IDENTIFICATION OF TYPICAL CHEMICAL AND PHYSICAL CONDITIONS IN APULIAN GROUNDWATER (SOUTHERN ITALY) THROUGH WELL MULTI-PARAMETER LOGS

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Abstract: *Apulia is affected by two types of human-related pollution: salt contamination and chemico-physical and biological pollution. The special severity of the situation calls for a rigorous approach based on available scientific knowledge and supplemented by up-to-date investigations of the evolution of groundwater quality. Particularly useful are to this end the multi-parameter logs which have been executed along the water column of the well, through the monitoring of temperature, salinity, pH, dissolved oxygen and oxidation-reduction potential of groundwater. This method, which has been tested in 120 wells over one year, has allowed to detect some typical trends of the parameters under study. These types, which are rather recurrent in space and time, allow an extensive use of the suggested method which can be easily applied to the preliminary detection of the hydrogeological conditions which determine the chemical and physical nature of groundwater and the occurrence of human- or salt-related contamination.*

1. INTRODUCTION

The rapid socio-economic growth, which has occurred in the past decades, has continued to stress conditions in the Apulian hydrogeological system in Southern Italy, thereby leading to different hazardous conditions. Groundwater for domestic, irrigation and industrial use has been withdrawn in large quantities over the years. The aquifers are increasingly becoming the ultimate "receptacle" for wastewater. Apulia is affected by two types of human-related pollution: salt contamination which is spreading over large portions of land, that reducing the availability of good quality water (Cotecchia, 1981; Fidelibus and Tulipano, 1996); and chemico-physical and biological pollution which is mainly confined to urban areas (Cotecchia and Polemio, 1995). In several areas groundwater salt contamination has reached such a level that many of the wells have been abandoned.

In Apulia there are four Hydrogeological Units (hereinafter HU). They exhibit varying geological, structural and morphological features (Figure 1). Apart from Puglia Tableland (Tavoliere), the remaining HU share some common features (Cotecchia and Magri, 1966; Ippolito et al., 1958; Cotecchia, 1977; Grassi, 1983; Zezza, 1975). They consist of large and deep carbonate aquifers (of Jurassic-Oligocene and mainly Mesozoic age), the predominant rock material of which is either limestone or limestone-dolomite. Aquifers are affected by karst and fracturing phenomena, also well

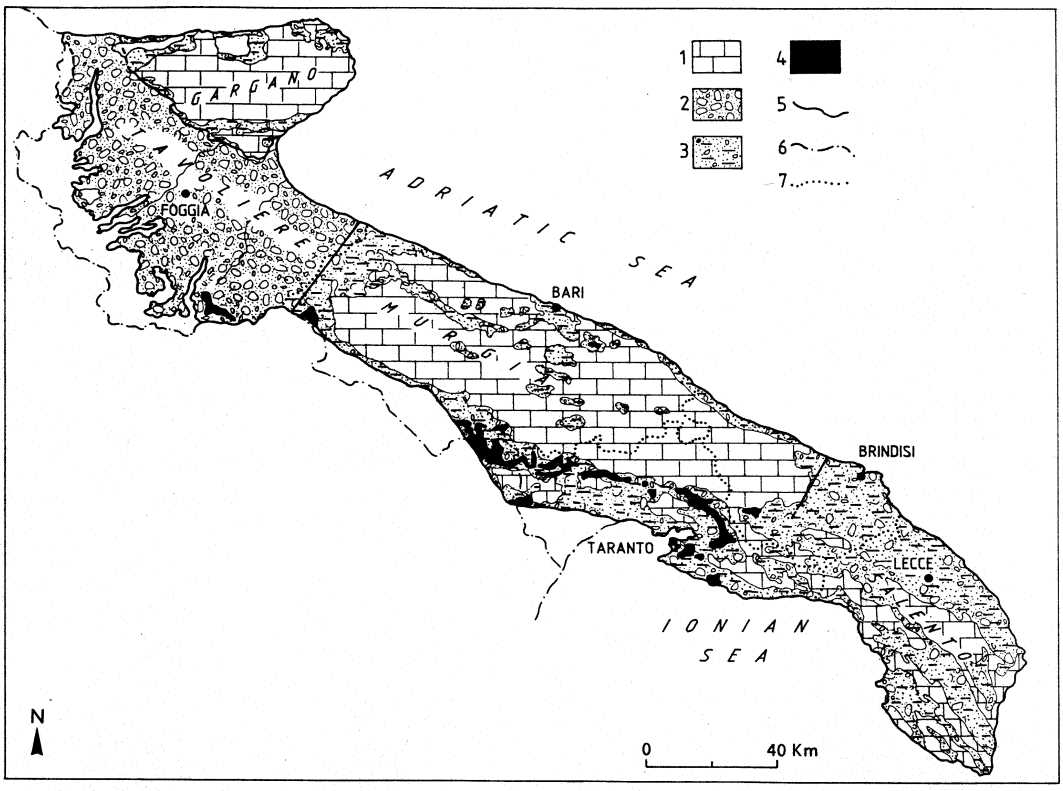

Figure 1 APULIAN HYDROGEOLOGICAL UNITS. 1) Carbonate rock outcrops of Gargano, Murgia and Salento units; 2) Tavoliere unit, mainly conglomerate and sands; 3) shallow aquifers and permeable lithotypes, calcarenites, clayey sands, sands, gravel, or conglomerates; 4) low permeable lithotypes, blue marly clays; 5) hydrogeological unit boundary, dashed where uncertain; 6) regional boundary; 7) provincial boundary.

below the sea level, whereas intruded seawater underlies fresh groundwater owing to a difference in density. In both the Gargano Promontory (*Gargano*) and the low Murge Plateau (*Murgia*) aquifers are under pressure except on a restricted coastline strip. In the Salentine Peninsula (*Salento*), subsurface water flow under phreatic conditions is prevailing. The Salento HU is the only unit which is lapped by the sea on both sides. Puglia Tableland (*Tavoliere*) HUconsists of a large porous aquifer (Pleistocene-Holocene) within a conglomerate sandy-silty succession, less than sixty meters deep with a clayey impermeable bottom. Only in the vicinity of the coast the aquifer is deep enough to allow seawater intrusion. Groundwater flows under phreatic conditions in the most internal and upstream portion of the HU, whereas it flows under pressure in the remaining part of the unit.

Along the borders between the Tavoliere and the Gargano or the Murgia, the sinking of the carbonate platform, which makes up these two last HU, is observed. A deep succession of clays, marly clays, sandstones and sands of Plio-Pleistocene age underlies the Tavoliere HU. This pelitic succession overlies a deep carbonate aquifer; it is the sunken carbonate platform. Inland, the Tavoliere border corresponds to outcropping impermeable clayey formations. The border between the Murge and the Salentine hydrogeological units is unclear. A gradual shift from the typical Murgia high depth to groundwater and low and mildly variable permeability to the Salento varying types of water flows, permeability and depth can be observed.

Nowadays, a strong connection between the increase in salt contamination and the lowering of piezometric levels, which can be ascribed to groundwater overdraft and/or a natural decrease in groundwater recharge, has been recognised in coastal aquifers. Despite the massive import of water, the Apulian groundwater supply hardly meets 20% of the local demand for drinking water. Furthermore, groundwater is often the only resource available for diffuse water-demanding production processes in the area (Cotecchia and Polemio, 1995). The special severity of the situation calls for a rigorous approach based on available scientific knowledge and supplemented by up-to-date investigations of the evolution of groundwater quality.

Particularly useful have proven the multi-parameter logs which have been executed along the water column of the well. The systematic use of probes equipped with sensors to check temperature (T), electrical conductivity (EC), pH, dissolved oxygen (DO) and oxidation-reduction potential (redox) have allowed to gather preliminary results on the chemical and physical characteristics of water as well as on the pollution level. The method has already been tested on 120 wells of Apulian region over one year, with surveys every three months (Figure 2). Some typical trends of the parameters under study have been identified which can be correlated with the local hydrogeological conditions. These typical trends which are rather recurrent in space and time - and of which significant examples are provided - allow an

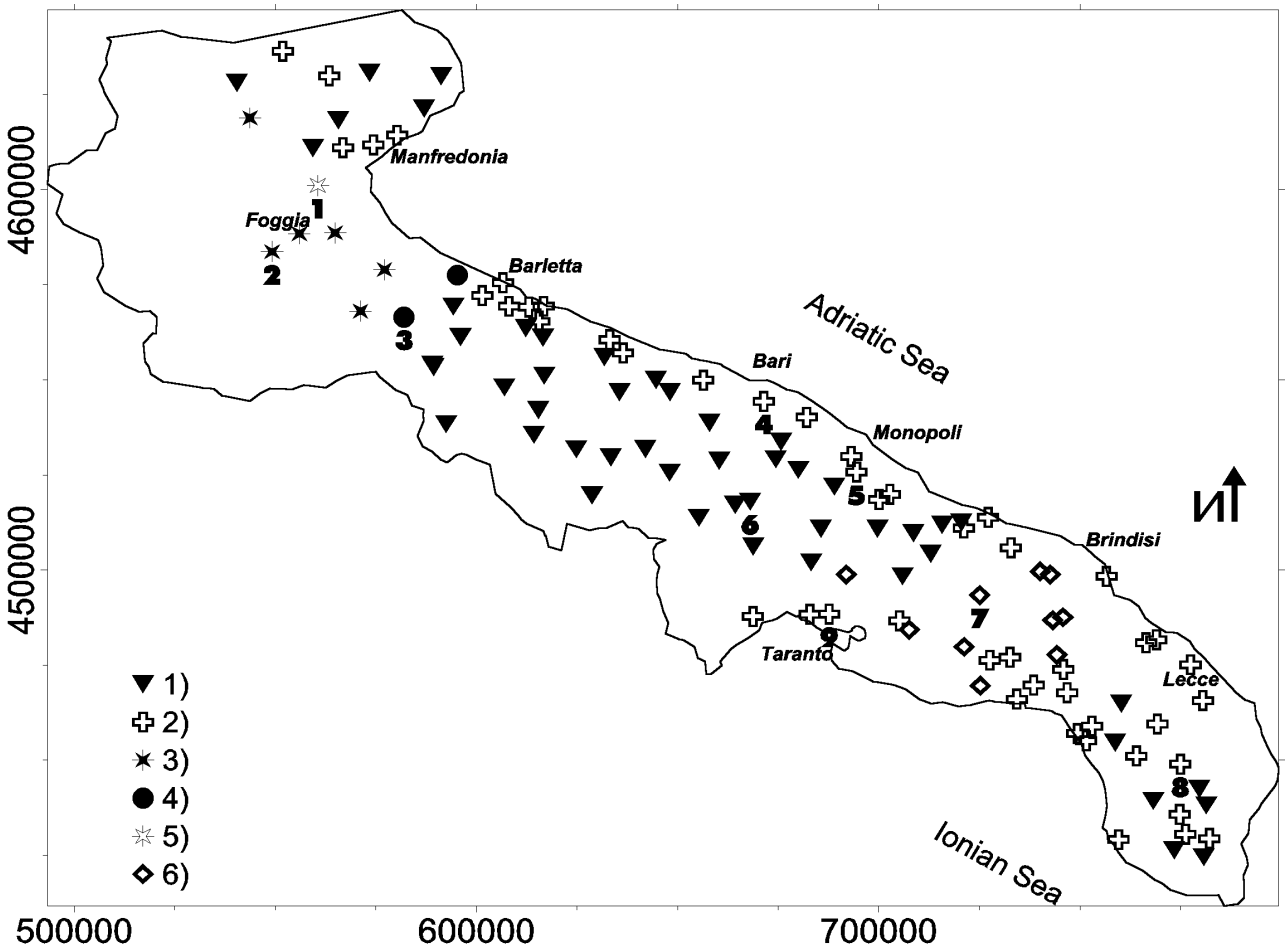

Figure 2 LOGGING WELLS AND LOGS TYPES. Log type: 1) A, Inner or recharge area, 2) B, coastal strip or sea water intrusion area; 3) C, Tavoliere shallow aquifer; 4) D transition zone between the Murgia and the Tavoliere HU; 5) E, transition zone between the Tavoliere and the Gargano HU; 6) F, transition zone between the Murgia and the Salento HU.

Table 1 MULTI-PARAMETER PROBE SENSOR SPECIFICATIONS.

Parameter	range	Accuracy	resolution
Pressure	0 to 1500 bar	0.25%	0.01
Temperature	-1 to 49 °C	0.1°C	0.01°C
Specific conductance	0 to 62 mS/cm	5%	0.10 mS/cm
pH	0 to 14	0.05	0.01
Dissolved oxygen	0 to 50 ppm	0.1 ppm	0.01 ppm
redox	-400 to 400 mV	10 mV	1 mV

extensive use of the proposed method which can be easily applied to the preliminary detection, in pre-existing works, of the hydrogeological conditions which determine the chemical and physical nature of groundwater and the occurrence of human-related pollution or intruded sea-water contamination.

The multi-parameter logs have been executed using probes equipped with six sensors to check the water pressure, the temperature, the electrical conductivity, the pH, the DO and the redox. Table 1 lists the major characteristics of the above sensors. The parameters have been determined, in the absence of sharp changes, with measurement intervals of 0.5 m, moving downwards from the static level to the bottom of the hole. Particular attention has been paid to the descent velocity - which has not exceeded 0.03 m/s - not to disrupt the stratification of the grondwater. The salinity of groundwater was indirectly inferred, as TDS, through rating curves varying in accordance with the chemical composition of the groundwater under study.

2. DETECTION OF THE CHEMICAL AND PHYSICAL TYPES OF APULIAN GROUNDWATER

Six typical trends of the multi-parameter logs have been identified. The chemical and physical properties of groundwater, as indicated by the tests, could somewhat correlate with the peculiar hydrogeological conditions of the prospected units: inner or recharge area (type A), coastal strip (type B), Tavoliere shallow aquifer (type C), transition zone between the Murgia and the Tavoliere (type D), transition zone between the Tavoliere and the Gargano HU (type E) and transition zone between the Murgia and the Salento HU (type F) (Figures 2 and 3).

The wells falling within the type A exhibit a temperature which ranges between 16 and 17 °C, salinity always lower than 0.5 g/l, pH ranging between 6.5 and 7.5, constantly high DO with max values between 5 and 8 mg/l and a generally positive oxidation-reduction potential (Figure 3). In addition, some parameters are constant, such as temperature, electrical conductivity, pH along the vertical axis of the well, whereas the remaining two parameters vary and tend to increase in the water flow areas.

Along the coast (type B) a parallel increase is observed in the values of temperature (by 1-1.5°C) and salinity (from 0.5 g/l in the fresh water portion to more than 40 g/l in the final part of the well, i.e. in sea-water) as depth increases. As regards pH, which exhibits average values of 7.5, it tends to increase in the saline portion of the aquifer, while the DO has generally a high concentration, though variable, in the portion of fresh water and then decreases and becomes null when intruded sea-water is reached, which has a poor or null mobility. Also the oxidation-reduction potential tends to decline with depth. This trend, which is decidedly more clear-cut compared to that of dissolved oxygen, shows positive values in the portion of the aquifer where fresh water flows and negative values in the remaining portion characterised by sea-water. Moreover, the transition zone between fresh water and saline water, the depth of which differs among the wells, exhibits a sharp change from salinity values of 3-5 g/l up to 41-42 g/l.

Water which flows in the shallow aquifer of the Tavoliere (type C) has a temperature which ranges between 16 and 17 °C, a salinity approaching 1 gram per litre, a pH of 7-8, DO which does not exceed 4 mg/l and redox ranging between slightly positive to broadly negative values. A key feature is the worsening of the chemical and physical properties with depth, as confirmed by the slight increase in temperature, electrical conductivity, pH and a simultaneous decrease in both dissolved oxygen and oxidation-reduction potential.

Types D and F have been detected in the wells located in transition areas from one hydrogeological unit to the other. Given the marked variability in the hydrogeological conditions observed in these areas and the limited number of available wells, a preliminary scheme is drawn for types D and F.

Type D wells (Murgia and Tavoliere) cross the Quaternary soils of the Tavoliere with blank casings and reach the groundwater contained within Mesozoic limestones. This water exhibits a temperature which exceeds 20 °C, a salinity which exceeds 1 gram per litre and tends to increase with depth, a more or less constant pH, with average values approaching 7, very low DO (values below 2 mg/l) and a constantly negative redox.

Type E wells (Tavoliere and Gargano) cross the Quaternary soils of the Tavoliere with blank casings and reach the groundwater contained within the Mesozoic limestones. A highly mineralised groundwater is detected which is subject to very poor mobility. Temperature (30-33 °C) and salinity (37-40 g/l) increase with depth. pH is basically constant along the water column and reaches an average value of 6.5, while the dissolved oxygen, except for a portion where water flows seems more active, is absent. Lastly, the oxidation-reduction potential is always negative.

In the transition zone between the Murgia and the Salento (type F), where water from the first units outflows into the second unit, the chemical and physical characteristics of water indicate the presence of rather rapid and stratified circuits. The monitored parameters exhibit the following characteristics: temperature ranging between 16.5 and 17° C, salinity lower than 0.5 g/l, pH between 6 and 8, dissolved oxygen variable along the water column ranging between 2 and 4 mg/l and broadly positive oxidation-reduction potential.

3. MULTI-PARAMETER LOGS AND THE IMPACT OF HUMAN AGENCY

The field research has highlighted that multi-parameter logs show clearly some peculiar conditions where human agency has caused groundwater degradation or modification, owing to polluting activities or overdevelopment. As regards the latter, this study has provided useful information on the evolution of intruded sea-water inland with the subsequent gradual salinisation of groundwater induced, to a large extent, by human agency. Under natural conditions, fresh groundwater, floating above the intruded saline water, takes a depth which ranges between a few metres in the proximity of the shoreline to some hundred metres in the innermost areas of the region. In addition, the shift from

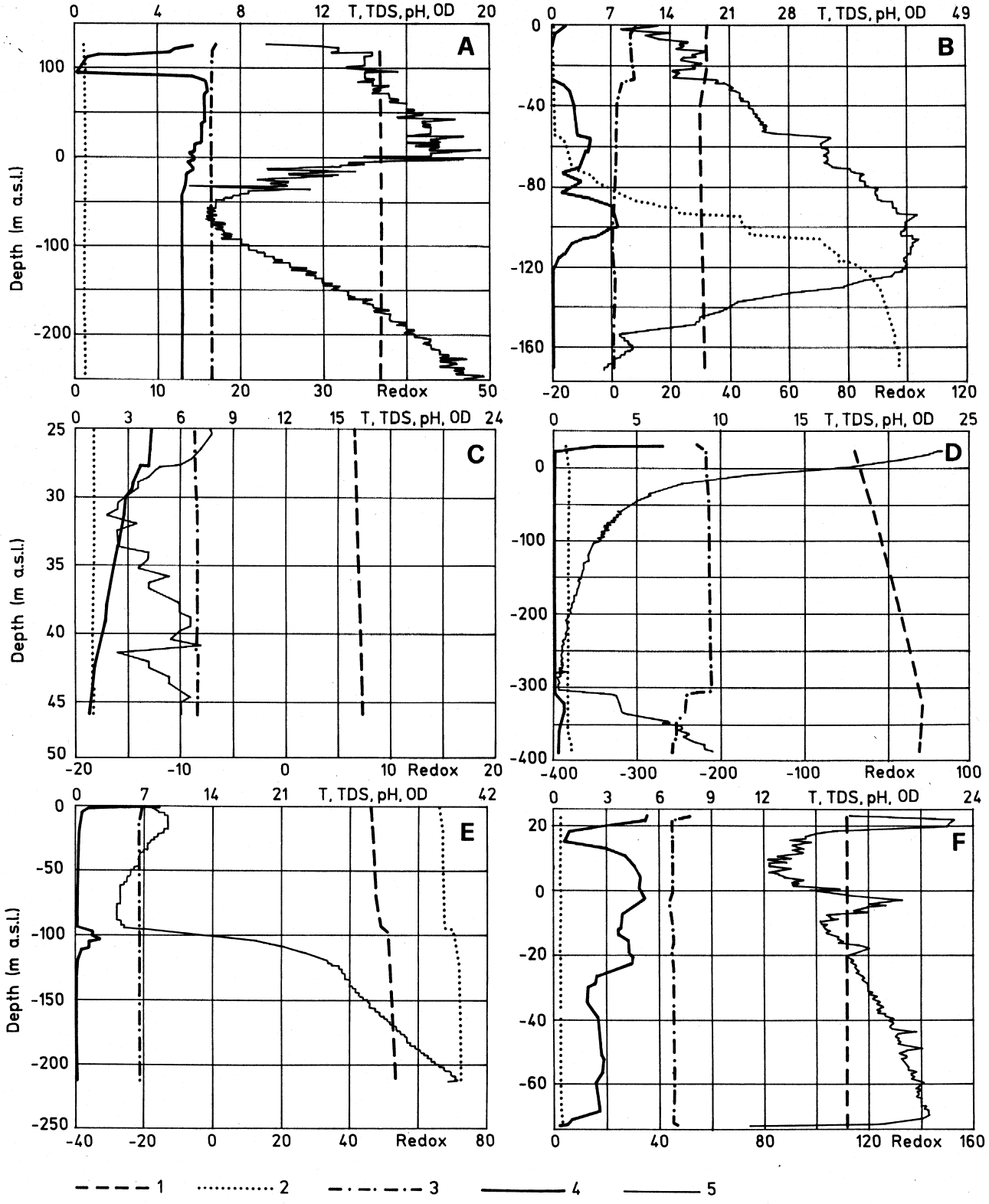

Figure 3 MULTI-PARAMETER LOG TYPE. Parameters: 1) Temperature (T, °C), 2) TDS (g/l), 3) pH, 4) dissolved oxygen (DO mg/l), 5) oxidation-reduction potential (redox, mV). Log type: A) Inner or recharge area (well No. 1), B) coastal strip or sea water intrusion area (well No. 2), C) Tavoliere shallow aquifer (well No. 3), D) transition zone between the Murgia and the Tavoliere HU (well No. 4), E) transition zone between the Tavoliere and the Gargano HU(well No. 5), F) transition zone between the Murgia and the Salento HU (well No. 6). For well location see Figure 2.

groundwater to sea water is not always sharp, but goes through the transition zone which is located between the two types of water (Cotecchia, 1977).

Along the coastal area, excessive withdrawals disrupt the equilibrium between fresh water and saline water, thus resulting in the recovery of brackish water laterally and upwards and the subsequent salinisation of the groundwater. The phenomenon is amplified in some areas where, owing to peculiar geological and structural conditions, some truly preferential pathways are formed and facilitate the intrusion of sea water inland (Tadolini, 1990; Polemio and Limoni, 1998).

It is generally accepted that there exists a link between the depth of the transition zone and the distance from the sea. In the vicinity of the coast, the shift from the piezometric head to the underlying sea water is achieved within a few metres or it does not exist as to the complete mixing of fresh-salt water, whereas inland the shift is gradual, with a transition zone which is some dozen metre deep (Tadolini and Tulipano, 1970, Cotecchia, 1977a). The magnitude of the fluctuations of the transition zone - both in terms of depth and height changes - varies from one site to the other. Fluctuations generally tend to increase far from the coast. As for the wells located close to the coast, fluctuations are almost imperceptible and generally exhibit an interval from 0 to 5 metres. Farther away from the coast, the fluctuation in the transition zone may exceed 30-40 metres.

The fluctuations of the transition zone, in the absence of human influences, are closely related to alternating periods of recharge and depletion of the aquifer, though a certain unbalance is likely to occur between water received from precipitation and the corresponding lowering of the piezometric surface. Particularly significant is the example of the well 7 (Figure 4). The fluctuations of the transition zone - both in terms of height and depth - are closely related to the trend of the piezometric level. In other words, the depth decreases when the overlying hydraulic head tend to increase and vice-versa.

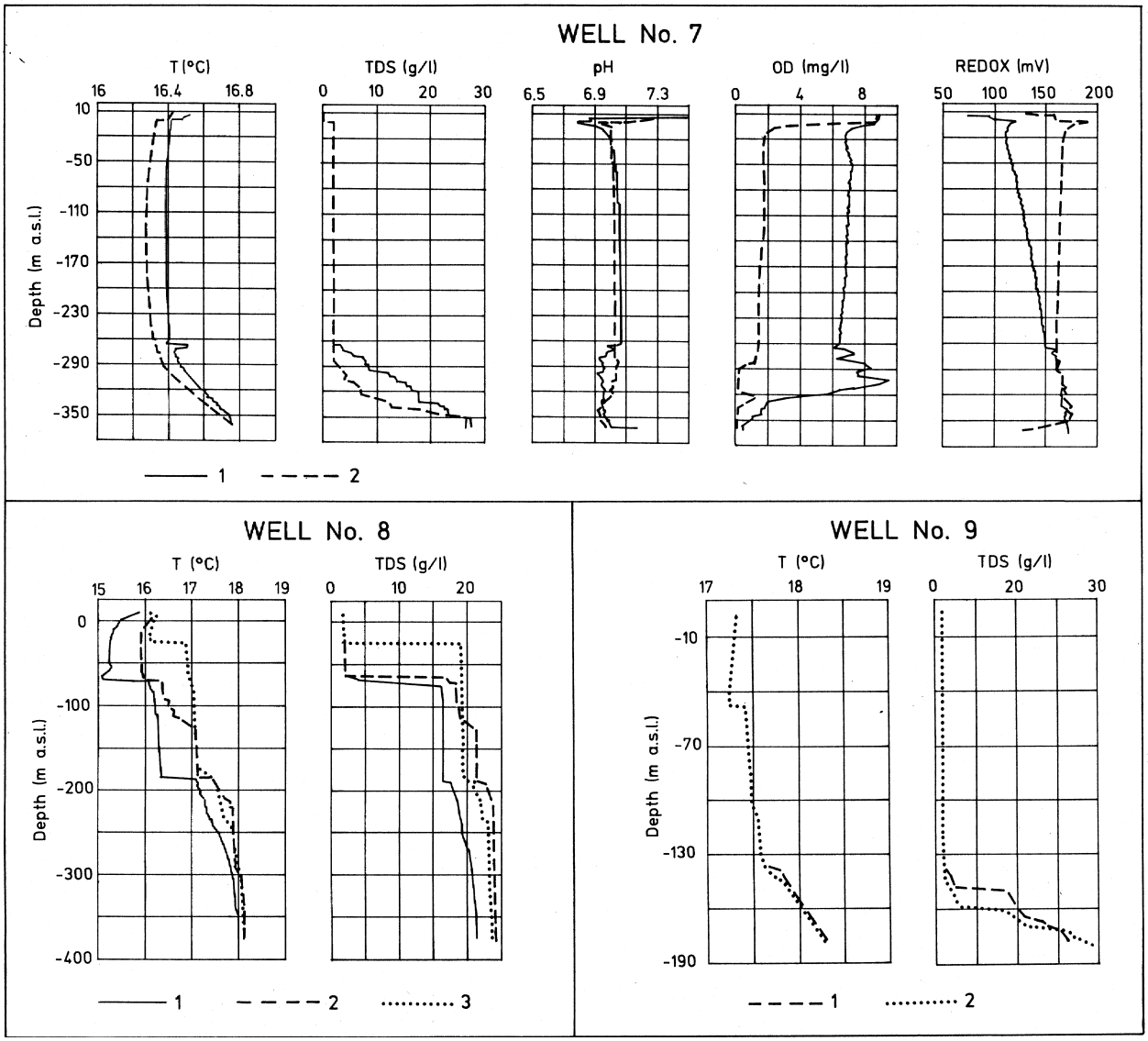

Figure 4 Multiparameter log influenced by human-related pollution. Logging date of the Well No. 7: 1) 8/9/95, 2) 3/19/96. Logging date of the Well No. 8: 1) 4/5/96, 2)6/10/96, 3) 1/9/97. Logging date of the Well No. 9: 1) 4/5/96, 2)6/10/96, 3) 1/9/97

.In some other cases, the modifications in the transition zone are attributable to the withdrawals occurring in the vicinity of the well. Particularly symbolic is the case illustrated in the well 8 (Figure 4), where 2 months after the first log, a clear-cut increase is recorded in salt content along the whole transition zone. The scenario has decidedly worsened over time. Logs made 8 months after the first sampling have indicated a considerable upward expansion of the transition zone, with a significant reduction in fresh water depth.

A case contrary to the above mentioned one is observed in the well 9 (Figure 4) where almost 1 year after the first sampling, a clear improvement is acknowledged in the quality of water, which is related to a substantial lowering of the height of the transition zone, associated with a reduction in the depth. This condition is due to an increase in rainfalls in 1996 and can only be partly associated to a probable reduction in withdrawals which are, however, not documented.

4. CONCLUSIONS

This study has allowed to identify some typical trends of the multi-parameter logs, which can correlate with peculiar hydrogeological conditions. This may prove particularly useful for practical purposes, since the execution of these surveys allows to easily identify or verify at a low cost the chemical and physical nature of water, the hydrogeological conditions and the occurrence of polluting human factors.

The systematic and periodical use of logs to check the temperature and the salinity in the wells located along the coastal area has paved the way for a qualitative and quantitative assessment of the evolution of sea-water intrusion.

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