tests.

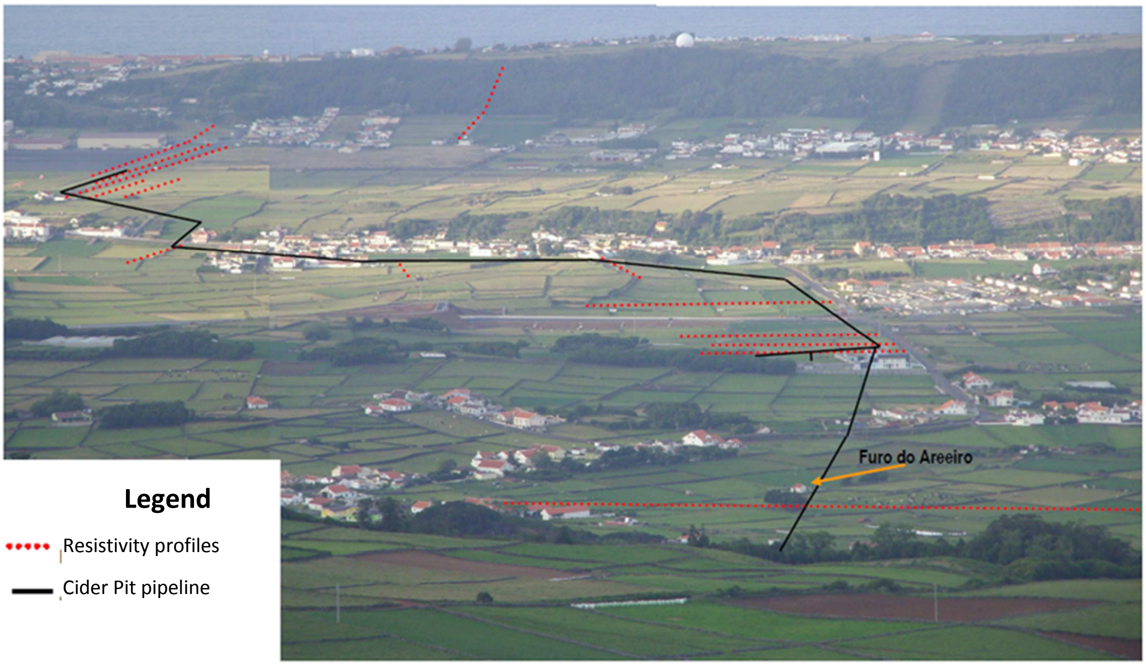

Figure 3 – Location of the electrical resistivity profiles done in the vicinity of Cinder Pit pipeline (cf. Mota and Novo, 2010)

- Installation of new infrastructures in 7 sites: 6 wells and 7 piezometers in the basal aquifer, and 8 piezometers in the perched hydrogeological formations detected during drilling. Their aim was to characterize the lithology / geology / hydrogeology, to conduct pumping tests and to provide quantitative and qualitative groundwater monitoring. Each site had at least one well and one piezometer in the basal aquifer and one piezometer at the perched aquifer, when existing.
- Execution of 7 pumping tests in the basal aquifer in order to assess its hydraulic properties (permeability and storage coefficient).
- Piezometric levels measurement in about 60 points of water, manually and with continuous recording probes, in order to characterize the groundwater flow directions and analyse the tide effect in the basal aquifer.
- *On site* and laboratory analyses of 14 surveys to collect soil samples at different depths.
- *In situ* monitoring and collection of 90 water samples in about 54 points, at various times and at different depths, for carrying out 11,610 chemical analyses.

RESULTS AND CONCLUSIONS

The analysis of the above information, as well as their processing and integration in a groundwater flow numerical model, allowed the following conclusions:

- The simplified conceptual hydrogeological model of the study area can be defined by up to three groundwater levels: (1) the first discontinuous hydrogeological level being composed of a low permeability top hydrogeological formations (fully saturated with water levels at the Main Gate (Porta de Armas) ca. – 2.2 m from the surface), (2) a perched aquifer (with water levels at the Main Gate ca. – 14.4 m from the surface), and (3) a deeper basal aquifer system (with water levels at the Main Gate ca. about – 53.3 m from the surface, Figure 4).
- The two first hydrogeological levels (referred to (1) and (2) above) result from the occurrence of sub-horizontal low permeability strata, intercalated with volcanic

formations, which act primarily as aquitards with sufficient extent to allow the retention of water in a hydrogeological body. Several discontinuous hydrogeologic units are formed.

- The basal aquifer system is phreatic in the study area monitored by LNEC. In the coastal zone it feeds a set of coastal springs, also located underwater. It is a fractured aquifer of medium to high yields, with some spatial variability dependent on the hydrogeological characteristics.

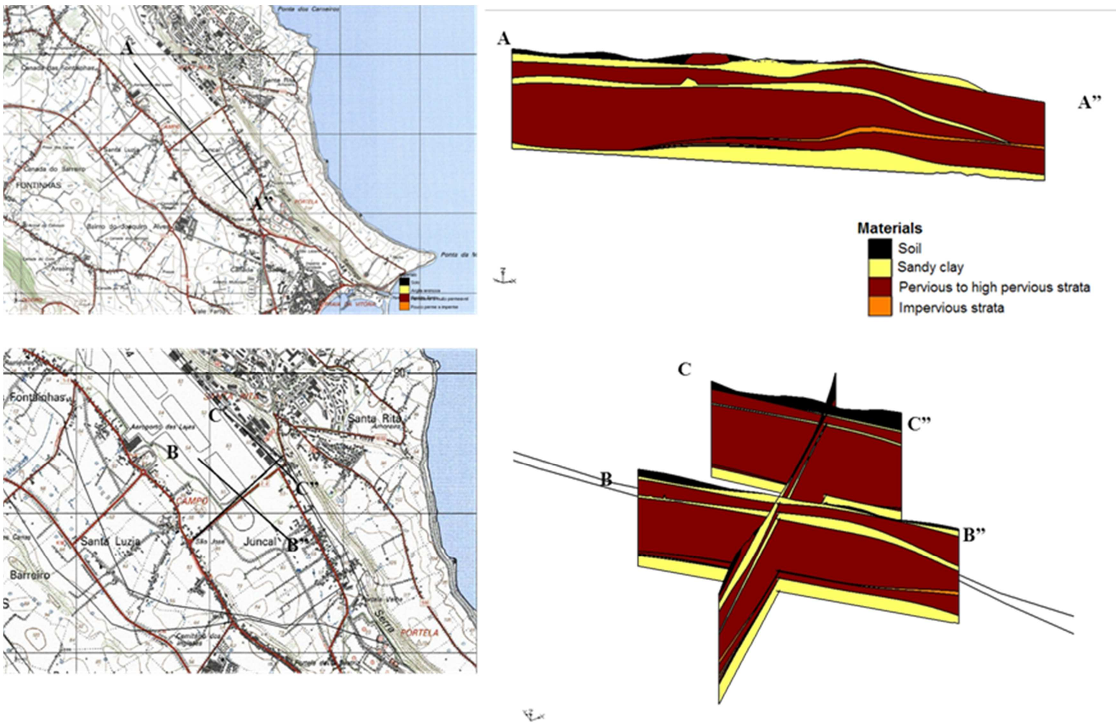

Figure 4 – Map and simplified geological profile of the study area (cf. Lobo-Ferreira *et al.*, 2010)

- These two levels are in contact through hydraulic leakage, which was considered as a recharge value to the basal aquifer in the model, with values between 15% and 20% of the shallow aquifers recharge. The greater or lesser interconnection between these two systems depends also on the degree of fracturing and local rock weathering.
- The presence of restricted areas declared as polluted was confirmed, highlighting the South Tank Farm (DISC Site 5001) and Main Gate (Porta de Armas) (DISC Site 3001) perimeters (Figure 1).
    - The compounds found in both areas include aromatic hydrocarbons (BTEX), PAHs, volatile organic compounds and semi-volatile compounds, halogenated and non-halogenated, as well as heavy metals.
    - In South Tank Farm the most affected sites remain the same over the last decade, showing an apparent stagnation of the hydrocarbons plume, although there are variations in pollutant concentration between samples.
    - Outside and downstream South Tank Farm perimeter the analysis results show a near absence of contaminants, which confirms that the plume of hydrocarbons is relatively immobile.
    - In this area, the possibility of the basal aquifer contamination based on surface

direct migration of contaminants it is not totally excluded. However, historical data point to a physical contention of the problem. Moreover, the distance to the supply wells (at Juncal) is greater than 1 km, and the preferred direction of the flow takes place to SE, preventing the arrival of pollutants to sites located upstream (Figure 5 and Figure 6).

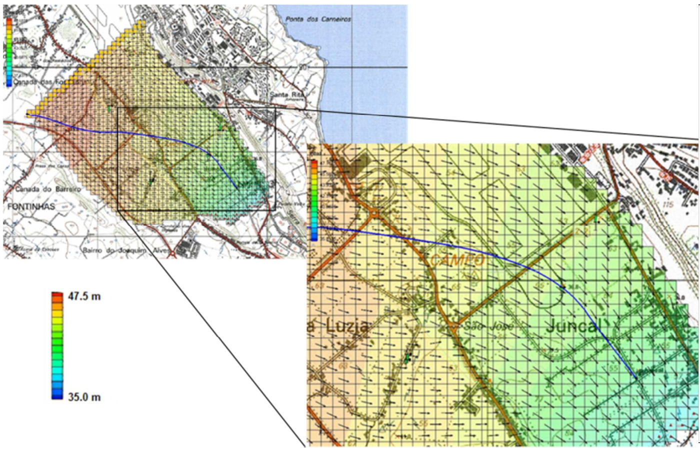

Figure 5 – Piezometric level after running the model, groundwater flow arrows and MODPATH particle tracking, in the perched aquifer (cf. Lobo-Ferreira *et al.*, 2010)

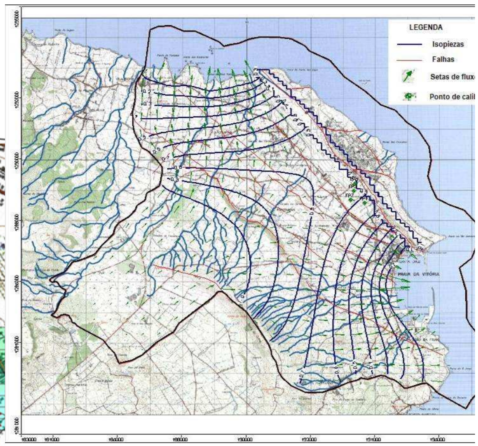

Figure 6 – Piezometric groundwater in the basal aquifer system (cf. Lobo-Ferreira *et al.*, 2010)

- In the piezometers near the Main Gate (Site 3001) there is considerable heterogeneity in concentrations between samples taken at different times and also at different depths (Figure 7).

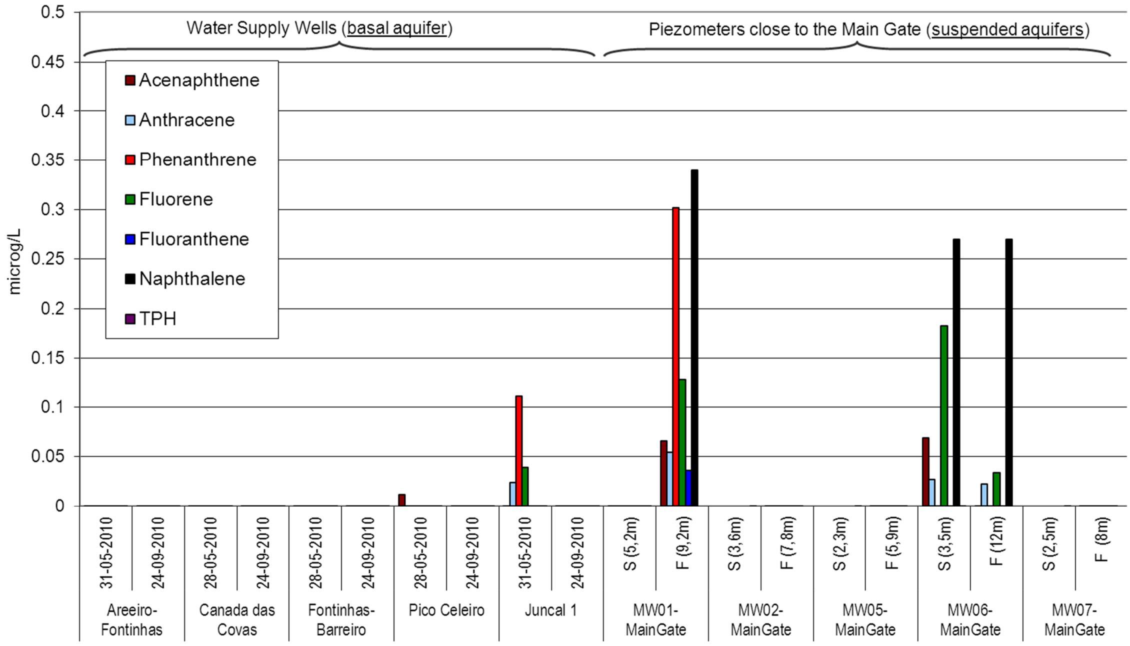

Figure 7 – Concentration of PAHs and TPH in supply holes (deep aquifer) and piezometers (shallow aquifer) close to the Main Gate (S - well top water sample; F - well bottom water sample) (cf. Lobo-Ferreira et al., 2010)

- In this DISCO Site 3001 at least two separate plumes of hydrocarbons, whose concentrations are above the allowed values, are referred (Figure 8).
- In the perched formations outside these perimeter (the direction of groundwater flow takes place mainly to SSE), concentrations of hydrocarbons are observed, e.g. FP3A piezometer, but not exceeding the standard limits defined.

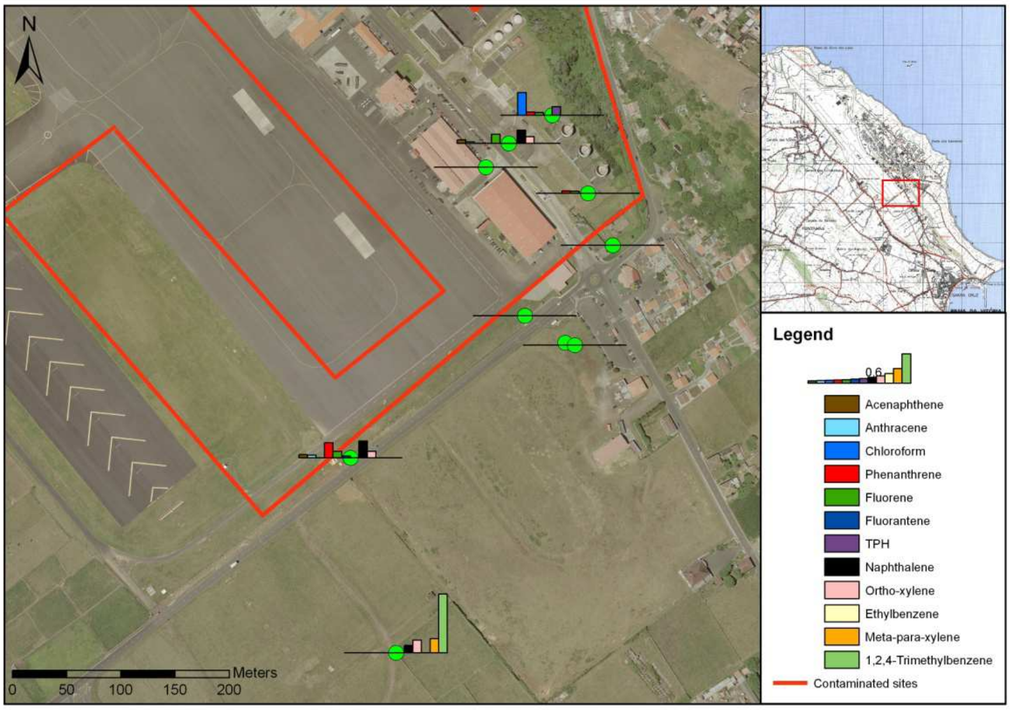

Figure 8 – Hydrocarbon concentrations in shallow piezometers located near the area of the Main Gate (cf. Lobo-Ferreira *et al.*, 2010)

- In the basal aquifer the public water supply is adequate, being chloride and, rarely, sodium, the parameters that may show concentrations above the standard values. It was not observed the presence of hydrocarbons higher than the limits permitted in water, and most results are below the detection limits (Figure 7).
- In other locations of the basal aquifer it was possible to observe the presence of hydrocarbons in some points of analysis, although its presence had not been confirmed for different monitoring periods. This indicates the need to further continue the monitoring programme and the analysis of pollution potential risk.
- For the remaining chemicals concerning the general state of water quality in the basal aquifer, there is a tidal influence in all the deep wells of the island, which does not imply the existence of saltwater intrusion. This can indeed be enhanced in the case of wells whose drains capture the brackish water that exists under the freshwater lens or in the case of a drawdown locally caused by excessive water abstraction.
- Another element which sometimes occurs in high concentrations, but not exceeding the quality standard, is the nitrate ion. Its presence in the basal aquifer also shows the influence of land use and the misuse of traditional wells as septic tanks in several parts of the island.
- In addition to the major elements above referred there is a set of heavy metals which were examined, which sometimes have concentrations above the standard value. This

is the case for aluminium, chromium, cobalt, iron, lead, manganese, molybdenum, nickel, silver and vanadium. The presence of some of these elements may be due to the geological environment where water circulates. An exception is the presence of lead and manganese, whose highest concentrations were found in polluted areas. It is therefore important that during the River Basin Management of the Azores this theme is further developed in order to set the background concentration of these waters, i.e. "the concentration of a substance or the value of an indicator in a body of groundwater corresponding to no, or only very minor, anthropogenic alterations to undisturbed conditions", so that the "quality thresholds" may be defined taking into account the hydrogeochemistry of the island.

- The analysis of the resistivity models (Mota and Novo, 2010) depicts the following features:
    - Geophysical discontinuities have spatial correspondence with previously identified geological discontinuities (Carta Vulcanológica da Ilha Terceira (1/200 000) and Rodrigues (2002)), namely Santiago and Areeiro faults (Figure 9). It was also possible to identify hydrocarbons potentially contaminated sites. These presumably contaminated sites are:
        - Area of the buried tanks in Pico Celeiro;
        - Deployment Area of Cinder Pit pipeline and fuel storage site in the Bairro da Joaquina;
        - Main Gate area;
        - Old Pier 7;
        - North Storm Sewer.
    - Identification of potential discrete levels which can prevent the vertical migration of water vertically and, consequently, possible contamination from the surface.

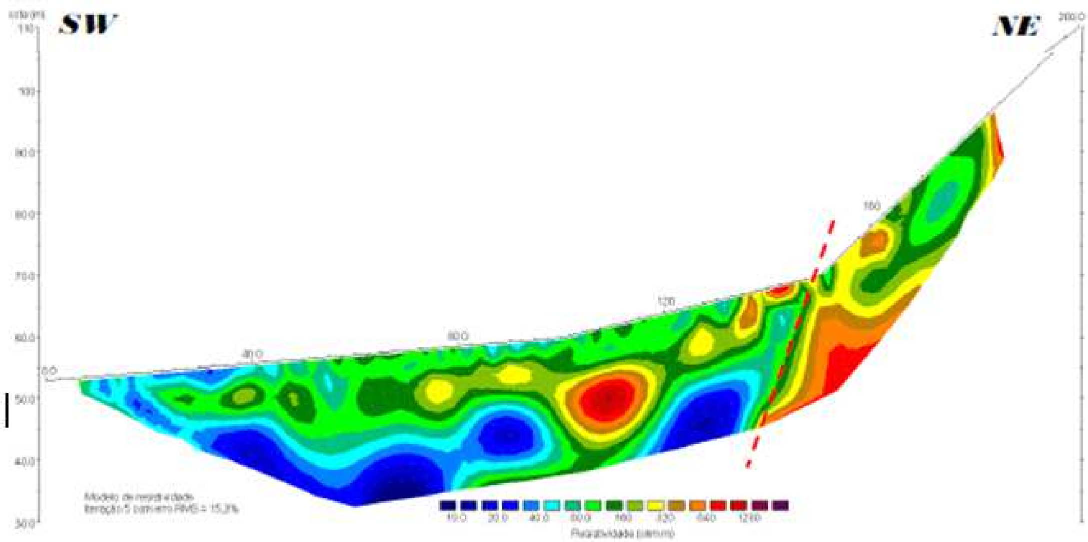

Figure 9 – Resistivity model obtained in one electrical profile where Santiago fault can be clearly seen (cf. Mota and Novo, 2010)

Given the findings presented, a set of recommendations were proposed for groundwater resources protection in the study area, particularly for the basal aquifer that shows an intermediate vulnerability, and which serves for domestic supply.

It is finally noted that the knowledge now acquired does not exhaust the characterization of all areas potentially affected by pollution. Based on the project aim, the target of the study was focused on the polluted areas closer to the water supply wells and their potential risk to public health. The results of geophysical prospecting indicated other areas, possibly minor in expression, which should be further analysed.

An overall conclusion is that, despite the characterization of the environmental status of the areas analysed has confirmed the presence of groundwater polluted areas in the studied region, there was only one situation in wells or piezometers that capture the basal aquifer where pollutants concentration was above the levels allowed. Note, however, that the mere presence of water with concentrations above the detection limits is an indication of a potential risk that should continue to be monitored in the future. Given the findings presented, a set of recommendations is proposed including the control of pollution sources, and the beginning of the rehabilitation process in the restricted areas affected.

REFERENCES

Aqualis (2010). *Instalação de Furos e Piezómetros no Concelho de Praia da Vitória, Ilha Terceira – Açores*. Aqualis Lda.

Jorge, C. (2010). *Análise e Parecer Sobre a Situação Ambiental nas Áreas de Captação dos Furos de Abastecimento do Concelho de Praia da Vitória – Açores - Avaliação da Caracterização da Contaminação de Solos Junto a Potenciais Focos de Poluição*.

Leitão, T.L., Jorge, C., Novo, M.E., Lobo-Ferreira, J.P., Oliveira, M.M. (2009). *Especificações para a Instalação de Furos de Ensaio, de Piezómetros, de Sondagens de Amostragem e de Análises Químicas de Solos e Águas na Região do Graben das Lajes - Concelho de Praia da Vitória, Ilha Terceira, Açores*. Relatório 225/2009-NAS, 46 pp.

Lobo-Ferreira, J.P., Leitão, T. E., Novo, M.E., Oliveira L. S., Oliveira, M.M., Henriques M. J. e Martins, T. (2010). *Análise e Parecer Sobre a Situação Ambiental nas Áreas de Captação dos Furos de Abastecimento do Concelho de Praia da Vitória – Açores - Relatório Final da Avaliação das Águas Subterrâneas*. Relatório 424/2010-NAS, 196 pp.

Morais, J. (2010a). *Relatório de Ensaios – Amostragem e Análise de Águas Subterrâneas*. AmbiPar Control, Lda., 254 p.

Morais, J. (2010b) *Relatório de Ensaios – Amostragem e Análise de Solos*. AmbiPar Control, Lda., 88 p.

Mota, R. e Novo M.E. (2010). *Prospecção Geofísica, pelo Método da Resistividade Eléctrica, no Concelho de Praia da Vitória, Açores*.

Novo, M.E. (2010). *Descrição Geológica Detalhada das Colunas Litológicas obtidas nas Carotes dos Novos Piezómetros*, Laboratório Nacional de Engenharia Civil, NAS/DHA, 113 p.

Oliveira, N.P. (2010). *Realização de Sondagens para Recolha de Amostras de Solos e Posterior Instalação de Piezómetros no Aquífero Superficial da Região do Graben das Lajes - Concelho de Praia da Vitória, Ilha Terceira – Açores*. Direcção de Fundações e Geotecnia da Mota-Engil, 91p.

Rodrigues, R. (2002) *Hidrogeologia da Ilha Terceira (Açores-Portugal)*. Angra do Heroísmo, Universidade dos Açores, Departamento de Ciências Agrárias, Tese de Doutoramento.

Schaller, J., Hansen, J., Mowerey, H.A., Ninglegen, W., Göllinger, F. (2005). *Hydrogeological Report Lajes Field, Azores, Portugal – Final*. CH2M HILL, US AIR Forces in Europe. Fevereiro 2005.