Anthropic evolution and its effects over the depletion of the unconfined aquifer in the Vomano river plain (central Italy)

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Abstract: the Vomano river alluvial plain in central Italy is an example of how the presence of river bed located quarries and hydropower plants affect the depletion of the alluvial aquifer water table. The dramatic daily discharge variations induced a major erosion phenomenon in the riverbed during the last 20-30 years and the split of the aquifer.

Key words: Hydrogeology, Hydrochemistry, Depletion, Accelerated erosion, Italy.

Introduction

Presented here are the results of hydrogeological research on the plain of the Vomano river, carried out with the aim of highlighting the relationships between variations in fluvial morphology produced by human activity over the last thirty years and the recharge conditions of the unconfined aquifer. The analysis was performed by comparing the present-day hydrogeological and morphological setting of the plain with the same historical aspects (Fig. 1).

The Vomano plain is made up of alluvial deposits distributed over four main orders of terraces: the oldest of these (orders I and II) are mainly present on the hydrographic left, while the more recent orders (III and IV) are present also on the hydrographic right. The older terraces are not very thick, and are separated in places by outcrops of clayey substrate. This means that they do not constitute an aquifer of any great importance, but they often represent isolated aquifers whose function is to recharge the aquifer in lower terraces (orders III and IV). The recent terraces, on the other hand, are very extensive and can reach a thickness of about 28 m in the coastal area. The unconfined aquifer is present in these deposits. The ancient and recent alluvial deposits of the Vomano river plain (Fig. 2) consist of gravelly, sandy-gravelly and gravelly-sandy bodies. Above these, in the middle-low part of the plain, clayey-muddy-sandy and muddy-sandy-clayey deposits are present, varying in thickness from few metres up to ca. 20 m near the coastal belt. Sandy-gravelly deposits crop out in the upper part of the river valley. The substrate beneath the alluvial deposits (Fig. 1) mainly comprises lithotypes with low permeability which act as aquicludes, such as the marly clays and clayey marls of the Cellino Formations and Argille Grigio Azzurre. In the upper part of the plain, however, the substrate is made up of more permeable lithotypes: these are arenaceous marly deposits originating from the Laga Formation and Messinian deposits. The top of the substrate of the alluvial deposits is characterised by the presence of a paleo-thalweg, shifted some hundreds of metres north or south in relation to the present-day riverbed (Fig.1).

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The hydraulic conductivity (CASSA PER IL MEZZOGIORNO, 1971) of the gravelly and sandy-gravelly deposits lies between the values of 2 x 10^{-3} and 1 x 10^{-3} m/s, whereas conductivity of the clayey-muddy-sandy deposits presents values in the order of 10^{-4} m/s. Hydraulic conductivity of the Plio-Pleistocene marly-clayey substrate deposits underlying the alluvial deposits present values of around 3 x 10^{-6} m/s.

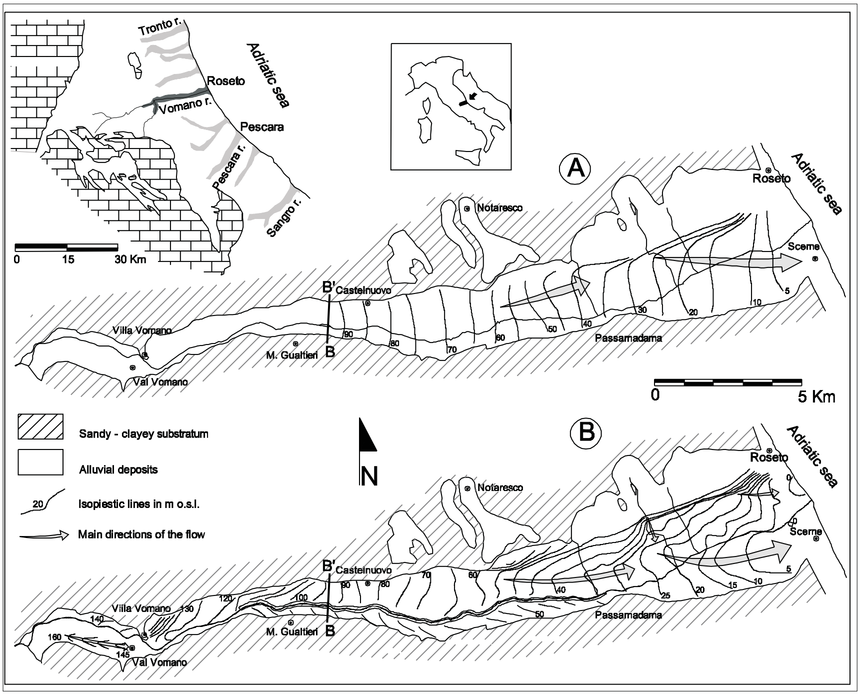

Figure 1. Localization and piezometric map of the alluvial aquifer of the Vomano river. A: by CASSA PER IL MEZZOGIORNO (1971); B: remarks of the year 2000.

RESULTS AND DISCUSSION

In the context of the present paper, research into the hydrogeology of the Vomano river plain has allowed the following conclusions to be drawn.

- In the upper and middle-low part of the plain, exclusively in the deposits of the low terraces (orders III and IV), the unconfined aquifer presents monolayer features (Fig. 2), with medium-high hydraulic conductivity. Near the coastal belt, however, the unconfined aquifer has the characteristics of a multilayered aquifer: the bottom layer is always made up of gravelly, sandy-gravelly, or gravelly-sandy bodies, while the upper one is represented by clayey-muddy-sandy and muddy-sandy-clayey deposits with low conductivity.
- The unconfined aquifer is recharged mainly by fluvial waters from calcium-bicarbonate facies of Apennine origin, as confirmed by the values of electrical conductivity and groundwater temperature. River recharge is further testified by the chemism of the groundwater.

Close to the riverbed in fact, the waters present calcium-bicarbonate facies with low saline content. Waters of this type are also found near the main drainage axes, which drain the waters of the Vomano river and its primary affluents through paleo-thalwegs.

- The aquifer is also recharged by deep waters of Pliocene or Messinian origin (Desiderio et al., 2001). These waters, rising along fault-associated fracture zones in the Plio-Pleistocene substrate deposits, are carried to the base of the unconfined aquifer. The mixing of sodium-chloride and calcium-sulphate facies Pliocene and Messinian mineralised waters with the calcium-bicarbonate waters of the aquifer lead to different hydrochemical facies in the aquifer areas close to the zones where the mineralised waters emerge. Recharge by the Messinian and Pliocene waters is very slight and mainly influences the chemism of underground waters, causing enrichment in Cl^-, Na^+, Mg^{++} and SO_4^{--} of the calcium-bicarbonate waters originating from fluvial recharge.
- Water circulation in the aquifer is closely dependent on the paleo-thalwegs, along which there are the main drainage axes.

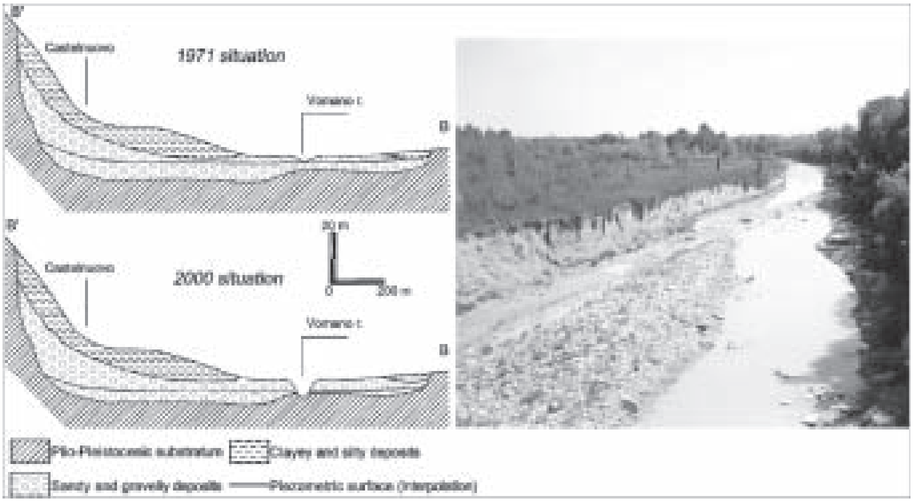

Figure 2. At left: evolution of profile of the section B-B' since 1970 till today (mark in Fig. 1). The first section created with the study of 1971(Cassa per il Mezzogiorno) while the second one created with the present study. At right: the Vomano riverbed deeply embanked in its alluvial deposits and in Plio-Pleistocene sequence for at least 20 m.

A comparison between maps of the years 1961 and 1971 (Cassa per il Mezzogiorno, 1971; Desiderio et al., 2003) and those created with the present study has made it possible to highlight the disconnection between fluvial waters and alluvial deposits in the intermediate portion of the plain (Figs. 1 and 2). This break has been caused by accelerated riverbed erosion, attributable to human activity (presence of river-bed located quarries and hydro-power plants), which has brought to the surface the clayey substrate on which the alluvial deposits remain for a stretch of over 10 km (Fig. 1), deepening the riverbed by up to 20 m in the last 20 years or so. This accelerated bed erosion has not only affected the hydraulic

continuity between fluvial waters and alluvial deposits; it has also modified the recharge and circulation characteristics of the groundwater. In 1971 (Fig. 2), in the stretch of river where the substrate presently surfaces, the aquifer of the plain was recharged by the fluvial waters. Nowadays, however, in this section of the riverbed, the groundwaters are drained into the river.
As compared to the period preceding 1971, then, the aquifer of the plain has undergone a marked decrease in fluvial recharge. The sharp reduction of the water table has therefore been caused by diminished fluvial recharge, and by the altered hydraulic relationship between river and alluvial aquifer. This phenomenon is of course accentuated even further by the considerable increase in water withdrawal resulting from water supply due to the economic development of the lower Vomano valley.

CONCLUSIONS

The reduced water volume has been estimated by considering the hydrodynamic parameters of the aquifer and the differences between the 1971 piezometric map and that of the present day. In the mid-upper stretch of the valley (Castelnuovo and surrounding area), the groundwater discharge has been roughly estimated as $3*10^6$ m^3/year in the 1970s and $1.5*10^6$ m^3/year today. The dramatic piezometric modification in the lower part of the plain, with marked accentuation of the main drainage axis, is also to be referred to increased withdrawals in the area. Another probable consequence of the sharp reduction of water stored in the aquifer is the increased salinity due both to the contribution of Pliocene and Messinian mineralised water, and to pollution phenomena, as evidenced by the high nitrate content. The moderate increase in concentration of Cl^-, Na^+ and Mg^{++} near the coastal area is to be attributed to modest marine intrusion phenomena.

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