



Proceedings

# SWIM21

June 21-26 | 2010

Azores · Portugal 21st Salt Water Intrusion Meeting

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## Apulian coastal aquifers and management criteria

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### ABSTRACT

The quality of groundwater of Apulian carbonate aquifers is severely affected by seawater intrusion which reduces the availability of high quality groundwater. To reduce these risks, some regional regulations were defined from eighties with the purpose to control the number of wells, the location and the authorised well abstraction rates. The practical effects of these management criteria, the temporal and spatial trend of recharge, groundwater quality and seawater intrusion effects are discussed. Proposals for new management criteria are defined.

### INTRODUCTION

The Apulian region, dominated by highly fractured and karstic carbonate rocks, is widely exposed to groundwater quality degradation risks. The whole Apulian groundwater body has undergone a twofold pollution by human activities: saline pollution which is progressively affecting larger portions of land, and biological and chemical-physical pollution which is gaining importance and is mainly concentrated around urbanised areas. The latter effect is mainly due to the circumstance that these karstic aquifers are highly vulnerable (Polemio et al. 2009b). In the region the main hydrogeological features consist of the Gargano and Tavoliere units and the hydrogeological structures of Murgia and of Salento. All these areas are composed of carbonate rock, except for Tavoliere, which is a large sedimentary aquifer not significantly affected by seawater intrusion (Figure 1). Vulnerability to seawater intrusion is substantially lower in Gargano, than in Murgia and Salento. For this reason, and because of the low data availability, Gargano has not been studied in detail and attention is focused on Murgia and Salento (Polemio *et al.* 2009a and relative references, 2009c).

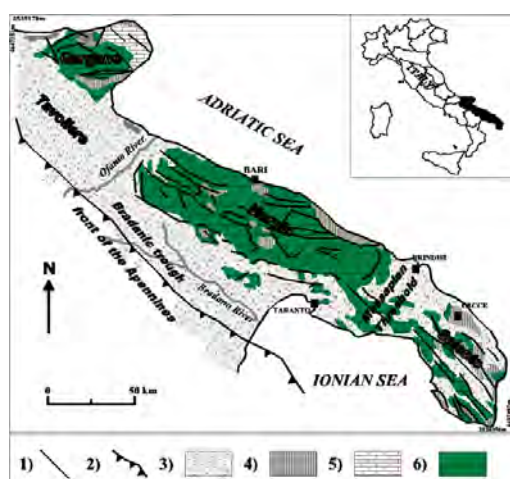
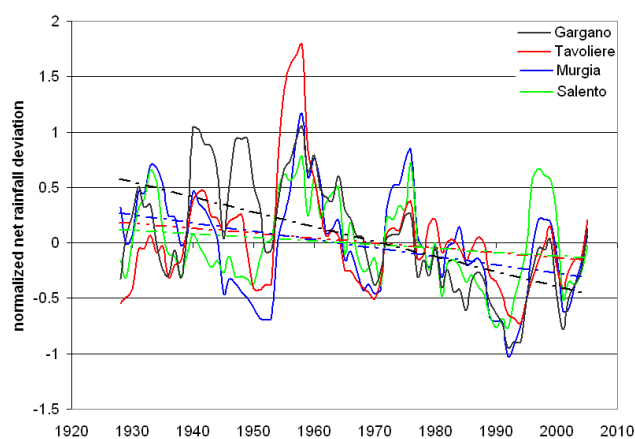


Figure 1. Geological scheme. 1) Fault, 2) front of the Apennines, 3) recent clastic cover, 4) bioclastic carbonate rocks and calcarenites, 5) carbonate platform rocks, 6) chert-carbonate rocks.

### RECHARGE AND DISCHARGE TREND

Rainfall and temperature monthly time series from 1916 till 2005, using data published by National and Regional Hydrological Service, were analysed. Mean annual rainfall (MAR) varies from 430 to 1170 mm in the Apulia region, with an average value of 644 mm (Polemio & Casarano 2008). Over the whole study period, the Apulian annual rainfall trend is equal to -0.43 mm/yr. Due to the karstic nature of the main Apulian aquifers, the amount of runoff is a very low percentage of net rainfall. The yearly annual recharge can therefore be roughly assessed by taking the net rainfall as annual rainfall minus real evapotranspiration.

Mean annual net rainfall (1924-2005) varies from 52 to 675 mm in the region, with a regional average of 146mm. For each time series, the net rainfall trend (NRT) was strongly negative. The absolute value of NRT roughly increased or rather got worse as MAR



**Figure 2. Normalised deviation of 5-year moving average of annual net rainfall and trend for main Apulian hydrogeological units and structures.**

increased. NRT ranged from  $-0.23$  to  $-3.52$  mm/yr, grouping the time series by mean annual rainfall. In the whole period, the decrease of net rainfall amounts to 21.6 - 42.2% of mean net rainfall. The 5-year moving average of annual net rainfall was assessed (Figure 2). Negative trends are evident for all spatial domains; an anomalous sequence of negative values is evident since 1980.

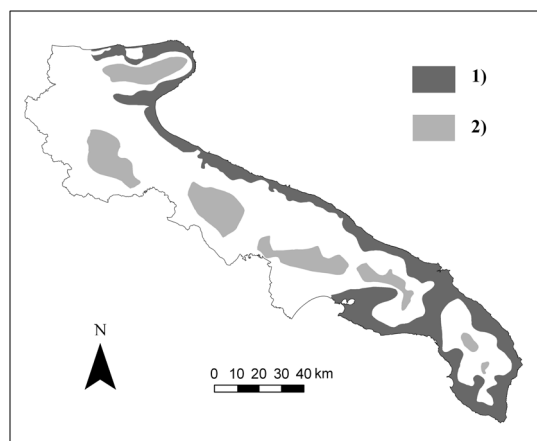
Pallucchini (1936) described the existence in Apulia of only some deep wells located in Tavoliere area in 1936. The level of Apulian groundwater utilisation was very low (zero in large areas) until the end of the Second World War. A continuously increasing trend of groundwater abstraction started in the

second half of 1950s due to new well constructions; this trend is still going on. The current well number is not well known due to a high percentage of abusive wells; anyhow, this number approximates many tens of thousands. The continued effect of recharge variability and increasing exploitation can be assessed by measurements of piezometric heads and coastal spring discharge. Tens of monthly piezometric time series (1929-2008) demonstrate that the spatial piezometric trend is declining, ranging from a low rate (Gargano) to average (Salento) and a high rate (inland portion of Murgia and Tavoliere). A significant coastal spring was selected along the Adriatic Sea. The discharge of this spring (Sorgente Fiume Grande) was measured from 1926 to 2009. Its mean discharge in the last hydrological year was equal to 60% of the mean annual discharge (620 L/s) notwithstanding the last year being not dry at all. The straight line trend of spring discharge highlights a decreasing trend equal to  $-4.4$  L/s year<sup>-1</sup> in the whole period (Polemio *et al.* 2009c).

## GROUNDWATER REGULATIONS IN APULIA

Until 1984, groundwater abstraction in Apulia (and roughly in Italy) was regulated by law mainly from an administrative point of view, but the effects of seawater intrusion and the application of hydrogeological management criteria were completely neglected. In 1984, the regional authorities defined by law the safeguarding and decontamination plan called PRA, which determines the quality zonation of Apulian groundwater and the regulation of groundwater and aquifer utilisations as a function of the risk of groundwater degradation (Apulia Regional Administration 1984). As an example, the drilling of new pumping wells was forbidden where the salinity was too high due to the mixing with saline groundwater (no-abstraction zone, called NOD zone hereafter, Figure 4). These areas, where water quality was lowest, are located along the coast as an effect of seawater intrusion. The boring of new abstraction wells was regulated where groundwater quality was so high to permit drinking utilisations (Figure 3). This was roughly the case for the main recharge areas of Apulian aquifers.

The Water Protection Plan PTA (Apulia Regional Administration 2007) distinguishes zones of quantitative protection (QP zone), as in the example of Tavoliere, the most overexploited Apulian aquifer, in which new abstraction permissions are suspended (Figure 4). For the coastal and karstic aquifers, zones hit by seawater intrusion (NOD' zone), located along the coast, and zones defined as qualitative and quantitative protection zones (QQP zone), located between recharge or inland areas and NOD zones, are distinguished. In the NOD' zone the issue of permits for constructing new wells and for abstraction of fresh groundwater is "suspended" even when the probability to find fresh groundwater in this zone is low. It is only possible to drill for new pumping wells when using deep and saline groundwater for specific purposes, but a specific assessment is required. The



**Figure 3. Groundwater quality zonation, as regulated in 1984 (PRA): 1) low quality groundwater by salt contamination (NOD zone), 2) high quality groundwater (abstraction for drinking use permitted).**

**Figure 4. Groundwater quality zonation, as regulated in 2007 (PTA): 1) low quality groundwater by salt contamination (new fresh water abstraction not allowed, NOD' zone), 2) qualitative and quantitative protection zone (QQP zone, regulated new pumping wells), 3) quantitative protection zone (QP zone, new abstraction permits suspended).**

authorization renewal of pre-existing wells is only possible on the condition of two criteria: the well bottom (m below sea level) should be less than 30, 25 or 20 times the piezometric head (m above sea level), in the case of respectively Gargano, Murgia and Salento; the maximum abstraction rate must cause a drawdown (m) less than 50% (Murgia) or 30% (Gargano, Salento) of the piezometric head (m asl).

In the QQP zone, new authorizations are again regulated considering the well bottom (condition quite similar to NOD' zone, but declined if groundwater is locally confined) and maximum allowed abstraction. It should cause a drawdown (m) less than 60% (Murgia) or 30% (Salento) of piezometric head (m asl); TDS should be less than 1 g/l and chloride concentration should be less than 500 mg/l.

Both plans do not explain in detail the criteria defined to plot NOD zones and QQP zone but clearly consider areas in which the salinity and the concentration of pumping wells are high.

## THE ASSESSMENT OF QUALITY DEGRADATION FOR SEAWATER INTRUSION

A very simple criterion to detect the absence or presence of seawater intrusion quality degradation was defined for karstic Apulian aquifers (Polemio *et al.* 2009a). The key idea is to define a boundary or threshold between pure fresh groundwater and any type of mixing between fresh and saline groundwater. On the basis of a hydrogeochemical classification, the upper salinity limit (TDS) or threshold value for pure fresh groundwater was determined equal to 0.5 g/L, by statistical analysis.

A multitemporal spatial analysis was then performed considering the time variations, from 1981 to 2003, of the threshold contour line TCL. TCL divides the aquifer into two portions, which change as time varies: the upper one, including the recharge areas, where pure fresh groundwater flows, and the lower portion, bounded by the coast, where groundwater flowing towards the sea becomes progressively contaminated by seawater (Polemio *et al.* 2009a). TCLs showed a shrinking or a quality worsening, especially in Salento, with small and secondary exceptions. This trend was also demonstrated by the time series of chloride concentration (Figure 5). Three types of areas with overlapping TCLs can be distinguished: in the first type salinity remained permanently below the threshold, indicating a low vulnerability to seawater intrusion. In the coastal zone, salinity is always above the threshold due to sea water contamination. In the intermediate or transition zone, salinity is a delicate function of climate, recharge and exploitation variability or, predominantly, to man's ability to manage groundwater resources (Polemio *et al.* 2009a).

## CONCLUSIONS

The PRA approach failed to protect groundwater quality and availability. It is too soon to assess the practical effects of PTA approaches in terms of groundwater quality and availability. From a methodological point of view, PTA seems too much linked to a single-well criterion, based on the Ghyben-Herzberg principle of a sharp interface, and does not consider overlapping effects of nearby wells and the whole amount of abstraction as compared to the variable recharge.

On the basis of the results, some management criteria for groundwater resources are proposed. Excluding the coastal zone, the abstraction of fresh groundwater could be increased up to the limit of annual or multi-annual recharge, in the latter case assessing carefully the aquifer compensation effect during drought or wet periods. Abstraction for drinking purposes in the inland zone could be increased without restrictions. The effects of the abstraction should be assessed in detail in the intermediate zone. Pumping in the coastal zone should be allowed only for specific uses for which

**Figure 5. Map of zones vulnerable to seawater intrusion and salinity trend in selected wells (Polemio et al. 2009a): 1) salinity always greater than 0.5 g/L (very high vulnerability), 2) salinity always less than 0.5 g/L (low vulnerability), 3) salinity above or below threshold depending on time (mean to high vulnerability), 4) selected spring, 5) negative and 6) positive trend of chloride concentration.**

brackish or saline water are acceptable. The abstraction plan should be defined by taking into account different pumping and recharge scenarios. In the intermediate and coastal zones, the wells (number, location, geometry and construction techniques) should be optimised on the basis of local hydrogeological characteristics. If these goals can be achieved, the high quality of fresh drinking groundwater in the inland zone will be permanently maintained and will remain free from the effects of seawater intrusion.

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