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vulnerability and evaluation of groundwater

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# Assessment of water table aquifer intrinsic vulnerability and evaluation of groundwater quality in an area including the Ticino Valley Natural Park Valley (NO, Piemonte, Italy).

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## Riassunto

La necessità di tutelare le risorse idriche sotterranee, rende fondamentale che una superficie sempre maggiore di territorio italiano venga studiata al fine di valutare la vulnerabilità intrinseca degli acquiferi all'inquinamento. In questo contesto è stata esaminata un'area comprendente il Parco Naturale della Valle del Ticino.

La vulnerabilità intrinseca dell'acquifero libero è stata valutata mediante la metodologia SINTACS, tramite la definizione dei 7 parametri caratterizzanti l'acquifero in oggetto e del tipo di impatti riconosciuti.

Sono stati inoltre analizzati alcuni parametri geochimici per verificare le qualità specifiche delle acque sotterranee, allo scopo di individuare eventuali relazioni tra vulnerabilità dell'acquifero e qualità delle acque.

[Parole chiave: acquifero libero, complessi idrogeologici, nitrati, vulnerabilità]

## Abstract

The need of protecting groundwater requires the study of a growing fraction of the Italian territory, in order to assess aquifers intrinsic vulnerability to pollution. In this context an area including the Ticino Natural Park has been examined.

SINTACS has been used for the evaluation of intrinsic vulnerability; this method requires values to be assigned to the seven SINTACS parameters which describe the aquifer and the impact scenario in the area.

Moreover, in order to evaluate groundwater quality and to identify the relationship between aquifer vulnerability and groundwater chemistry, some geochemical parameters have been analyzed.

[Key words: water table aquifer, hydrogeologic complexes, nitrates, vulnerability]

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## 1. INTRODUCTION

Aquifers Vulnerability Maps are an important tool for environmental planning, as they combine data related to human activities responsible for an effective or potential degrade, and data related to aquifer intrinsic characteristics.

Groundwater vulnerability maps allow to evaluate the impact on environment caused by accidental, continuous or periodic events.

To make a vulnerability map it is necessary to collect, catalogue and select all the available data concerning physical and human aspects of the territory under study. Subsequently the data is mapped on a cartographic basis.

The initial phase of the study consists of the derivation of the hydrogeologic description, the intrinsic vulnerability assessment of the water table aquifer, and the qualitative and quantitative analyse of the environmental situation.

For this purpose, a preliminary study on hydrogeologic and hydrogeochemical characterization of the area has been fundamental;

the area has an extension of more than 320 km<sup>2</sup>, including all the towns belonging to the Ticino Valley Natural Park in Piemonte.

The geomorphologic main elements are the plain surrounding Novara and a portion of the morainic structure of Verbano and the “highland”, situated between Marano and Bellinzago, directly connected with the morainic hills.

## 2. HYDROGEOLOGIC INFORMATION AND COMPLEXES IDENTIFICATION

The geology of the area shows a dominant presence of fluvial and fluvial-glacial deposits of different age and glacial till belonging to different glaciations, and a minor presence of aeolic and slope deposits and alluvial fan. On the basis of this geologic scenario 8 hydrogeologic complexes have been identified and they are shown in table 1 and in Figure 1.

**Table 1 - Description of hydrogeologic complexes individuated**

Hydrogeologic complex	Complex description	Average thickness	Permeability (m/s)	Notes
<b>Clayey Complex</b>	marine clay alternated with sandy layers, little gravel	unknown	very low (estimated)	it is the base of the described sequence
<b>Sandy-Clayey Complex</b>	alternate between sand and clay, subordinately gravel	unknown	variable between medium to low, according to which level is considered	in the complex there are confined aquifers or aquitards in coarser levels
<b>Sandy-Gravelly-Clayey-Complex</b>	alternations between sand and clay, gravel and pebbles, often with clay; sediments are partially or plentifully altered	from 0 to 100 meters	mainly of the order of 1E-04 m/s; sometimes un order less	in the complex there is the water table aquifer
<b>“Highland” alluvial complex</b>	fluvial-glacial deposits, sand and gravel often over consolidated	From a few meters to about ten meters	medium-low	no aquifer
<b>Principal alluvial complex</b>	fluvial-glacial deposits, generally characterized by gravel, sand et little clay. Sometimes thin clayey-silty layers are prevalent among coarser materials	From about ten meters to beyond 50 meters	variable between 1E-04 m/s and 1E-03 m/s	water table aquifer except in eventual limited sectors

<b>Floodplane complex</b>	late fluvial deposits (mostly gravel), slope deposits, slope deposits and alluvial fan (sand and gravel).	mainly about ten meters, sometimes more	High	water table aquifer
<b>Morainic Complex</b>	glacial till, glacial-lacustrine and a partly fluvial-glacial deposits	maximum value exceeds 80 meters	high permeability variation due to the grain size heterogeneity and silt presence	complex contains water table aquifer, with high depth to groundwater and perched aquifers of secondary importance
<b>Silty Complex</b>	aeolic thin sediments (chiefly silt), deeply altered	a few meters	Very low permeability of the order of $1E-7 \div 1E-8$ m/s	no aquifer

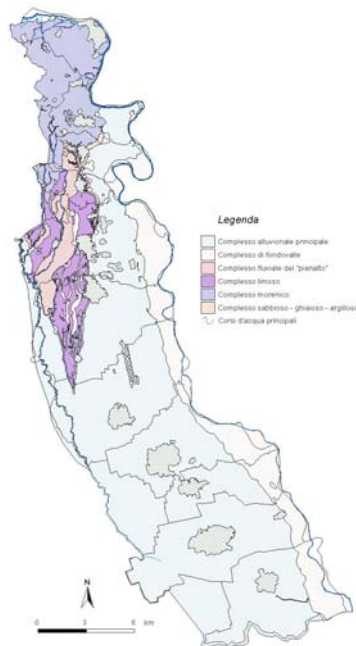


Figura 1: Hydrogeologic complex Map

### 3. HYDROGEOLOGIC STRUCTURE

The analysis of the underground geological structure, together with hydrogeochemical analysis, have allowed to build a conceptual model

in which two aquifers have been identified, a water table aquifer and a deeper one, confined or semi-confined. Relationships between them are at times not so well defined.

Hydrogeochemical differences between them, particularly in high concentrations of iron and manganese in deeper waters and of nitrates in superficial ones, do not seem to be sufficient to describe the normal geochemical characterization of a single aquifer. Thus, terms like *deep part* of the aquifer and *water table aquifer* (or *superficial part* of the aquifer) have been used to indicate two sectors of the hydrogeologic system with different geochemical and hydrostructural characteristics.

The deep part, placed in the more permeable levels of the sandy-clayey complex, has a permeability of  $1E-04$  m/s and is mainly exploited by industries and aqueducts. Chemical characteristics distinguish it from the superficial part of the water table aquifer as iron and manganese concentrations are higher than in the superficial sector, while nitrates are often lower. Other parameters can have different concentrations, but their differences are not relevant since not largely present.

#### 3.1 Water table aquifer

The water table aquifer, situated in bottom-valley complex, alluvial principal complex sandy-

gravely-complex and sometimes in morainic complex, extends itself over the plain area. Only the deeper part of the morainic structure is interested by this aquifer, while in the superficial region secondary perched aquifers can be found. The groundwater flow pattern is shown in Figure 2



Figure 2: Water table aquifer Map

Depths to groundwater change a lot between plain and hilly areas. In the first case values vary from a few meters in the western area (where there are blowout aquifers), to about 15 meters near to the terrace in the principal plain, towards the Ticino river, and again lower values in the Ticino valley. In the second case, on the contrary (except the Castelletto Ticino area), depth to groundwater is higher, from 10 m in the southern area of “highland”, to more than 50 m between Varallo Pombia and Oleggio.

The plain is characterized by a largely exploited aquifer, with a permeability of  $1E-04$  m/s  $\div$   $1E-03$  m/s, while the hilly area, both morainic and fluvial-glacial, has a permeability of  $1E-05$  m/s and a minor specific discharge, with a consequent lower number of wells.

The flow pattern of the water table aquifer (isopiezometric lines have N-S direction in the eastern sector) shows a strong drainage effect performed by the Ticino river, which flows enclosed in its valley, representing the local lower piezometric level.

In the principal plain, where the Ticino river does not provide any influence, the main drainage action is caused by the Po river (located beyond the study area), causing the isopiezometric lines to flow in direction approximately E-W or NW-SE. Where flow lines change direction the most evident mobile ground water divide is individuated.

In the area more to the North, isopiezometric lines show convergent and divergent patterns with related ground water divide and drainage axes, of which the most pronounced is located in the “highland” zone.

Near slopes or escarpments isopiezometric lines are brought closer, with gradients variable between 1% e 3%, as happens also along morainic relieves, where there is a lower permeability degree. The main plain has instead a lower gradient, which varies between 0,1% e 0,4%.

Water table aquifer is mostly recharged by irrigation, by meteoric precipitation, by eventual loss from canals, by some water streams in certain periods of the year. Discharge are due mainly to the drainage action of rivers, to blowout aquifer and to wells withdrawal.

The principal cause for the increasing piezometric level has been identified in irrigation, while precipitations cause only temporary peaks in the annual regime. The Maximum takes place between August and September, while minimum occurs between January and March. The beginning of the piezometric level ascending phase occurs from the end of March or the beginning of April, when the flooding irrigation of rice-field begins, and it continues to increase until August or

September. When irrigation stops, piezometric levels start to decrease.

The time necessary for the ascending phase is rather long and it is justified by the medium permeability degree of  $1E-04$  m/s, obtained through elaboration of the available data.

Average oscillations of piezometric level change according to the area. While in the plain variations of 3-4 meters can occur, even if mainly they are in the order of 1 or 3 meters, in the hilly area maximum variations reach hardly 1.5 meters. Near to the main morphologic terrace oscillations are strongly limited because of the drainage action of the Ticino river, which mitigates piezometric level oscillations and reduces its variations.

In the "highland" area the situation is different. Here recharge is due to precipitations, as cultivated areas are smaller with respect to the plain. The slow response of the aquifer to the precipitation input is due to the low permeability in this area ( $1E-05$  m/s) and to the high depth to groundwater values (mainly between 20 and 50 m, some value around 10 m) that cause long time of travel for the infiltration water.

The Ticino river, deeply enclosed in the Novarese plain, produces almost always a drainage effect. However, in periods of strong precipitations, its level goes up quickly and the closer portion of the aquifer will receive water from the river.

The Terdoppio torrent, located in the western part of the area, is in an equilibrium condition with water table piezometric levels, since in some areas it seems to drain the aquifer, while in other ones it gives water to it.

In the sector between Cameri and Cerano, there are a lot of blowout aquifers, located along a narrow band, that extends until Vaprio d'Agogna, which drain the water table aquifer.

#### 4. GROUNDWATER QUALITY

Drinking groundwater quality is defined through the water classification for potable use according to the methodology proposed by IRSA GNDICI (Civita *et al.*, 1993), which refers to DPR 236/88, providing maximum acceptable concentration levels for different physical, chemical, microbiological parameters considered

important for human health and consequently used to define potable criteria for drinking water.

These parameters are divided into two groups: hardness, specific electric conductivity at  $20^{\circ}\text{C}$ , chloride, sulphates, nitrates belong to the first group, while ion ammonium, iron and manganese belong to the second group.

Each parameter concentration allows to classify water quality in three categories. Water that can be used for human consumption without any treatment and also available for almost all irrigation and industrial uses belongs to the first class A; potable water without treatment and with some limitations for industrial and irrigating uses belongs to class B; to the last class C belongs water that can not be used for drinking purpose (it requires some treatments) and that has important limitations if used for irrigation and industrial purposes.

Samples collected in wells, superficial water bodies and blowout aquifer have been analyzed and parameters concentrations distribution has been computed. All the samples of the water table aquifer have shown concentration values of conductivity, chloride, sulphates inferior to the limit between A and B classes (respectively  $\leq 1000 \mu\text{S/cm}$ ,  $\leq 50 \text{ mg/l}$ ,  $\leq 50 \text{ mg/l}$ ), therefore the parameters that determine the quality are hardness (a single sample) and nitrates.

Then the total quality map was generated, where it is possible to see the presence of classes A and B in the area under study (class C is not present, since there is no water samples collected from the water table aquifer that have very high parameters concentrations).

Water quality in the unconfined aquifer is often included in class B. This water can be used for potable uses, with some restrictions for other applications. Samples belong often to this class since nitrates concentration exceeds the limit of  $10 \text{ mg/l}$  (maximum amount allowed in class A). About 80% of the analyzed wells, exploited for drinking purposes and localised mainly in the towns of Bellinzago, Cameri, Galliate, Oleggio, Pombia, Romentino e Varallo Pombia, (wells that are located in both parts of the aquifer), are included in class B. Only some wells located in

the “highland”, in the proximity of Oleggio, and other ones in Cameri and Oleggio are excluded.

Samples collected in the Ticino Valley contain water of the river, taken in three different points. None of them has high nitrate concentration, so in this sector the water also belongs to class A; this is likely due to the water exchange typical of drainage zones. In regards to the morainic area, a large number of samples have been collected from superficial water; therefore the class B rating assigned to this area is mainly specific to superficial water.

## 5. INTRINSIC VULNERABILITY TO POLLUTION OF THE WATER TABLE AQUIFER

Characteristics of the water table aquifer, supported by other information, have allowed to assess aquifer intrinsic vulnerability to pollution.

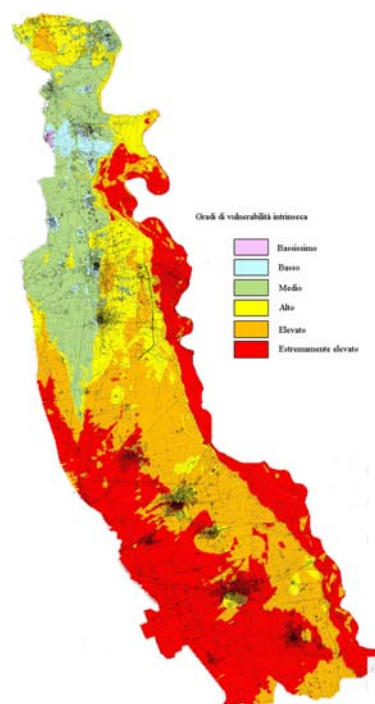
A SINTACS rating has been assigned to the measured, computed or collected data of depth to groundwater, to fluid capacity infiltration in different complexes and in the aquifer, to hydrogeologic characteristics of the aquifer and unsaturated zone, to soil/overburden characteristics (if present), and to hydraulic conductivity range of the aquifer and topographic slope; moreover weight strings, chosen according to the impact scenario for each part of studied territory, have been associated to the SINTACS ratings.

By means of this procedure (SINTACS R5 – Civita & De Maio, 2000) the Intrinsic Vulnerability Map of the water table aquifer has been obtained and it is shown in (Figure 3).

A large part of the area is characterized by an extremely high or high vulnerability. The causes are the lack of soil, the reduced depth to groundwater, the medium permeability (sometimes medium-high) of the system aquifer as well as the weight string chosen to describe the scenarios of the area; in fact the severe impact string has been chosen according to the presence of urbanized and intensive cultivated areas. Where permeability is higher, depth to groundwater is also larger. Moreover cultivated areas are not so diffused, consequently the impact is less severe.

The same vulnerability degree is determined in the interior Ticino valley. In this case vulnerability

is also influenced by aquifer features, medium-high permeability, lack of soil and small depth to groundwater; all these aspects are consistent with a seepage impact, typical of drainage areas.



**Figure 3: Vulnerability Map**

In the principal plain the lower vulnerability degree in the area between Oleggio and Bellinzago is due to the thickness of the soil (that exceeds 1 m) and to the different features of the aquifer, which is characterized by a higher percentage of fine materials.

In the Northern area vulnerability is again high and extremely high, due to the depth to groundwater (it decreases, until some springs are originated along the connection hill-plain), increasing hydraulic conductivity and partial infiltration.

In regards to the hilly area, intrinsic vulnerability degree is lower (primarily medium) in comparison with the plain area, because of higher depth to groundwater, lower permeability degree, presence of thin grained sediments in the

unsaturated and saturated zones and thick soil existing almost everywhere. Obviously, distribution of these factors is not uniform, so there are some local differences in vulnerability degree. Where depth to groundwater reaches low values and unsaturated zone characteristics change appreciably according to an increasing presence of coarser materials (between Castelletto and Borgo Ticino), high and very high vulnerability degree are reached.

## 6. CONCLUSION

The main objective of this study is to highlight areas that are more easily subject to contamination, as well to analyze groundwater quality. Based upon the collected data and the Intrinsic Vulnerability Map, it is possible to conclude that the hilly area is less vulnerable to pollution while in the plain vulnerability is considerably higher (especially in low depth to groundwater areas). Despite these conclusions, even in low vulnerability areas, water quality is not the best, given to nitrates concentration high enough to warrant a class B rating.

All water samples collected in superficial water streams and blowout aquifer except those collected in Ticino river, are included in class B. This fact may be attributed, besides possible natural causes, to the fact that superficial water bodies are often subject to illegal dumps, and to agricultural waters leaching, carrying strong chemical elements.

Thus it is easy to understand how the area is strongly affected by human intervention, which has likely modified groundwater natural characteristics.

The Ticino Natural Park occupies the eastern portion of the studied area, near the river. According to the flow pattern the park is placed downwards with respect to the groundwater flow direction. The river has in fact a strong drainage action and consequently it receives poor quality waters (mostly in class B) from the aquifer. But river waters are on the contrary in class A, with low concentrations of all parameters analyzed, since continuous and large water exchange

existing in drainage areas and river alimentation guaranteed by the lake likely lead to dilution of nitrates and other parameters.

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