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title: **Integration of aquifer and wellhead protection in agricultural areas: a case study in the Piemonte region (NW Italy)**

author(s): **Stefano Lo Russo**
Politecnico di Torino — DITAG, Land, Environment and Geo-Engineering Department, Italy, stefano.lorusso@polito.it

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INTRODUCTION

Valuable land management policies reducing the groundwater pollution hazard typically adopt two approaches, aquifer protection and wellhead protection that have to be combined in a suitable way (U.S. EPA, 1991; Foster et al., 2002).

A key factor influencing the hazard posed by a certain land-use activity to a groundwater supply (well or spring) is its proximity. In order to eliminate completely the risk of unacceptable pollution of a supply source all potential polluting activities would have to be prohibited of fully controlled within its entire recharge capture area. This will often be unsustainable or uneconomic especially in developed areas with pre-existing land use constraints. Thus, some division of the recharge zone is required, so that the most stringent land use restrictions will only be applied in areas closer to the source (Barry et al., 2009).

Such an area is referred to as the wellhead protection area (WHPA). The zone of travel can be described as an isochrone indicating the transfer time — time of travel (TOT) — necessary for water or a conservative contaminant to reach the well from that location. The TOT will depend on the pumping rates and the aquifer characteristics such as transmissivity, hydraulic gradient, porosity and aquifer thickness. It has to be noted that the level of aquifer vulnerability should address the selection of TOT identifying the WHPAs. In fact, water wells exploiting low vulnerable aquifers can be protected by limited WHPAs (low TOT values) without any significant prejudice for the protection of drinking water and human health. On the opposite wells exploiting vulnerable aquifers requires extended WHPAs (high TOT) to ensure adequate safeguard for withdrawn groundwater. The proper evaluation of the aquifer vulnerability and the selection of suitable TOT for WHPAs is thus important to avoid overestimates (or underestimates) of land protection measures especially in agricultural areas where fertilizers, agrochemicals and pesticides are intensively utilized.

The problem of the proper association between the aquifer vulnerability and the WHPAs identification has been stressed by the Piemonte region environmental authority (NW Italy) by means of specific regulations (Regione Piemonte, 2006). This study shows through a case study the main characteristics of these procedures.

METHODS

Identifying WHPA in Piemonte region (NW Italy): techniques and regulations

As implemented in the Piemonte region, a wellhead protection area consists of 3 different decreasing protection levels as we move away from to the well (Table 1).

The WHPA is usually differentiated into two sub-areas namely the inner and the outer protection zone (IPZ and OPZ respectively). The IPZ is always individuated by the 60-days isochrone whilst the TOT identifying the OPZ depends by the exploited aquifer vulnerability. Four aquifer vulnerability categories are individuated by regulations, namely, Very High, High, Medium and Low. For low aquifer vulnerability the OPZ must be calculated by means of the 180-days isochrone whilst in the other vulnerability situations the 365-days isochrone is utilized. It should be noted that regulations don't provide any specifications about the methodology assessing the aquifer vulnerability. The suitable method must be decided case by case.

Table 1. WHPAs differentiation and allowed land uses according to the Italian water regulations (modified after Repubblica Italiana, 2006).

WHPA Zone	Individuating criteria	Land uses
Total Protection Zone (TPZ)	Fixed radius (10 m minimum)	None. This zone should be fully preserved, impermeabilized, enclosed, and with limited access for authorized personnel only.
Inner Protection Zone (IPZ)	Time of Travel (isochrone 60-days)	Strongly limited. No excavation and subsurface work is allowed. Hazardous activities should be re-located if they are present. New buildings construction is prohibited.
Outer Protection Zone (OPZ)	Time of Travel (isochrone 180-days for Low vulnerable aquifers or 365-days for Medium, High and Very High vulnerable aquifers)	Limited. Only minor anthropogenic activities are allowed, and safeguard measures against groundwater pollution are necessary for existing and new buildings.

For WHPAs overlaying agricultural areas a specific fertilizers and phytosanitary management plan must be developed integrating the general land use management plan. It should ensure the safe application of fertilizers, agrochemicals and pesticides taking into account the attenuation capacity of the soil cover respect the groundwater pollution. These soil data are generally available on the overall plain territory and the soil protection capacity has been evaluated by IPLA (2006) and it is currently available on the web. Four soil protection capacity categories are individuated, namely Very High, High, Medium and Low.

Combining the exploited aquifer vulnerability and the soil protection capacity within the WHPA in a suitable way (Table 2) four levels of land use restrictions are individuated and the corresponding limitation to agriculture practices have been defined specifically (Table 3).

Table 2. Identification of the protection levels required within the WHPA in the agricultural areas by the association of aquifer vulnerability and soil protection capacity. See Table 3 for details concerning authorized land uses and agricultural practices (modified after Regione Piemonte, 2006).

		Soil protection capacity as regards the groundwater pollution	
		Very High and High	Medium and Low
Aquifer vulnerability	Low	Level 4 (minimum protection)	Level 3
	Medium	Level 3	Level 2
	High and Very High	Level 2	Level 1 (maximum protection)

Table 3. Authorized land uses and agricultural practices within the WHPAs according with the protection levels derived by the association of aquifer vulnerability and soil protection capacity (see Table 2) (simplified and modified after Regione Piemonte, 2006).

Water supply Protection Level	In the inner protection zone (isochrone 60-days)	In the outer protection zone (isochrone 180 or 365-days)
Level 1 (maximum protection)	Pasture, fertilizers and phytosanitary products are fully prohibited	Fertilizers balance plan is mandatory. Nitrogen effluent discharges are limited below yearly 170 kg/ha maximum value. Phytosanitary products are authorized under European regulations for organic farming (EU, 1991)
Level 2	Fertilizers balance plan is mandatory. Nitrogen effluent discharges are limited below yearly 170 kg/ha maximum value. Phytosanitary products are authorized under European regulations for organic farming (EU, 1991)	Like the IPZ. A wider range of phytosanitary products and weed practices can be allowed case by case under specific conditions and regulations defined by the public surveillance authority.
Level 3	Fertilizers balance plan is mandatory. Nitrogen effluent discharges are limited below yearly 170 kg/ha maximum value. Phytosanitary products are authorized under European regulations for organic farming (EU, 1991). A wider range of phytosanitary products and weed practices can be allowed case by case under specific conditions and regulations defined by the public surveillance authority.	Like the IPZ
Level 4 (minimum protection)	Fertilizers balance plan is mandatory. Nitrogen effluent discharges are limited below yearly 170 kg/ha maximum value. Phytosanitary products and weed practices are allowed case by case under specific conditions and regulations defined by the public surveillance authority.	Like the IPZ

Test site: the Castagnole well

The procedure individuating the WHPAs described in the section 2.1 has been tested on a water well supplying the Castagnole countryside municipality, 20 km S the urban area of Turin (see Figure 1), the capital of the Piemonte region (well geographical coordinates 45°54’01.93’’N, 7°33’23.55’’E).

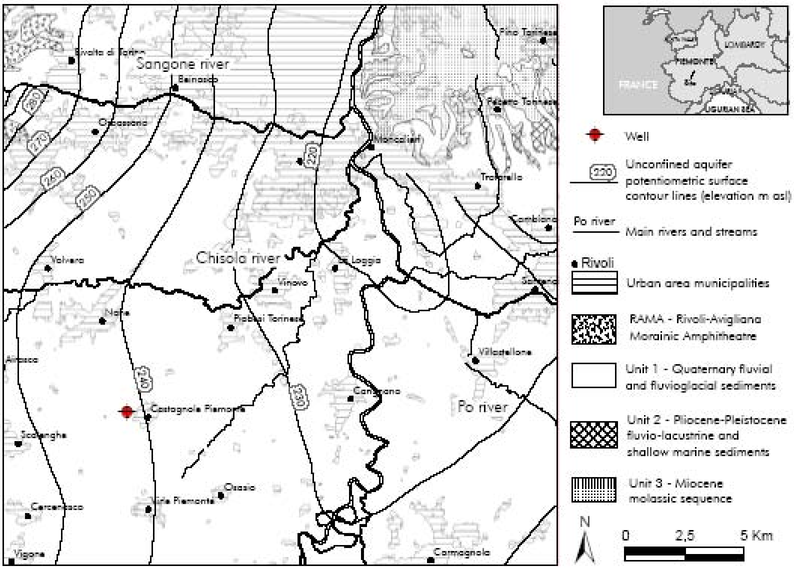

Figure 1. Hydrogeological map of the southern Turin area and location of site (modified after Civita et al., 2004).

The site ground surface is at 244 m a.s.l. The tested well is 88 m deep. The diameter of the casing is 650 mm. The well is cemented from the land surface to 28 m depth. Three screened sections are present in correspondence of productive sandy-gravelly layers between 46–50 m, 67–69 m and 78–81 m deep respectively. The undisturbed water level of the exploited confined aquifer (without any pumping) stabilizes at 243 m a.s.l. (Figure 2).

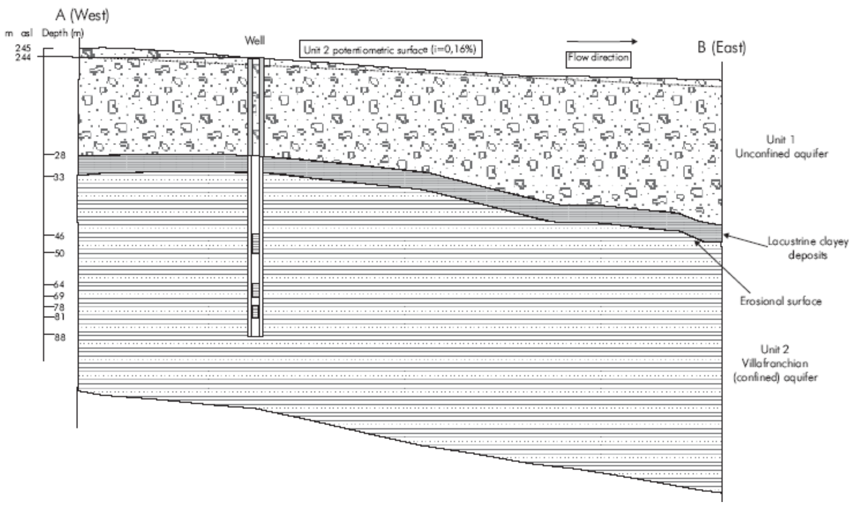

Figure 2. Schematic hydrogeological cross section of the site under study. i: gradient of confined aquifer potentiometric surface.

The Castagnole area is mainly developed on the outwash plain constituted by several glaciofluvial coalescing fans connected to the Pleistocene-Holocene expansion phases towards E of the Alpine glaciers. On the well vertical it is possible to identify (Figure 2):

Unit 1 — (Middle Pleistocene – Holocene; from the surface to 28 m depth). Continental alluvial cover composed mainly of coarse gravel and sandy sediments (locally cemented) derived from alluvial fans aggraded by the Alpine rivers downstreaming towards the east. At the base of the unit there are clayey lacustrine deposits (ca. 4–5m thick) that extend over the entire area and act as a confining layer between Units 1 and 2. The base of Unit 1 (erosional surface) dips gently (0.5%) towards the east, overlaying Unit 2.

Unit 2 — (Early Pliocene – Middle Pleistocene; from 33 m depth). Fluvio-lacustrine facies usually referred to as the "Villafranchian", consisting of fine-grained sediments (sand, silt and clay with interbedded gravel) divided into several sedimentary bodies. The top of the Unit 2 has been eroded away and covered by the lacustrine facies and alluvial deposits of Unit 1.

MODELLING

The modelling study was performed using the finite-element FEFLOW® package developed by Diersch (2005). A conceptual model with three layers was simulated using physical properties appropriate to the hydrogeology of the formation. Layer 1 represented the unconfined aquifer in Unit 1, Layer 2 corresponded to the 5-m thick clayey impermeable level at the base of this aquifer, and Layer 3 to the confined aquifer system of Unit 2. The model was assumed to be closed to fluid flow at its top and bottom. Rainfall infiltration was not included in the calculations due to the lack of measured infiltration data. Instead, the recharge to the system was simulated by fixing groundwater levels at all the outer boundaries of the model (Dirichlet conditions). The simulations were run assuming steady-state conditions for groundwater flow. The withdrawal rate on the tested well (12 L/s) corresponds to the abstraction peak conditions. In reality, such conditions never actually occur because of variable (transient) water demand and the presence of a groundwater storage tank. Therefore, the actual impacts on the aquifer in terms of potentiometric surface changes due to the well pumping will be smaller than those computed by the model. As a result the WHPAs individuated by means of the calculated isochrones will be slightly overestimated and thus cautious.

Aquifers vulnerability and soil protection capacity as regards the groundwater pollution

To identify the suitable isochrones values delineating the WHPAs the exploited aquifer vulnerability must be computed numerically. In this study the modified GOD method (Foster et al., 2002) has been utilized. The calculated Unit 2 GOD value results 0.112 corresponding to a low vulnerability degree. Thus, the OPZ must be identified by the 180-days isochrone. The modelling domain overlays different soil units characterized by a proper level of protection capacity as regards the groundwater pollution. Table 4 and Figure 3 highlight the result of a GIS analysis operated on the modelling domain.

Table 4. Soil Units in the modelling domain and corresponding degree of soil protection capacity as regards the groundwater pollution. (simplified and modified after IPLA, 2006).

Soil Unit	Soil classification	Area (m^2 and %) in the modelling domain	Soil protection capacity as regards the groundwater pollution
U0096	Dystric Fluventic Eutrudept, coarse-loamy, mixed, nonacid, mesic	295 668 (1%)	Medium
U0677	Typic Endoaquept, coarse-loamy, mixed, nonacid, mesic	2 048 817 (9%)	Low
U0095	Dystric Fluventic Eutrudept, coarse-loamy, mixed, nonacid, mesic	4 881 752 (23%)	Very High
U0118	Psammentic Haplustalf, coarse-loamy, mixed, nonacid, mesic	966 420 (5%)	Very High
U0583	Typic Endoaquept, coarse-loamy, mixed, nonacid, mesic (70%UTS - Unit Territorial Surface) Aquic Dystric Eutrudept, coarse-loamy, mixed, nonacid, mesic (30%UTS)	6 633 431 (31%)	Medium
U0586	Dystric Eutrudept, coarse-loamy, mixed, nonacid, mesic (60%UTS) Aquic Dystric Eutrudept, coarse-loamy, mixed, nonacid, mesic (40%UTS)	2 678 799 (12%)	Very High
U0662	Typic Endoaquept, coarse-loamy, mixed, nonacid, mesic (70%UTS) Aeric Endoaquept, coarse-loamy, mixed, nonacid, mesic (30%UTS)	2 484 626 (11%)	Medium
U0678	Fluventic Dystrudept, coarse-loamy, mixed, acid, mesic	1 764 497 (8%)	Medium

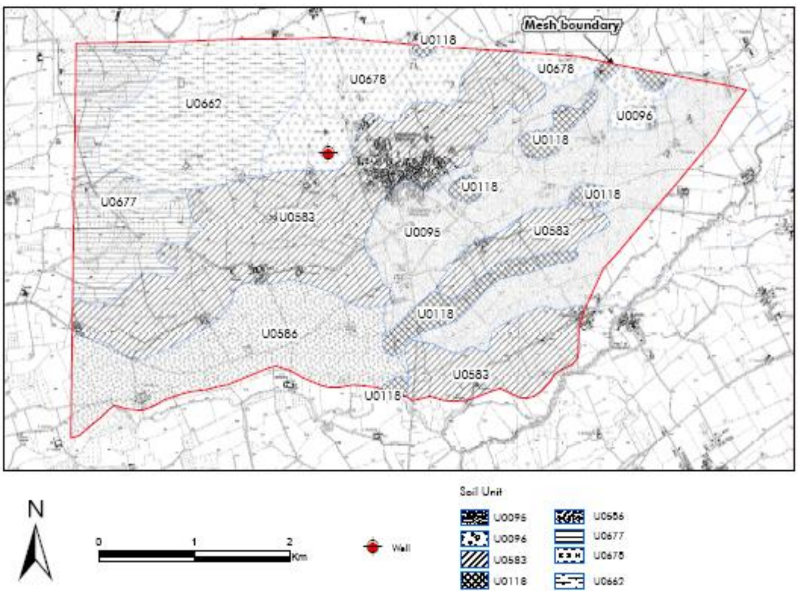

Figure 3. Soil units in the modelling domain (modified after IPLA, 2006). See Table 4 for description.

RESULTS AND DISCUSSION

The calculated test site WHPA is delineated in Figure 4.

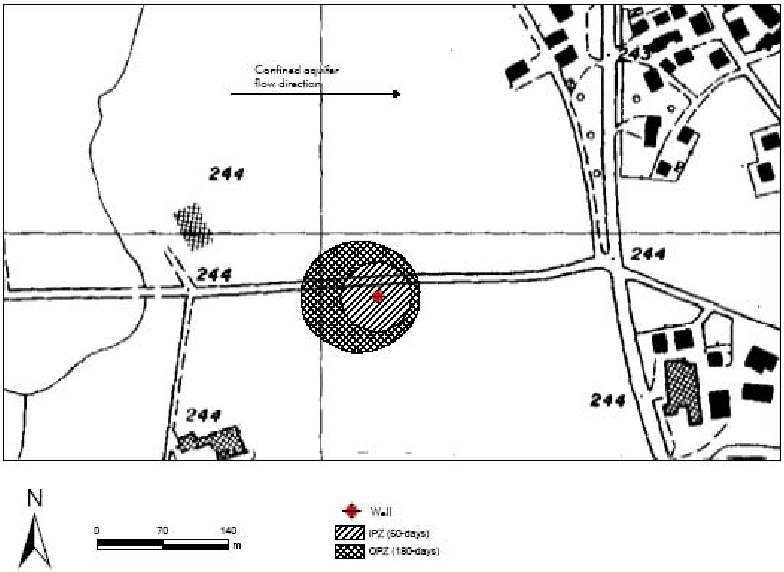

Figure 4. Wellhead protection areas identified by means of isochrones.

The 60-days isochrone (IPZ) covers about 4334 m^2 whilst the 180-days isochrone (OPZ) covers 11734 m^2. Combining the aquifer vulnerability (low) and the medium soil protection capacity of the soil unit overlaid by the WHPA (U0678) the corresponding level of protection (Level 3) is individuated by means of Table 2. The corresponding land use restrictions for agricultural practices are described in Table 3.

CONCLUSIONS

This study has highlighted a technical approach developed in Piemonte region aimed to protect drinking water wells from pollution combining the aquifer vulnerability assessment and the WHPAs delineation. In particular the selection of TOT delineating the WHPA have to be defined depending on the exploited aquifer vulnerability. The methodology has been successfully tested on a drinking water well supplying a public community.

The procedure appeared affordable and effective but highlighted a main methodological criticism that should be overcame in the next future by light adjustments and modifications.

REFERENCES

Barry F., Ophori D., Hoffman J., Canace R., 2009: *Groundwater flow and capture zone analysis of the Central Passaic River Basin,* New Jersey. Environ. Geol. 56:1593–1603. doi 10.1007/s00254-008-1257-5.

Civita M., Lo Russo S., Vigna B., 2004: *Hydrogeological sketch map of Piemonte (NW Italy) 1:250.000.* In: Map presented at the 32nd International Geological Congress (32IGC), Florence, Italy, August 21–28.

Diersch H. J. G., 2005: *Reference Manual for FEFLOW®.* WASY GmbH, Berlin, Germany, pp. 1–292 (see also http://www.feflow.info/).

EU, 1991: *Council Regulation (EEC) 2092/91 of 24 June 1991 on organic production of agricultural products and indications referring thereto on agricultural products and foodstuffs.*

Foster S., Hirata R., Gomes D., D'Elia M., Paris M., 2002: *Groundwater quality protection.* World Bank, Washington, DC, 103 p.

IPLA (Istituto per le piante da legno e l'ambiente), 2006: *Soil map of Piemonte region.* http://www.regione.piemonte.it/agri/suoli_terreni/suoli1_50/carta_suoli/gedeone.do.

Repubblica Italiana, 2006: *Decreto Legislativo 3 aprile 2006, n. 152 "Norme in materia ambientale".* G.U. n. 88 del 14 aprile 2006 – S.O. n. 96. (in Italian).

Regione Piemonte, 2006: *Regolamento Regionale 11 dicembre 2006 n. 15/R recante: "Disciplina delle aree di salvaguardia delle acque destinate al consumo umano (legge regionale 29 dicembre 2000, n. 61).* BU.R.P. n. 50 del 14 Dicembre 2006 – S.O. n. 1, http://www.regione.piemonte.it/acqua/cons_umano.htm. (in Italian).

U.S. EPA, 1991: *Delineation of wellhead protection areas in fractured rocks.* EPA-570/9-91-009. Washington, DC: U.S. Environmental Protection Agency, Office of Water.

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