GROUNDWATER SALINIZATION IN VERSILIA (ITALY)

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SUMMARY

In the Versilia coastal plain (Tuscany), groundwater represents the main water source for civil supply, industry and agriculture. The intense summer exploitation of groundwater in proximity to the coast, carried out especially for bathing establishments, hotels and vacation houses, favours the intrusion of seawater.

This study, carried out in 1999, aims to:

1. assess the extent of groundwater salinization;
2. verify whether the phenomenon is deteriorating, by comparing the present situation with that of previous years;
3. ascertain the causes behind salinization and establish what interventions are necessary to control the phenomenon.

GEOLOGICAL AND HYDROGEOLOGICAL PICTURE

Versilia is a coastal plain about 5 km wide, delimited on its eastern side by the Apuane Alps. The plain continues to NW with the Riviera Apuana and to SE with the Pisa plain.

The Apuane Alps reach heights of 2,000 meters and their name is due to their rough morphology, which is a consequence of their recent uplifting and of their predominant carbonate lithology. The plain is formed by a graben which probably dates back to the Upper Miocene and which still shows a subsidence motion. More than 1,000 meters of non-consolidated sediments fill the tectonic depression. In the Quaternary, tectonic phases and eustatic variations of sea level have determined an alternation of continental sediments (gravel, sand and silt) and marine deposits (mainly sands).

The plain can be subdivided into three belts (Figure 1 and 2). The coastal belt is characterized by the presence of marine and aeolic sands, which form a continuous layer reaching depths of at least 100 meters. The intermediate belt mainly consists of palustrine sediments and of lagoon and marsh infilling deposits: here the water basins have for the most part been reclaimed, but some still exist. Some areas still lie under sea level, currently showing a subsidence motion due to sediment compacting. Underneath these fine sediments we can find an alternation of marine sands and continental deposits with different granulometries. The innermost belt consists of the alluvial fans formed by the streams descending the Apuane Alps.

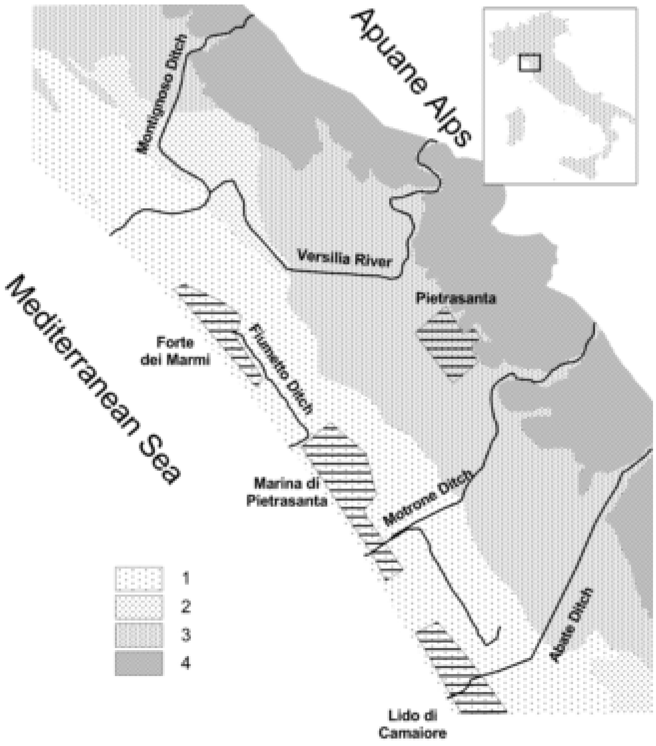

Figure 1 *Geological sketch of the Versilia Plain.*
1: Marine and aeolic sand. 2: Marsh and lagoon deposits. 3: Fluvial deposits. 4: Rock formations.

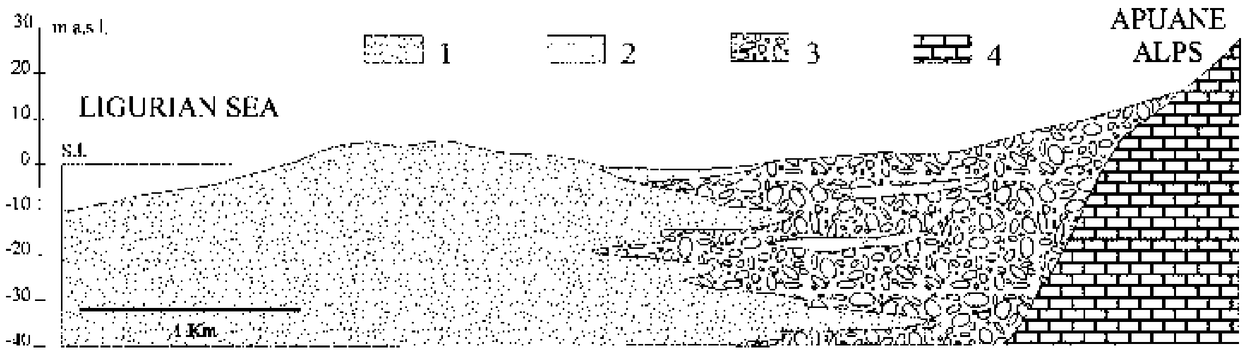

Figure 2 *Geological cross section of the Versilia Plain.*
1: Marine and aeolic sand. 2: Marsh and lagoon silt and clay.
3: Gravel and sand with lenses of silt and clay. 4: Limestones.

The aeolian and marine sands of the coastal belt represent a free aquifer with medium-high permeability. This aquifer is currently being exploited mainly through domestic or agricultural wells; in the summertime a great number of superficial wells (usually less than 10 meters deep) are activated for beach resorts, hotels and summerhouses.

The alluvial fan deposits are mostly composed of gravels and pebbles with lenses of sand and clayey silts. These represent a free aquifer in the piedmont band, which becomes confined in the central part of the plain, where clayey palustrine sediments cover it. At various depths the calcareous gravels somewhere become a carbonate-cement conglomerate. Such a conglomerate is impermeable and it subdivides the aquifer into various confined overlapping aquifers. The alluvial gravels form the plain's main aquifer, exploited by 100 m and more deep wells used for potable and agricultural purposes; well exploitation for industrial purposes is scarce in this area and it is mainly referred to the marble sawmills.

THE PIEZOMETRIC SURFACE AND ITS VARIATIONS

In 1999 two surveys have been performed in order to measure the water level in the wells; the spring survey has been carried out between April 28 and May 5, 1999 and 162 wells have been measured; the summer survey has instead been performed between August 30 and September 3, 1999; in this case 176 wells have been measured. The choice of these specific periods of the year has been made in order to allow an analysis of the two extreme situations of the groundwater: the first period corresponds in fact to the end of the major rainfall events and of the period of minimum groundwater exploitation; the second survey, performed at the end of the dry season, is related to the period which follows the maximum exploitation, especially of the wells distributed near the coast.

Figures 3 and 4 show the structure of the water table respectively in the spring and at the end of the summer.

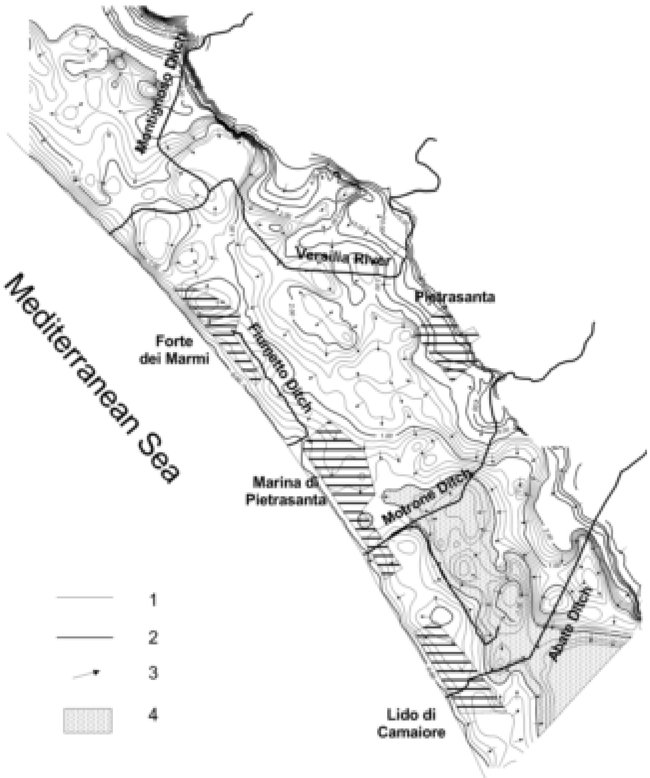

Figure 3 *Isopiezometric map, April 1999. 1: Isopiezometric contours, interval 20 cm. 2: Isopiezometric contours, interval 1 and 5 m. 3: Flow lines. 4: Areas with piezometric surface under sea level.*

Already in April, in the reclaimed lands extending as far as Motrone Ditch, the water table lies under sea level, reaching a maximum depth of one meter. This situation can be considered as physiological as the area itself is topographically depressed, with heights which are almost equal or lie just below sea level: in fact a reclamation system keeps the soils dry by draining and pumping the groundwater.

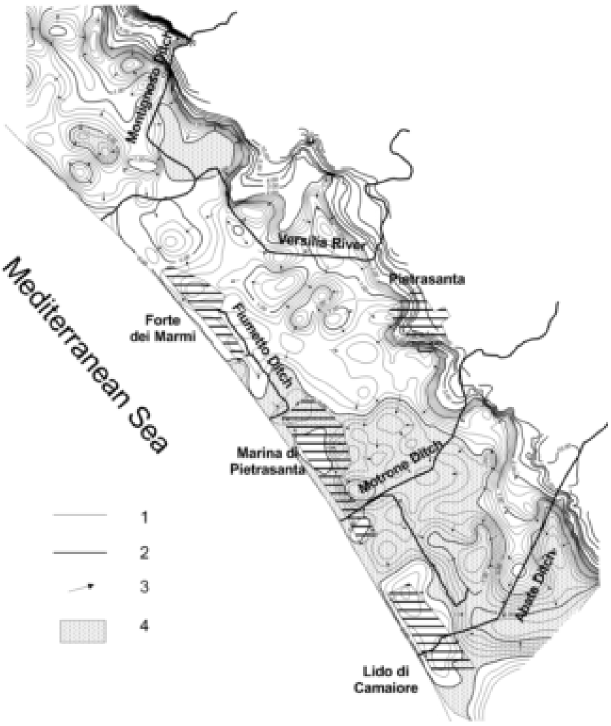

Figure 4 *Isopiezometric map, September 1999. For captions see Figure 3.*

In September we can observe a relevant increase in the size of the piezometrically depressed area, which now extends inland, almost up to the foot of the Apuane Alps. This is a consequence of the water pumping for irrigation purposes. In some areas along the coast the water table remains above sea level, whereas in others it goes slightly under sea level. An average fall of 0.51 meters can be recorded in the well's levels of the Versilia (Figure 5).

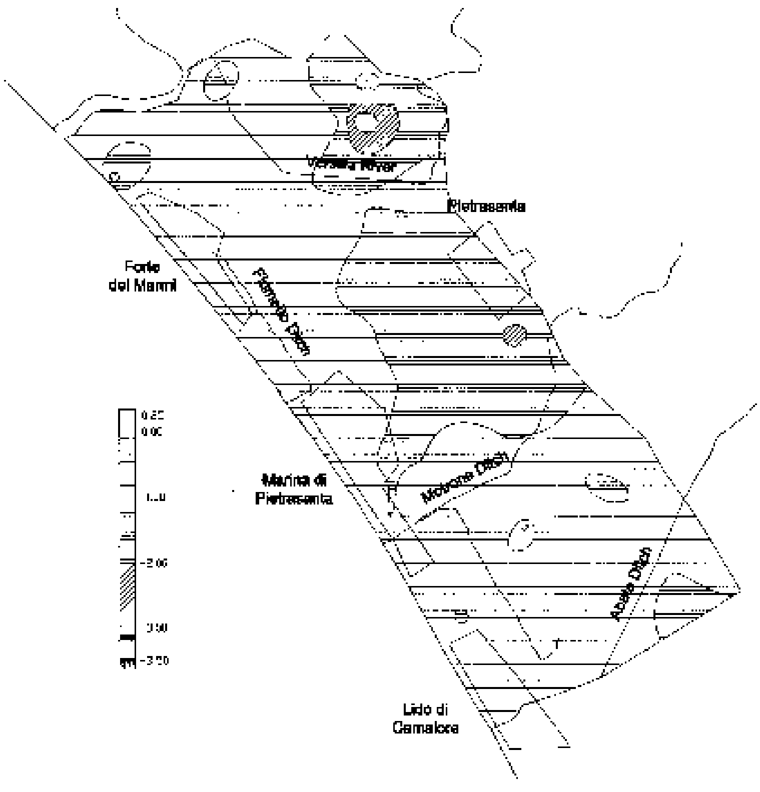

Figure 5 *Variations (meters) in the piezometric surface between April and September 1999.*

The availability of four piezometric surveys prior to 1999, - two dating 1982 (Serretti, 1983) and two dating 1994 (Salvatori, 1994) - allows us to report the phreatic surface variations in time.

In Figure 6 it is possible to observe the differences between September 1982 and September 1999. It is easy to recognize raising areas and lowering areas, with a maximum lowering of –2.40 m. The costal sand sector is completely characterized by lowering, but limited to 1.2 m.

The comparison between the two reconstructions shows that after 17 years a fall in groundwater levels prevails; however a general and marked lowering like that feared as a result of the increase in agricultural activity and in summer tourism has not occurred.

Concluding, in the marine and dune sand sector a consistent fall of the water table can be observed between the spring and the summer, but persistent depressions have not been recorded. This is probably due to the fact that here the groundwater users are careful not to exploit the wells too much in order not to pump salt water. Inland, where groundwater is mainly exploited for agriculture (with wide areas covered by greenhouses) and for marble sawmills, it is possible to recognize in the areas with piezometric raising from 1982 to 1999 the beneficial effects of water recycling.

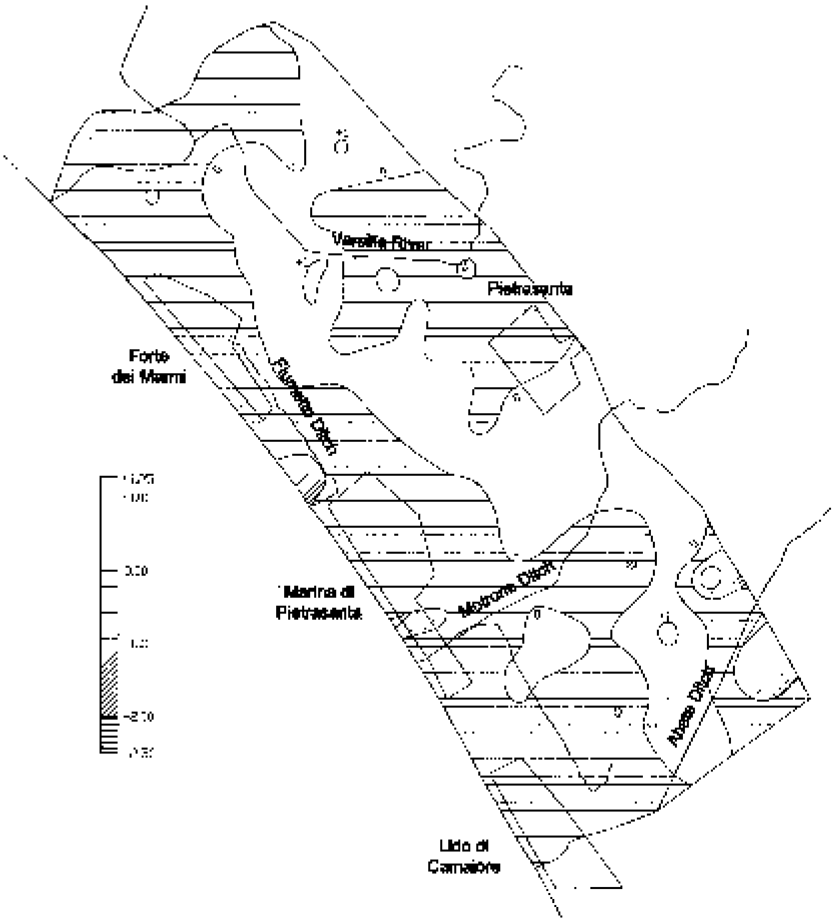

Figure 6 *Variations (meters) in the piezometric surface between September 1982 and September 1999.*

SALINITY OF THE GROUNDWATER

During the piezometric level measurements performed in 1999, a further survey has been carried out in the Versilian plain, with the purpose of measuring the electric conductivity of well and surface waters. 178 wells were measured in April and 335 wells in September. The readings mainly concerned wells of low to medium depth (i.e. within 20 meters), therefore the salinity picture in this study only refers to the upper part of the aquifer. In the deeper wells, higher conductivity levels have generally been recorded, showing a stratification of the water on the basis of its salinity. Unfortunately, the deep wells resulted to be too scarce in order to allow us to survey the distribution of salinity in the deeper aquifer layers.

In Figure 7, which describes the situation at the end of summer 1999, we can observe electric conductivity maximums in the lands surrounding the Versilia River estuary and in the areas characterized by drainage canals. Readings of the electric conductivity of the Versilia River have allowed us to verify that marine water runs up the river for at least 1 Km inland, as an effect of tides and sea storms. This ingression is favoured by the fact the Versilia River estuary is a canal port and its bed is periodically dredged down to 2 meters below sea level. This way the seawater entering the river infiltrates its bed and causes an increase in the salinization of the surrounding groundwater. In the reclaimed areas the high salinity is a consequence of the rise of the freshwater-seawater interface, as an effect of the canal's drainage in an area that lies below sea level.

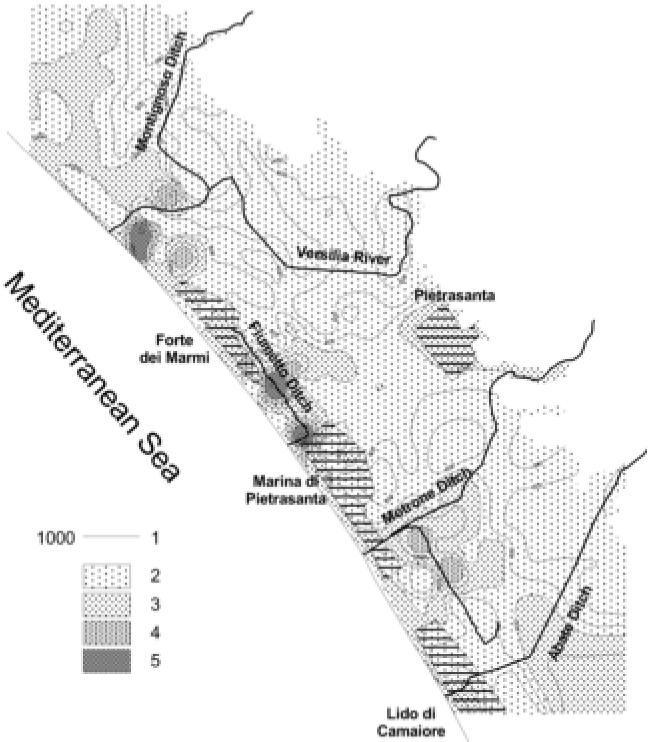

Figure 7 *Electrical conductivity of the well's water, September 1999.*
1: Isolines and their value in microSiemens/cm. 2: EC less than 1,000 µS/cm.
3: 1,000 to 2,000 µS/cm. 4: 2,000 to 3,000 µS/cm. 5: More than 3,000 µS/cm.

Inland the salinity values are generally lower than 1,000 µS/cm; the differences between the various areas are linked both to the different exploitation levels of groundwater and to the distance from the streams which generally feed the aquifers.

Figure 8 shows the variations in electric conductivity between the spring and the end of the summer 1999. In September it has been possible to observe not excessively high increases in electric conductivity, together with more scanty decreases. The average increase is around 300 µS/cm, which can be considered as a physiological value if related to the seasonal imbalance between the exploitation and the reloading of the aquifer.

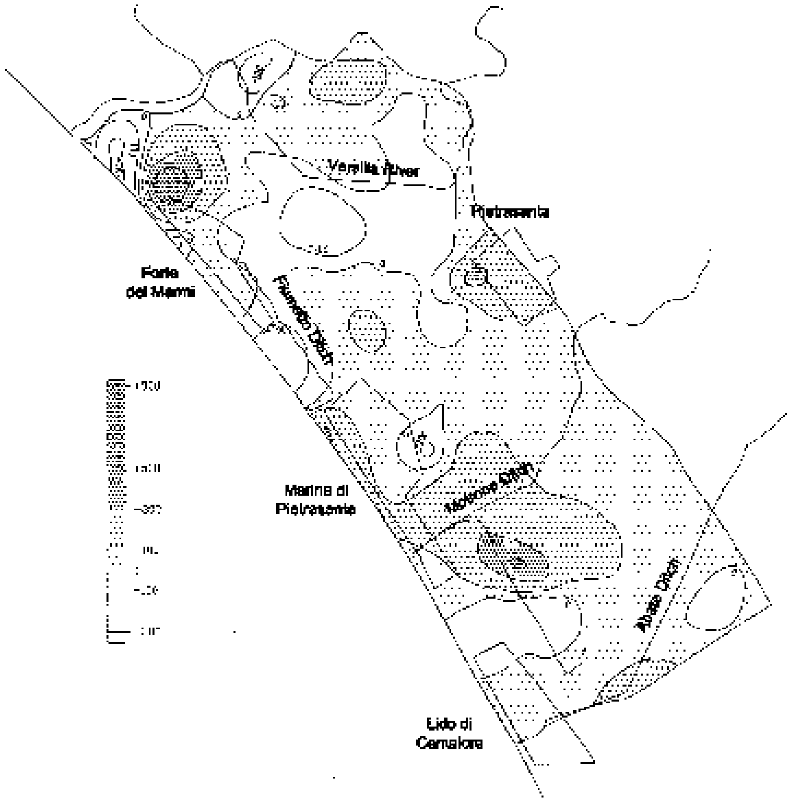

Figure 8 *Variations (µS/cm) in the electrical conductivity of groundwater between April and September 1999.*

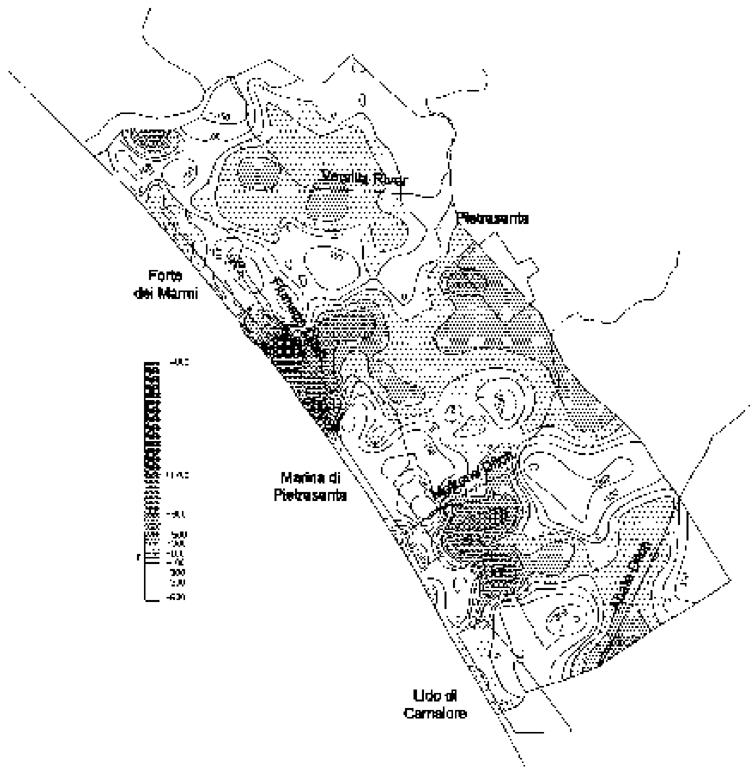

Figure 9 *Variations (µS/cm) in the electrical conductivity of groundwater between September 1982 and September 1999.*

Like for the piezometric level measurements, reconstructions are available of the groundwater electric conductivity in the past years (Serretti, 1983; Salvatori, 1994). Figure 9 shows the comparison between the electrical conductivity in 1982 and in 1999. We can observe a predominance of areas where salinity increased, up to 1,500 μS/cm. This shows that the 17-year-long period studied is characterised by a worsening in the average water quality; however, the presence of areas where salinity has diminished indicates that the situation is reversible.

In order to verify the causes for the salinity of the groundwater, an analysis for the determination of the Cl^- content has been performed on various samples of well water. 61 of these samples have been gathered in April 1999 and 277 in September.

46 samples were used to determine the main ion concentrations: the results indicated that generally the main chemical facies is alkaline-earth bicarbonate, which is normal for underground waters of recent infiltration; in the coastal belt the waters with an electric conductivity of over 1000-1500 μS/cm have a prevailing chemical facies of Na–Cl. Ca-Cl type waters also occur, which can be explained by inverse cat ion exchange (Na→Ca; Appelo & Postma, 1993) in salt water trapped in recent sediments

Figure 10 shows the chloride distribution related to the September 1999 readings, i.e. in conditions of maximum annual concentration following the summer exploitation. It is possible to observe three areas in proximity to the coast with high chloride concentration values, corresponding to the areas with the highest electrical conductivity values.

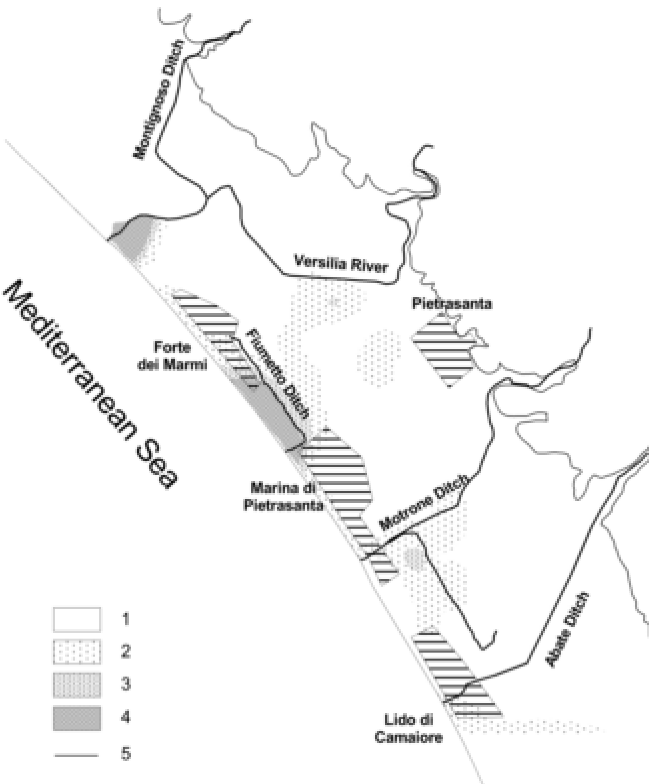

Figure 10 *Chloride concentration (mg/l) in the well's water, September 1999.*
1: Cl^- less than 100 mg/l. 2: 100 to 300 mg/l. 3: 300 to 500 mg/l. 4: More than 500 mg/l. 5: Plain boundary.

The two relative maximums present inland, with Cl^- values higher than 100 mg/l, cannot be due to the rising of the interface, given the high distance from the sea. The salinity values are therefore due to the fact that these are connate waters, still present in the sediments of recent deposition.

Figure 11 *Nitrate concentration (mg/l) in the well's water, September 1999.*

The nitrate concentration in 64 well water samples has also been determined (Figure 11). In a wide internal area we can observe values between 20 and 40 mg/l, with a maximum of over 50 mg/l. The nitrate pollution can be ascribed more to the sewer's leakage than to agriculture; in fact the most agricultural area is the Camaiore territory, where nitrates are less than 10 mg/l.

CONCLUSIONS AND PROPOSED ACTIONS

The information gathered has allowed the identification of the following causes for the salinization of the coastal sand aquifer:

1. the intrusion of salt water in the free aquifer of the coastal sand following the summer over-exploitation;
2. the direct entry of seawater into the reclamation canals and in the river mouths;
3. the rise of the freshwater-seawater interface in the reclamation areas, where the water table levels lies under sea level.
4. the rise of the interface following the continuous-pumping systems, built in order to keep the water table below the basements of some buildings (hotels, hospitals etc.).

To avoid the worsening of the situation, the following measures are suggested:

a) increase the rain infiltrating areas. Rain represents the aquifer's only source of reloading. In the past years the impermeable areas have greatly increased, as well as the rain collecting and draining systems. All this brings to a decrease in the infiltration rate and in the feeding the aquifer.
b) control and limits on the pumping activity discussed in point 4 above; the basements of buildings could be made impermeable instead of pumping the groundwater.

Inland the anomalous values of electrical conductivity are linked to:

1. anthropic pollution;
2. draining of connate marine water in the marine and lagoon deposits.

In order to improve the quality of the ground waters it is necessary to eliminate the sources of pollution and not to exploit the groundwater in the reclamation areas. We remark that the water resource in Versilia is considerable: in the plain the annual rainfall is between 1,000 and 1,200 mm, while the streams running across the plain come from the Apuane Alps where rainfall is over 3,000 mm/year. Since these streams have high flow rate variability, an increase in the water availability in Versilia could come from the realization of artificial groundwater recharging systems.

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