SOMMARIO

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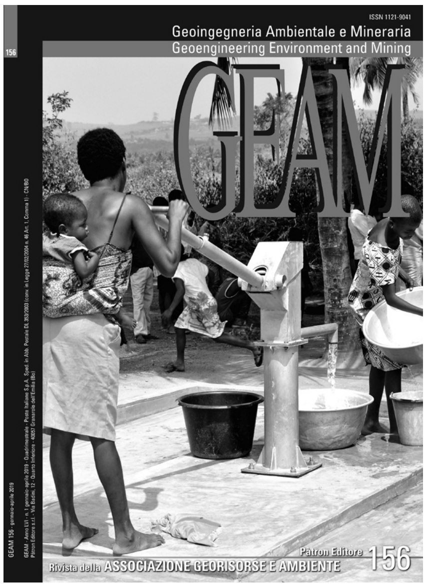

In copertina:
A woman pumps clean water at a well in Ghana.

Una donna pompa acqua fresca da un pozzo in Ghana

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USAID/Kasia McCormick, 2012.

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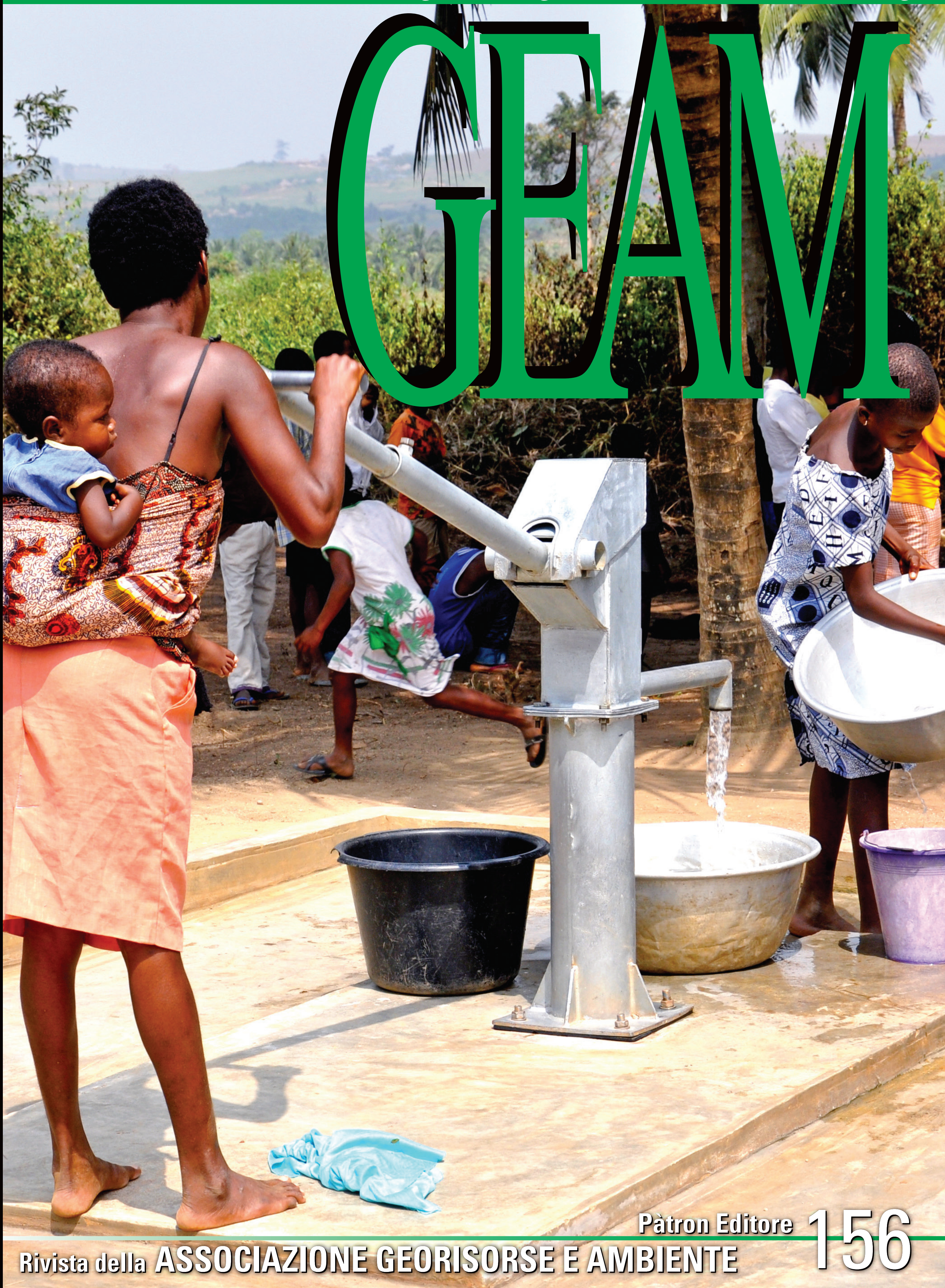

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Protection and knowledge of groundwater resource

The aim of this special issue "Protection and knowledge of groundwater resource" is to explore many issues and pressures relating global groundwater resources, some longstanding and some more recently acknowledged.
Among them, climate change, exponential population growth, growing urbanisation, increasing food production and waste management requirements, and inconsistent regulation are the most important and evident. Groundwater resources have never been more valuable or necessary, nor have they been under such strain.
Groundwater is a very important natural resource and has a significant role also in the economy. It is the main source of water for irrigation and the food industry. In general, groundwater is a reliable source of water for the agriculture and can be used in a flexible manner: when the climate is dry and there is a larger demand, more groundwater can be extracted; on the contrary, when the precipitation meets the necessities, less groundwater will need to be extracted. Globally, irrigation accounts for more than 70% of total water withdraw (both surface and groundwater). Groundwater is estimated to be used for about 43% of the total irrigation water use.
Moreover, groundwater plays a very important role also for the environment, because it keeps the water level and flow into rivers, lakes and wetlands. Specially during the drier months, when there is little direct recharge from rainfall, it provides the groundwater flow through the bottom of these water bodies and becomes essential for the wildlife and plants living in these environment. Groundwater also plays a very relevant role permitting the navigation through inland waters in the drier seasons. By discharging groundwater into the rivers, it helps keeping the water levels higher.
Groundwater is found almost everywhere and its quality is usually very good. The fact that groundwater is stored in the layers beneath the surface, and sometime at very high depths, helps protecting it from contamination and preserve its quality. Additionally, groundwater is a natural resource which can often be found close to the final consumers. Therefore does not require large investments in terms of infrastructure and treatment, as it often is necessary when harvesting surface water. The most important issue in using groundwater is to find the right balance between need and withdrawal, avoiding overexploitation and pollution.
In this context, a collection of six papers dealing with these important issues about groundwater protection and knowledge is reported in this special issue.

Domenico Antonio De Luca

Hydrochemical and isotopic analyses to identify groundwater nitrate contamination. The alluvial-pyroclastic aquifer of the Campanian plain (southern Italy)

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This paper concerns the evolution of the quality of the groundwater bodies over space and time, with special focus on nitrate. This case study deals with the qualitative status in alluvial-pyroclastic groundwater bodies located near Naples (southern Italy). The study is based on a significant hydrochemical database, gathered through: (i) groundwater sampling and water level monitoring, (ii) chemical analyses (Mg, Ca, K, Na, Cl, HCO_3, SO_4, NH_4, F, Li, Br, metals) and (iii) isotopic analyses ($\delta^{15}N$ and $\delta^{18}O$ in NO_3, $\delta^{18}O$ and δD in water). Such data, processed using maps and graphical elaborations, has been very useful for identifying groundwater nitrate contamination. Finally, the application of isotope techniques has been important for understanding and following the trend of possible attenuation processes of nitrate content in groundwater.

Keywords: *groundwater nitrate contamination, isotopic analyses, groundwater protection.*

Analisi idrochimiche e isotopiche per la definizione della contaminazione da nitrati nelle acque sotterranee. L'acquifero alluvionale-piroclastico della Piana Campana (Italia meridionale). *Questo lavoro è incentrato sull'evoluzione della qualità delle acque sotterranee dei corpi idrici sotterranei nello spazio e nel tempo, con particolare attenzione ai nitrati. Il caso di studio si occupa dello stato qualitativo dei corpi idrici sotterranei, di tipo alluvionale-piroclastico, presenti nei dintorni di Napoli (Italia meridionale). Lo studio si basa su un database idrochimico significativo, ottenuto attraverso: un campionamento delle acque sotterranee e il monitoraggio del livello piezometrico (i), nonché analisi chimiche (Mg, Ca, K, Na, Cl, HCO_3, SO_4, NH_4, F, Li, Br, metalli) (ii) ed isotopiche ($\delta^{15}N$ e $\delta^{18}O$ in NO_3, $\delta^{18}O$ e δD in acqua) (iii). Tali dati, elaborati mediante mappe e grafici, hanno consentito di definire la contaminazione da nitrati nelle acque sotterranee. Infine, l'applicazione di tecniche isotopiche ha consentito di comprendere e seguire l'evoluzione dei processi di attenuazione dei nitrati nelle acque sotterranee.*

Parole chiave: *contaminazione delle falde da nitrati, analisi isotopiche, protezione delle falde.*

1. Introduction

Nitrate contamination in groundwater, produced by the over-application of mineral and organic nitrogen fertilizers in agriculture or by anthropogenic sources as animal manures, industrial wastewater and leaks from sewage systems, is an important and growing risk to water quality in major *groundwater bodies* (here and after GWBs) around the world (Burow *et al.*, 2010; Capri *et al.*, 2009; Kammoun *et al.*, 2018; Nemčić-Jurec *et al.*, 2007; US EPA, 2000).

Recently, stable isotopes of oxygen and nitrogen have been used as valuable tools to determine natural and anthropogenic sources of nitrates (Aravena *et al.*, 1993; Kendall, 1998; D'Antonio *et al.*, 2009; Xue *et al.*, 2012; Heaton *et al.*, 2012; Stellato *et al.*, 2016; Cossu *et al.*, 2018). In general, isotopic composition of nitrogen can vary between –20 and +30 ‰; in particular: i) $\delta^{15}N$ values around zero ‰ (-5; +5) are characteristic of synthetic fertilizers; ii) $\delta^{15}N$ values between +3 and +25 ‰ are characteristic of animal dejection, since biometabolic processes and volatilization of urea and ammonia cause the enrichment of ^{15}N into the residue; iii) nitrogen compounds in precipitation do not generate an increase in nitrate concentration in agricultural soils and generally show very high variations in isotopic composition. As a consequence, nitrates derived from fertilizers can be distinguished from those coming from animal dejection or sewage (Kendall, 1998).

The $\delta^{18}O$ of nitrate originating from nitrification can vary from –10 to +10 ‰, while the $\delta^{18}O$ interval of nitric fertilizers is very narrow around +23.5 ‰ and finally the $\delta^{18}O$ of nitrate in precipitation spans over a wide range from +30 to about +80 ‰ (Xue *et* *al.*, 2012). Hence, the coupled use of $\delta^{15}N$ and $\delta^{18}O$ of nitrate allows to characterize nitrate sources in groundwater as well as to identify the occurrence of microbes mediated reactions such as denitrification, which is an important process able to reduce nitrate concentration in groundwater (Bottcher *et al.*, 1990; Sanders and Trimmer, 2006; Widory *et al.*, 2011).

In 2017, 23% of the Campania region (3,160 Km^2) was classified as nitrate vulnerable zone (NVZ), according to the EU's Nitrate Directive (91/676/CEE); two coastal GWBs of the Campanian plain the "Volturno-Regi Lagni" plain (P-VLTR) and the "Eastern plain of Naples" (P-NAP) are entirely classified as NVZ (fig. 1).

In these areas, the agricultural activities are very intensive and create a strong impact on groundwater. In particular, in the Volturno plain the land use shows a strong agricultural development, with a high percentage (81%) of cultivated fields (grain cereals and grass cultivations), mostly in association to the numerous livestock activities, predominantly composed of buffalo farming companies. Nevertheless, the urbanized environment represents a relevant percentage of the area (7.4%) and extends mainly along the coast (Aucelli *et al.*, 2016). Moreover, the studied areas can be identified as peri-urban areas, where, around a big city (Naples), industrial sett-

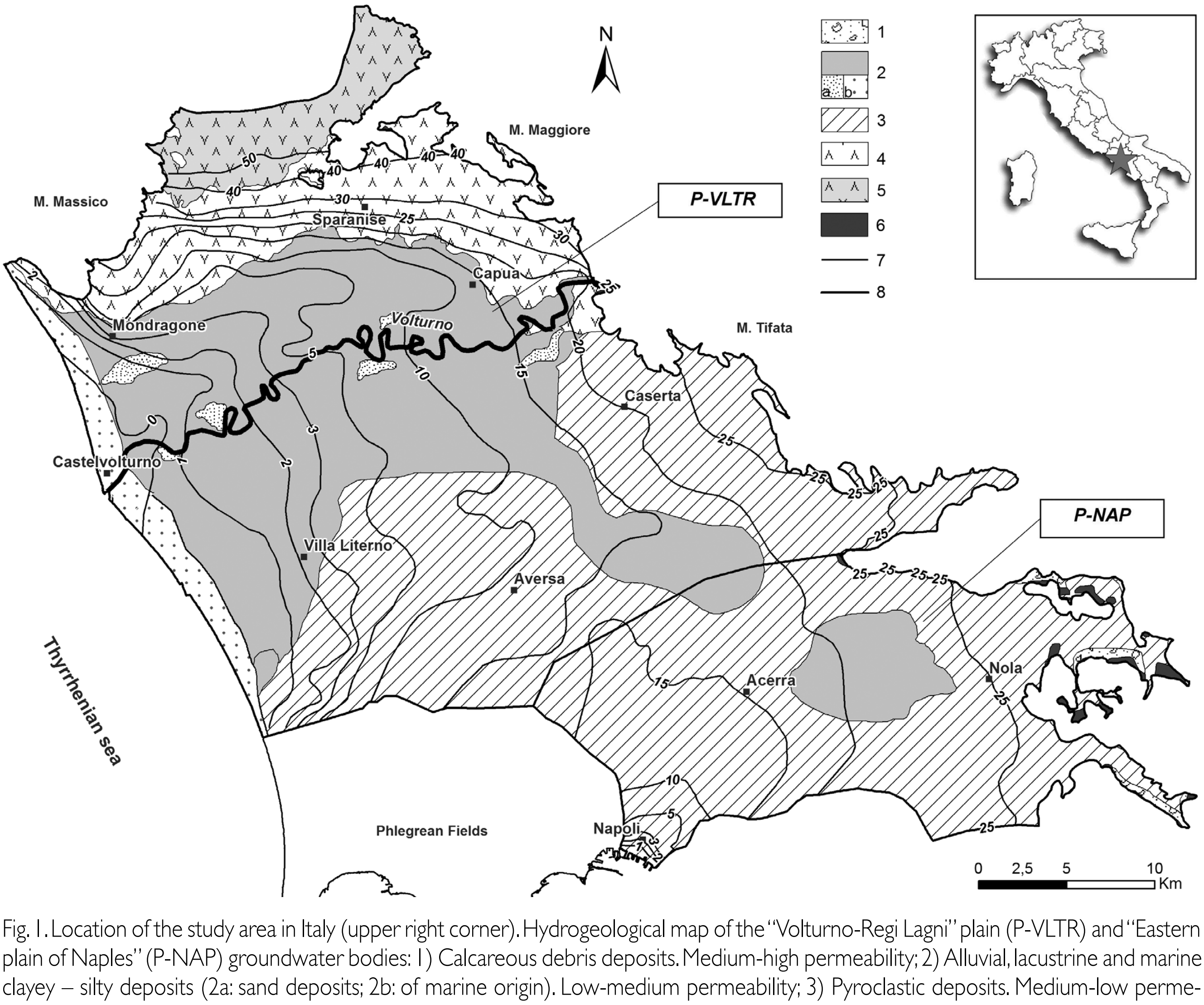

Fig. 1. Location of the study area in Italy (upper right corner). Hydrogeological map of the "Volturno-Regi Lagni" plain (P-VLTR) and "Eastern plain of Naples" (P-NAP) groundwater bodies: 1) Calcareous debris deposits. Medium-high permeability; 2) Alluvial, lacustrine and marine clayey – silty deposits (2a: sand deposits; 2b: of marine origin). Low-medium permeability; 3) Pyroclastic deposits. Medium-low permeability; 4) Campanian Ignimbrite, often covered by pyroclastic deposits. Low permeability; 5) Old tuffs. Low permeability; 6) Limestones and dolomitic limestones. High permeability; 7) Piezometric contour lines of the main aquifer (m a.s.l.;2004-2006); 8) limit of the GWBs.
Ubicazione dell'area di studio (in alto a destra). Carta idrogeologica dei Corpi Idrici Sotterranei della "Piana del Volturno-Regi Lagni" e della "Piana a Oriente di Napoli" 1) Detriti carbonatici. Permeabilità medio-alta; 2) Depositi alluvionali, lacustri, e marini limosi e argillosi (2a: sabbiosi, 2b: di origine marina). Permeabilità da bassa a media; 3) Depositi piroclastici. Permeabilità media-bassa; 4) Ignimbrite Campana, sovente coperta da piroclastiti sciolte. Permeabilità bassa; 5) Tufi antichi. Permeabilità bassa; 6) Calcari e calcari dolomitici. Permeabilità alta; 7) Isopiezometriche della falda principale (in m s.l.m. 2004-2006); 8) limite dei Corpi Idrici Sotterranei.

lements, natural and agricultural landscapes, and landscape between urban spaces coexist (Corniello *et al.*, 2007), causing many ecological disturbances. On top of that, in some areas there are illegal building developments with illicit sewage connections or on-site sewage disposal.

Since the nineties, for the two considered GWBs high nitrate contents in groundwater have been recorded (Corniello and Ducci, 2009; 2014; Corniello *et al.*, 2010; Ducci *et al.*, 2017a, 2017b). These high values, up to 300 mg/L in the shallow aquifer and until 150 mg/L in the deeper aquifer, were confirmed in next decade (Corniello and Ducci, 2009). In the P-VLTR GWB an increasing trend was recorded in the period 2011-2015 (Ducci *et al.*, 2017b). Isotopic studies carried out in a small sector of the area revealed that high contents of nitrate were prevalently due to the farming and the buffaloes breeding (Corniello and Ducci, 2009).

The aim of the present study is to advance the knowledge in the area on the qualitative status of GWBs, especially with respect to nitrate content (tab. 1) actualizing a very great number of previous datasets adding only a few monitoring wells measurements located at key locations, where additional isotopic analyses were performed ($\delta^{15}N$ and $\delta^{18}O$ of dissolved nitrates and $\delta^{18}O$ and δD of water), in order to better constrain the sources of nitrate contamination and to effectively plan proper protection measures.

2. Geological and hydrogeological characterization of the study area

The stratigraphy of the Campanian Plain is the result of marine, fluvial, and volcanic processes. Marine-transitional deposits are the deepest ones (Romano *et al.*,

Tab. 1. Groundwater samples collected in the wells shown in Figure 2 and used for isotopic analysis ($\delta^{15}N$ and $\delta^{18}O$ of dissolved nitrates and $\delta^{18}O$ and δD of water). (-) The symbols refer to the not executed analyses.

Acque sotterranee campionate nei punti d'acqua di Figura 2 usate per le analisi isotopiche ($\delta^{15}N$ e $\delta^{18}O$ dei nitrati e $\delta^{18}O$ e δD dell'acqua) e relativi valori. (–) I simboli si riferiscono alle analisi non eseguite.

Sample ID	GWB	NO_3	δD (‰ vs VSMOW) – H_2O	$\delta^{18}O$ (‰ vs VSMOW) – H_2O	d-excess	$\delta^{15}N$ (‰ vs AIR) – NO_3	$\delta^{18}O$ (‰ vs VSMOW) – NO_3
PC_V	P-VLTR	10.7	-40	-6.6	13	-	-
PC_U	P-VLTR	5.9	-26	-4.7	12	-	-
PC_T	P-VLTR	138	-36	-5.6	8	-	-
SMF_1	P-VLTR	1.7	-35	-5.7	10	-	-
SMF_2	P-VLTR	5.2	-36	-5.8	10	-	-
SMF_3	P-VLTR	1.4	-32	-5.6	12	-	-
SMF_4	P-VLTR	50.6	-37	-5.3	5	-	-
SMF_5	P-VLTR	63.5	-35	-5.3	8	-	-
VIL_1	P-VLTR	42.0	-30	-4.8	8	-	-
VIL_3	P-VLTR	59.5	-29	-5.2	12	6.3	6.7
VIL_4	P-VLTR	80.9	-33	-4.8	6	-	-
VIL_5	P-VLTR	77.3	-31	-5.3	11	-	-
PC_E	P-VLTR	55.7	-41	-8.2	24	8.8	5.1
PC_466	P-VLTR	96.9	-36	-8.0	28	7.4	6.6
PC_B	P-VLTR	55.3	-40	-7.3	18	6.3	5.3
PC_G	P-VLTR	62.8	-43	-8.5	25	8.5	5.2
PC_S	P-NAP	47.5	-	-	-	6.7	1.4
PC_H	P-NAP	147.0	-37	-5.5	7	6.4	4.5
PC_O	P-NAP	12.2	-35	-5.9	12	5.9	2.6
PC_L	P-NAP	175.0	-31	-5.5	13	8.3	7.2
PC_I	P-NAP	95.4	-37	-5.2	5	9.7	9.0
PC_R	P-NAP	130.0	-42	-8.5	26	7.0	0.5

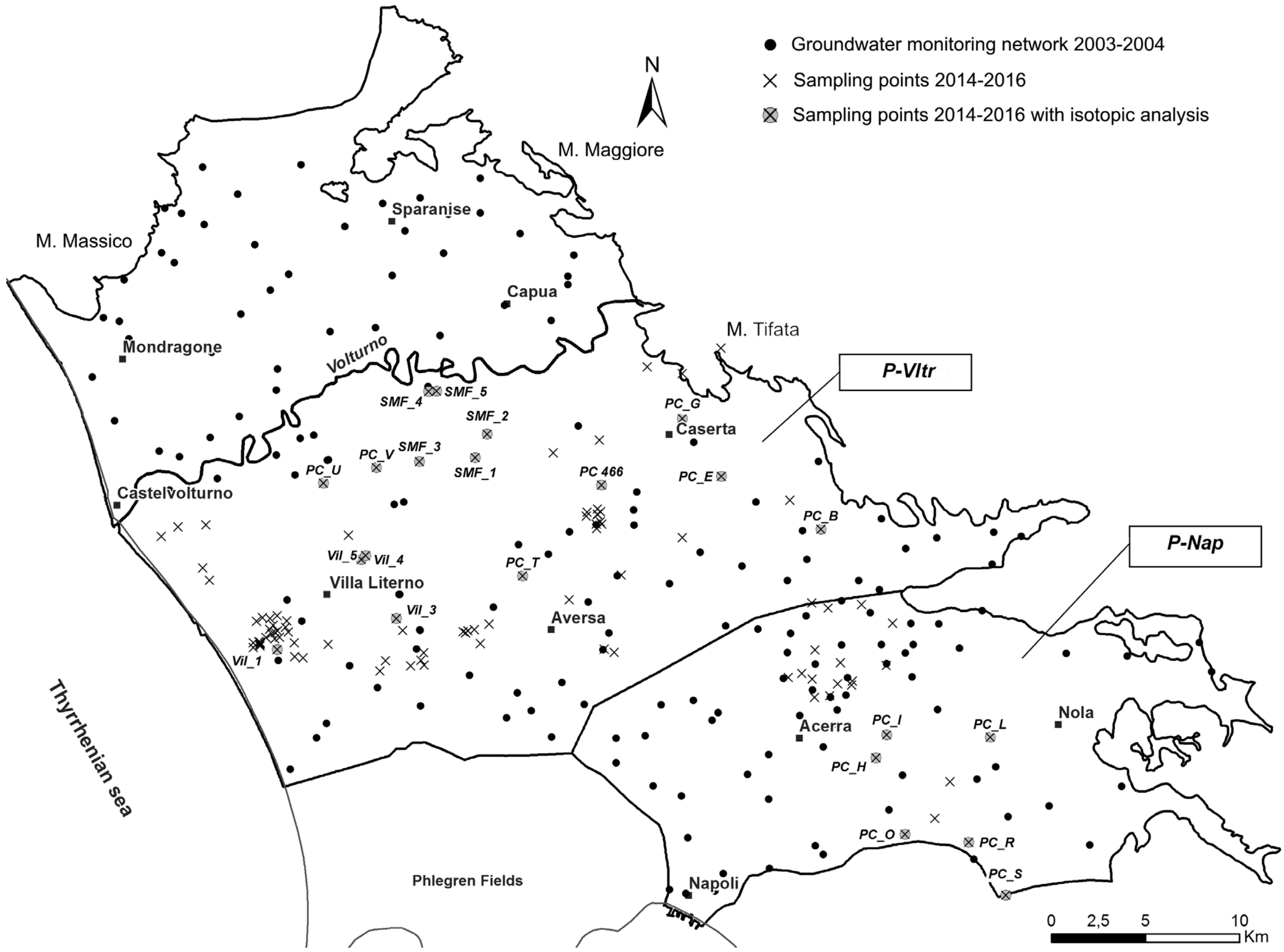

Fig. 2. Groundwater monitoring network 2003-2004 and 2014-2016. Isotopic analysis are labelled (seeTable 1).
Rete di monitoraggio delle acque sotterranee 2003-2004 e 2014-2016. Le etichette delle analisi isotopiche rimandano a tabella 1.

1994; Bellucci, 1998; Aprile *et al.*, 2004). Campanian Ignimbrite (also known as Grey Campanian Tuff) is the most widespread volcanic product across the Plain and it is located above transitional-marine deposits (fig. 1). The Campanian Ignimbrite extends over an area of about 30,000 km^2, including the Volturno river plain with thickness between 30-60 m (Corniello and Ducci, 2014). The Campanian Ignimbrite is absent close to the Volturno river, due to river erosion and there is a widespread presence of peat lenses, that determines negative redox conditions in groundwater (Corniello *et al.*, 2010).

In the Campanian Plain there are two GWBs. In the first, the P-VLTR GWB, the main aquifer is located in the alluvial, pyroclastic and marine porous sediments underlying the Campanian Ignimbrite, which plays, where present, the role of a semi-confining or confining bed; the aquifer is phreatic only near the coast.

In the southern part of the plain, in the P-NAP GWB, corresponding to the eastern plain of Naples (fig. 1), the stratigraphy and the hydrogeological setting are similar to those of the P-VLTR, except in the S sector. Here, the aquifer is located in the pyroclastic reworked deposits and is phreatic, locally confined by peat levels or by most impervious levels as Vesuvian or Phleagrean tuffs. Despite the local differences in the stratigraphy, the permeable layers of the P-NAP GWB are in hydrogeological continuity, constituting a single aquifer (Corniello and Ducci, 2013).

The hydrochemical patterns reflects the groundwater flow patterns in the plain, as could be expected. Near the limestone mountains (NE of the plain), where there is a conspicuous groundwater outflow (Corniello and Ducci, 2014), the r(Ca^{2+} + Mg^{2+})/r(Na^+ + K^+) ratio, and the HCO_3^- content are high, while along the coastal areas more alkaline conditions occur (Ducci *et al.*, 2016).

In the P-VLTR and P-NAP GWBs different types of "natural contamination", due to volcanic formations, are observed, such as high fluoride (almost everywhere > 1.5 mg/L, and often exceeding 3 mg/L) and high arsenic content (close to the Phlegrean Fields, where As >10 μg/L). The high As values derive mainly from water–rock interaction, and its mobility is favoured by the presence of steam-heated groundwater (Aiuppa *et al.*, 2003). In the sectors close to the Volturno river in the P-VLTR and close to the sea in the P-NAP, groundwater shows lower nitrate content (fig. 3), related to reducing conditions, also testified by low SO_4 and high Fe and Mn (Corniello *et al.*, 2010; Ducci and Sellerino, 2012; Ducci *et al.*, 2016).

3. Materials and methods

The groundwater quality database used in this study includes more than 300 samples collected in 180 sampling points in different time (2003-2004) and with different purposes (Corniello and Ducci, 2009; 2014; Corniello *et al.*, 2007; Ducci and Sellerino, 2012). 25 water points of this dataset belong to the groundwater monitoring network of the Agency for Environmental Protection of Campania Region (ARPAC) that started in autumn 2002 and was implemented in 2015 (Adamo *et al.*, 2007; Ducci *et al.*, 2017b). This database (fig. 2) constituted the background for planning the new sampling campaign.

The groundwater levels measurements and groundwater sampling were planned with the aim to investigate sectors with scarce knowledge of the piezometric pattern and geochemistry or where very high levels of nitrate measured in the past required to check the evolution of the contamination (fig. 2).The present study includes 107 new measurements of piezometric levels and sampling of the groundwater from the deep aquifer, collected in wells located in the southern part of P-VLTR and in the P-NAP GWBs (fig. 2).

In this new campaign, the coordinates (X-Y-Z) of groundwater monitoring point were recorded using a Garmin GPS. Before sampling, the wells were purged for removing stagnant water. All the groundwater monitoring points were analysed on site for EC, pH, alkalinity, temperature and piezometric levels. Subsequently, the samples were stored for metals and isotopes analysis in PE bottles, while in glass bottles for the analysis of dissolved elements (HCO_3, NO_x, NH_3, F, Cl, Br, SO_4, Li, Na, K, Ca, Mg).

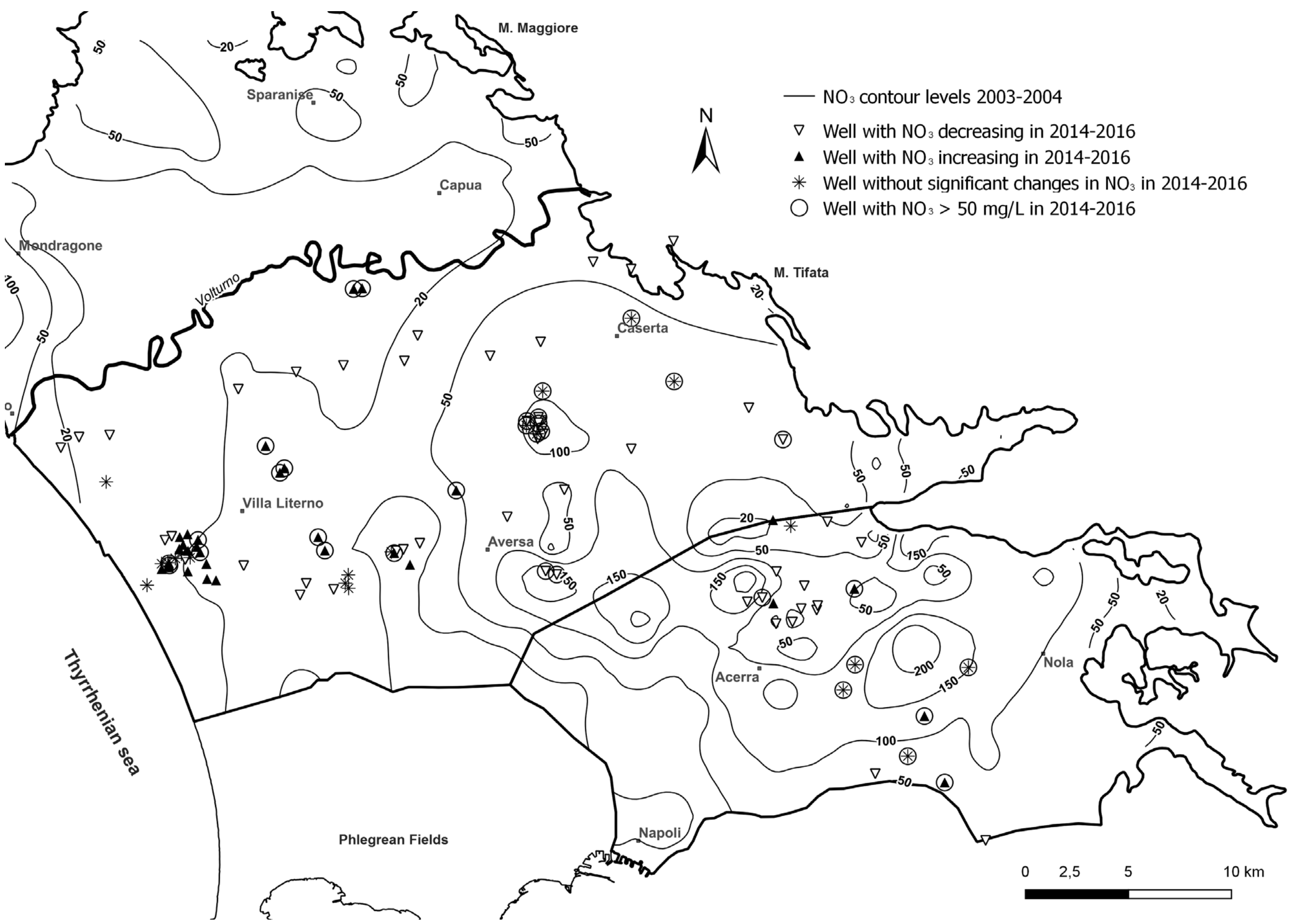

Fig. 3.Variation of the nitrate concentration in groundwater from 2003-2004 to 2014-2016.
Variazione delle concentrazioni di nitrati nelle acque sotterranee dal 2003-2004 al 2014-2016.

Chemical analysis, including major cations (Na, K, Ca, Mg), anions (Cl, SO_4, NO_3, HCO_3) and metals (Al, Ag, As, B, Ba, Be, Cd, Co, Cr, Cu, Hg, Fe, Mn, Ni, Pb, Sb, Se, Sn, Te, Tl, V, Zn) were performed by the laboratories of the University of Naples Federico II (Department of Chemical Sciences), by using ion chromatography and mass spectrometry on unfiltered samples stored at 4 °C. Most of the analyses (70%) show a charge balance error of less than 5%. The data obtained were organized in a database purposely designed to satisfy the analytical needs of GIS (ArcGIS 10 and QGIS 2.14.18), also used for the drawn up of the thematic maps.

22 water points (fig. 2), selected on the basis of their availability and significance, were also sample for isotopic analysis ($\delta^{15}N$ and $\delta^{18}O$ of dissolved nitrates and $\delta^{18}O$ and δD of water) in order to identify either the source of the high contents of nitrates and the groundwater origin. The samples were analysed at the CIRCE (Centre for Isotopic Research on the Cultural and Environmental heritage) laboratory of the Department of Mathematics and Physics of the University of Campania "Luigi Vanvitelli" (Caserta, Italy).

$\delta^{15}N$ and $\delta^{18}O$ of dissolved nitrate, reported as ‰ versus AIR and VSMOW, were measured in 11 wells by means of the silver nitrate protocol (Silva *et al.*, 2000) and analysed by a TC/EA-CF-IRMS system (Delta V Thermo Fisher). The precision of the whole procedure involving the preparation protocol of aqueous samples, reference materials and the isotopic analysis, reported as standard deviation (1 σ) of $AgNO_3$ measurements, is 0.7 ‰ and 1.2 ‰ for $\delta^{15}N$ and $\delta^{18}O$, respectively.

Water stable isotopes (δD and $\delta^{18}O$, reported as ‰ versus VSMOW) were measured in 21 wells by means of a TC/EA-CF-IRMS system (Delta V Thermo Fisher) with an analytical precision of 0.2 ‰ and 1 ‰, for $\delta^{18}O$ and δD, respectively.

The mean infiltration altitude can be estimated by means of the equation reported in Zuppi *et al.* (1974) for the peri-Tyrrhenian areas of Italy: Height (m)= $-1000*(\delta^{18}O + 5.14)/3.44$.

4. Results and discussion

The range of nitrate content measured in groundwater samples is 0.2-175.0 mg/L, with mean value of 40.0 mg/L and standard deviation 37.5 mg/L. The number of exceedances of the 50.0 mg/L threshold value (EU's nitrate directive) is 33 on 107 samples; the wells with groundwater exceeding the threshold are located in the central part of the P-VLTR and in the SW sector of the P-NAP. Despite the high levels of nitrate detected, comparing these data with those recorded during 2004, it is possible to assert that the contamination level has not worsened over time; the nitrate concentration is equal or less that in 2004 for 70% of the monitoring points (fig. 3). The remaining 30% of wells are located near the coast; here, there is no reduction in nitrate contamination, but rather a moderate increase (usually between 1% and 3%) due to the widespread presence of holyday's houses, mainly used in summer periods and not always connected to the sewer system.

In Figure 4 $\delta^{18}O$ and δD values for 21 wells sampled in the two GWBs are shown. All the values fall between the Global Meteoric Water Line (Craig, 1961) and the Eastern Mediterranean Meteoric Water Line (Gat and Carmi, 1970). As a reference, also the Southern Italy Meteoric Water Line presented by Giustini *et al.* (2016) has been reported. From the analysis of the isotopic results (tab. 1), all the piedmont wells (PC_G, PC_E, PC_466 and PC_B for the P-VLTR and PC_R for P-NAP) are characterized by more depleted values of $\delta^{18}O$ and δD and high deuterium excess values, indicating that the recharge of this area is originated by water infiltrating at high altitude from vapour masses formed in conditions of low humidity (65-70%) (Clark and Fritz, 1997). From the piedmont areas towards central areas of the plain more enriched values (SMF and PC wells) are observed, becoming even more enriched from central to coastal areas (i.e., VIL wells). The observed trend towards more enriched values is due to the mixing with water recharged locally at a lower altitude formed by humid (humidity 80-90 %) air masses, close to the sea, and therefore characterized by enriched values of water stable isotopes.

The mean value of $\delta^{18}O$ of piedmont wells (8.0 ± 0.5 ‰) can be used to estimate the mean infiltration altitude. The estimated elevation of the recharge area of the NE part of P-VLTR aquifer results between 680 and 980 m a.s.l., well supporting the hypothesis that the infiltration occurs mainly on carbonate mountains located at the NE border of the plain.

The diagram of Figure 5 shows the characteristic ranges of possible nitrate sources in surface water and groundwater (atmospheric depositions, nitric or ammonium fertilizers, manure, etc.) (Kendall, 1998). The two GWBs are contaminated mainly by nitrate originating from natural nitrification processes occurring in the soils and by manure spreading and/or sewage leaking from collectors or septic tanks. All the collected samples have a NO_3> 50.0 mg/L, except a sector of the P-VLTR GWB located on the left side of the Volturno River, where nega-

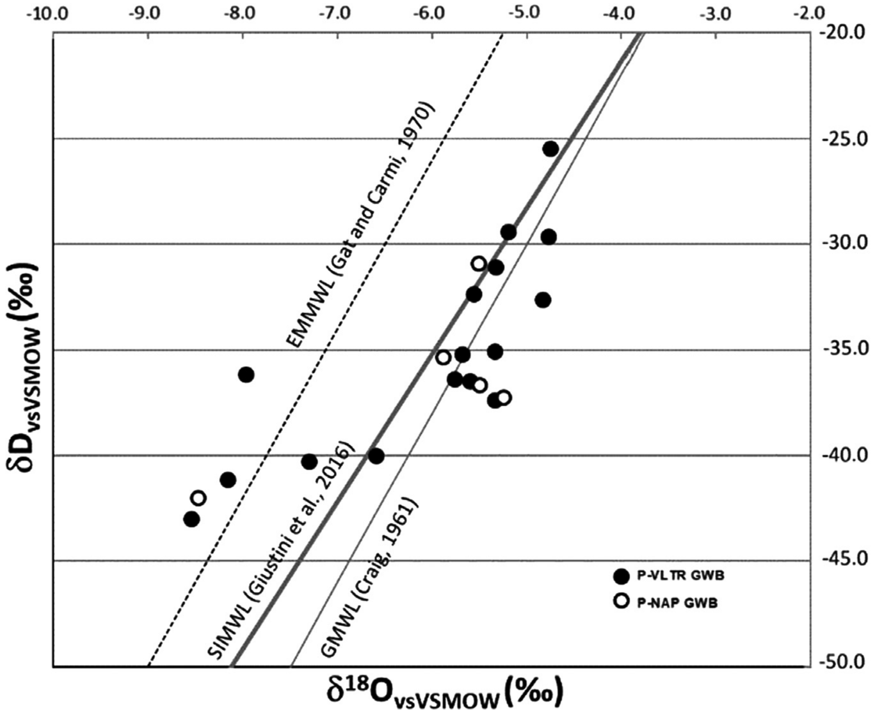

Fig. 4. δD vs. $\delta^{18}O$ diagram of the groundwater samples of Table 1and Figure 2. EMMWL: Eastern Mediterranean Meteoric Water Line (Gat and Carmi, 1970); SIMWL: Southern Italy Meteoric Water Line (Giustini *et al.*, 2016); GMWL: Global Meteoric Water Line (Craig, 1961).

Diagramma δD -. $\delta^{18}O$ dei campioni d'acqua di Tabella 1 e Figura 2. EMMWL: Eastern Mediterranean Meteoric Water Line (Gat and Carmi, 1970); SIMWL: Southern Italy Meteoric Water Line (Giustini et al., 2016); GMWL: Global Meteoric Water Line (Craig, 1961).

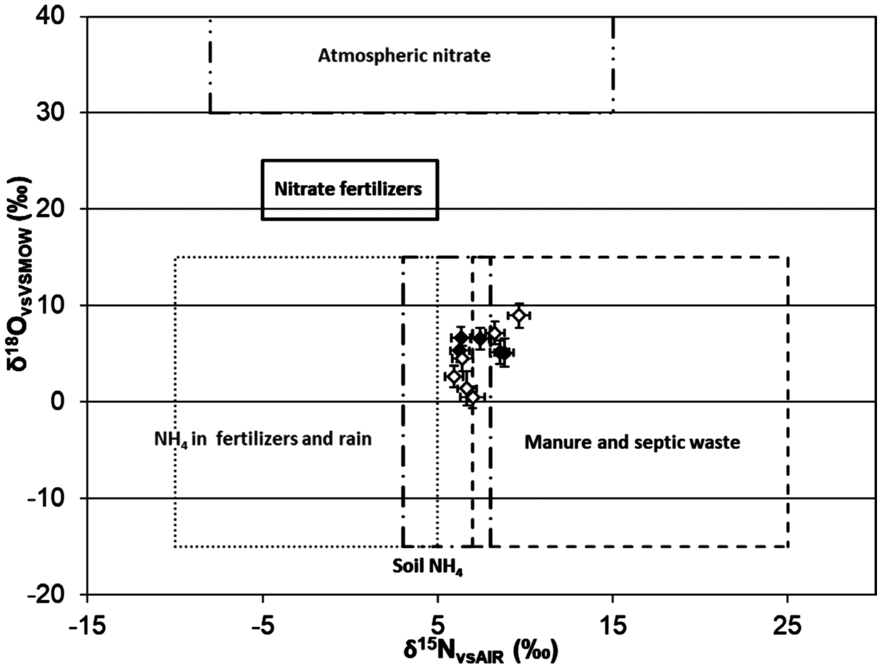

Fig. 5. $\delta^{18}O$-$\delta^{15}N$ diagram (Kendall, 1998) of the groundwater samples of Table 1 and Figure 2. The black symbols refer to the P-VLTR GWB and the white symbols to the P-NAP GWB.

Diagramma $\delta^{18}O$-$\delta^{15}N$ (Kendall, 1998) dei campioni d'acqua di Tabella 1 e Figura 2. I simboli neri si riferiscono al CIS P-VLTR, quelli bianchi al CIS P-NAP.

tive redox conditions occur (Corniello and Ducci, 2014), promoting a natural attenuation of the dissolved nitrate (i.e., denitrification). The denitrification process is evidenced in the observation points SMF_1, PC_U and PC_V in Figure 2, having NO_3<1 mg/L. On the other side, the P-NAP GWB is characterized by NO_3 always higher than 150.0 mg/L; in these areas, no self-purification processes are evidenced by isotopic and chemical data.

5. Conclusions

Hydrogeochemical and isotope data collected and acquired in two groundwater bodies located in Campania region (southern Italy) provided information about the persistence of the high levels of nitrate content recorded in past years, that gave a bad quality status to these GWBs.

The results of the hydrogeochemical study show that the application of rules and actions in the last 10 years has led to a control of the nitrate problem but not to a resolution; in the two GWBs the NO_3 content in groundwater seem generally decreased, probably thanks to the improvement of good agricultural practices and land use restrictions, to the control of the sewerage systems and to the prohibition of use of certain chemicals (EU's Nitrate Directive – 91/676/CEE). It is important to highlight the dilution effect operated by the groundwater inflow from carbonate mountains, as demonstrated by the elevation of the recharge area (between 680 and 980 m a.s.l.) individuated on the basis of $\delta^{18}O$ and δD and by the persistence of the nitrate contamination in the coastal sectors. The source of nitrate, investigated using the isotopic ratios of nitrogen and oxygen of dissolved nitrate, seems prevalently due to the spreading manure application to crops and to the urban sewage leakage. Indeed, this hypothesis seems confirmed by the changes in land use showing an increase of peri-urban areas, often not connected to the sewer systems (Corniello *et al.*, 2007; Ducci *et al.*, 2017b).

The application of isotope techniques has given an important support to understand and follow the trend of possible attenuation processes in nitrate content. In a near future, to better constrain the sources of nitrate contamination, the isotopic signature of the possible sources present in the study area should be determined. This could give also the possibility to apportion quantitatively the different contributes to the mixing (Xue *et al.*, 2012).

In conclusion, the dimension of the area and the very complex land use require a deeper monitoring and analysis, not viable without a purposed funding provided by new projects aimed to protect groundwater from nitrate contamination.

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Diffuse contamination assessment for the groundwater quality protection in Functional Urban Areas (FUA)

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The Lombard territory (Italy), characterized by a historical process of industrialization, is affected by significant contamination both of the ground and of the groundwater. The continuous development of urban areas needs to face the problem linked to the growing presence of portions of the territory where there is the presence of contaminated groundwater (mainly chlorinated solvents and hydrocarbons), for which it is no longer possible to identify the position of the sources of the contamination. This type of contamination is defined as diffuse contamination due to multiple point sources and represents a common environmental problem in many developed countries. This contamination often is among the elements that causes the non-achievement of the qualitative objectives defined by the European Groundwater Directive.

Furthermore, diffuse pollution causes a significant economic impact on society, due to the costs necessary for its management and remediation. Lombardy Region, which is one of the most urbanized and industrialized areas in Europe, has recently developed specific legislation action to address the problem, which includes a regional remediation program and a regional management plan for diffuse groundwater pollution.

Thanks to the presence of efficient monitoring networks and a huge qualitative and quantitative data concerning the groundwater of Lombardy, it was possible to start a process of assessment of the diffuse pollution in the Wide Area, consisting of the city of Milan and a sector of its hinterland located in the North-East. This made it possible to define a new Reference Threshold for Diffuse Contamination (RTDC) and a Management Plan containing the management methods and measures for the prevention of diffuse pollution. Lombardy Region (2017) has delimited the first area affected by diffuse pollution and approved the intervention measures and the regulation for the reclamation procedures falling within this area.

Following this first action on the management of diffuse contamination, the Lombardy Region and the Politecnico di Milano have started the AMIIGA project (Integrated Approach to Management of Groundwater quality in functional Urban Areas) project (CE32-Interreg 2016-2019) in which, it will be developed a new Management Plan for the North-West area of Milan. The Pilot Area will include 9 municipalities in the Milan surrounding and 2 in the Varese province. This article intends to present both the European and Italian regulatory framework and the regional Management Plan of the Functional Urban Area (FUA) of Milan, presenting the methodology adopted and the results obtained.

Keywords*: diffuse contamination, groundwater governance, Regional Operative Protocol, AMIIGA, Management Plan.*

Valutazione della contaminazione diffusa per la protezione della qualità delle risorse idriche sotterranee in aree urbane (FUA). *Il territorio lombardo, caratterizzato da un processo storico di industrializzazione, è interessato da contaminazioni del suolo e delle acque sotterranee significative. Il continuo sviluppo delle aree urbane deve sempre più confrontarsi con la problematica legata alla crescente presenza di porzioni di territorio dove si riscontra la presenza di acque sotterranee contaminate (principalmente solventi clorurati e idrocarburi), per le quali non è più possibile identificare la posizione delle fonti origine della contaminazione. Questo tipo di contaminazione viene definita contaminazione diffusa dovuta a molteplici fonti puntuali e rappresenta un problema ambientale comune in molti paesi sviluppati. Spesso, tale inquinamento, è tra gli elementi che causa il mancato raggiungimento degli obiettivi qualitativi definiti dalla direttiva europea sulle acque sotterranee.*

Inoltre, l'inquinamento diffuso determina un impatto economico notevole sulla società, a causa dei costi necessari per la sua gestione e il suo risanamento. Regione Lombardia, che è una del-

1. Introduction to Groundwater Governance: from European to Regional environmental legislation

In Italy, the management of the diffuse contamination undergo laws of three different levels: the European, the National and the Regional ones.

From the EU side, the framework is given by the Directive 2000/60/EC – Water Framework Directive (WFD, European Environment Agency, 2013) and the Directive 2001/42/EC – Strategic Environmental Assessment Directive (SEA). Measures to recover diffuse pollution of groundwater contribute to the achievement of quality goals for groundwater bodies defined under the WFD. Moreover, each plan or program that leads in significant environmental effects must be submitted to the SEA procedure.

The Directive was adopted by National law but the latter provides to give more detailed indications about contamination and

le zone maggiormente urbanizzate e industrializzate in Europa, ha recentemente sviluppato una legislazione regionale specifica per far fronte al problema, che comprendente un programma di risanamento regionale ed un Piano regionale di gestione per inquinamento diffuso delle acque sotterranee.

Grazie alla presenza di efficienti reti di monitoraggio e di numerosi dati quali-quantitativi riguardanti le acque sotterranee lombarde, è stato possibile avviare un processo di valutazione dello stato di inquinamento diffuso nell'Area Vasta, costituita dalla città di Milano e da un settore del suo hinterland posto a Nord-Est. Questo ha consentito di definire una nuova soglia di riferimento per la contaminazione diffusa (RTDC) e un Piano di Gestione contenente le modalità di gestione e le misure per la prevenzione dell'inquinamento diffuso. Regione Lombardia (2017) ha delimitato la prima area interessata da inquinamento diffuso e ha approvato le misure di intervento ed il regolamento per le procedure di bonifica ricadenti in tale area. In seguito a questa prima azione sulla gestione della contaminazione diffusa, Regione Lombardia e il Politecnico di Milano hanno avviato il progetto AMIIGA (Approccio Integrato alla Gestione della Qualità delle Acque Sotterranee nelle aree Urbane Funzionali CE32-INTERREG 2016-2019) nel quale, sarà sviluppato un nuovo piano di gestione per l'area nord-ovest di Milano L'area pilota comprenderà 9 comuni della provincia Milanese e due della provincia di Varese. Questo articolo intende presentare sia il quadro normativo europeo ed italiano che il piano regionale di gestione dell'area allargata (FUA) di Milano, presentando la metodologia adottata e i risultati ottenuti.

Parole chiave: *contaminazione diffusa, gestione dela falda, Protocollo Operativo Regionale, Piao di Gestione, AMIIGA.*

its management in each specific European State.

In Italy, the Legislative Decree (Dlgs. 152/06 which enforce the WFD) defines the anthropogenic diffuse contamination as the "chemical, physical and biological alteration of environmental matrixes and contaminations determined by diffuse sources and not linked to a point source". Furthermore, it designates Regions to enact actions when diffuse contamination is recognized and to define a scientific based Diffuse Pollution Background Levels (Azzellino *et al.*, 2019) for diffuse pollutants in groundwater.

Putting into actions the prescription of the Dlgs. 152/06, Lombardy Region published the Regional Remediation Program (RRP, 2014) including the Regional Management Plan (MP) for diffuse pollution of groundwater. The Plan is constituted by several chapters containing the criteria for economic and financial planning, the criteria for the priorities definition, a catalogue of the areas of diffuse pollution and the Operative Protocol for the management of the diffuse pollution of groundwater (Annex 17 of RRP). Recently, the RRP has been submitted to SEA Directive procedure.

The implementation phase of the RRP involves the definition of a MP for each area affected by diffuse pollution (fig. 2). The MPs are measures of the RRP and do not need to undergo again to the SEA.

On the other hand, the Operative Protocol is a technical tool that standardize the acting procedure to follow to manage potential situations of anthropogenic diffuse contamination.

The protocol envisages the definition of the MP for each area potentially affected by diffuse pollution and specifies the steps to be followed in order to assess its presence, to delimit its spatial extension and to identify the remediation measures. Moreover, it establishes to institute a technical panel, the Regional Implementation Group (RIG), for each single area where all the subject involved in the water management are invited.

During the meetings of the Regional Implementation Group (RIG), members jointly discuss, share decisions and evaluate results on the activities carried out to to be enacted in order to to manage the diffuse pollution in the area involved by the MP.

Lombardy Region coordinates the RIG, proposes drafts of remediation measures and takes care of submitting the MP to the approval of the Government of the Region. This paper aims to present the RRP development by Lombardy Region both by legal point of view and by the scientific-based methodology applied in the North-eastern sector of Milano Functional Urban Area.

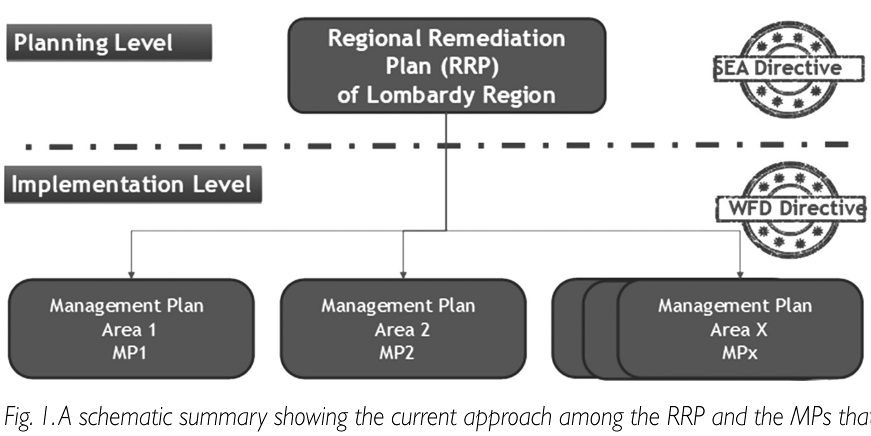


Fig. 1. A schematic summary showing the current approach among the RRP and the MPs that are developed for the different areas.

Schema riassuntivo che mostra l'approccio corrente tra il Piano Regionale delle Bonifiche ed i Piani di gestione che vengono sviluppati per le differenti aree.

2. The case study application: Functional Urban Area of Milan (FUA) and Wide Area

Since 2013, Lombardy Region has developed many studies to

Fig. 2. Milan FUA (bold contour) and the AMIIGA Pilot Area filled in grey. Milano city is filled by line symbol. The points represent the monitoring network.
FUA di Milano (in grassetto) e colorati in grigio i comuni dell'Area Pilota del Progetto AMIIGA. Il Comune di Milano è rappresentato con linee. I punti rappresentano la rete di monitoraggio.

deepen and remediate the contamination of groundwater in the metropolitan area of Milan. The studies have been extended to the Functional Urban Area (FUA, fig. 2) (OECD, 2012) to consider all the possible sources (green contaminated sites in the Figure 2) of pollution that affect the groundwater in Milan.

The FUA of Milan is one of the most densely populated and industrialized areas in Po Plain within Lombardy Region. It covers Milan and a crown of municipalities at its borders. The northern area of FUA has been heavily industrialized (since early 1950s) and is characterized by a dense agglomeration of industries (mainly automotive, refineries, chemical plants, still and tires production). Because of the high hydraulic conductivity and the high groundwater withdrawal rate (Alberti *et al.*, 2014; Colombo *et al.*, 2018), Milan represents the drainage area of groundwater in the FUA and many pollutants flows from the suburban area into city groundwater. The FUA considered in this study[1] includes 34 municipalities, is about 521 km^2 wide and has about 2 Million inhabitants. The monitoring network (fig. 2) used for the studies includes idrochemical data from 3,477 wells/piezometers, over 49,000 stratigraphic records. The database consists of 618,258 records, corresponding to 19 hydro-chemical parameters for the period 2003-2014.

[1] The FUA originally circumscribed covered 31 Municipalities and an area of about 486 km^2, 3 more municipalities were added to include several plumes that originate North-Western of Milan have a significant effect on the deterioration of the groundwater quality in Milan. The focus and the development of the MP on the North-Western area of Milan will be done within AMIIGA project.

The first studies performed highlighted that in Milan FUA there is a presence of a multitude of contamination points and that the contamination given cannot more be traced back to the single source (Alberti *et al.*, 2018). This kind of contamination, named diffuse pollution, requires effective intervention at a medium scale, neglected in existing legislation. The issue regarding these areas is that they cannot be managed with the usual remediation techniques used for small contaminated sites, mainly for two reasons: a) the difficulty to identify specific point sources and b) the wide extension of the contaminated plumes areas. Both aspects require alternative approaches.

Recently, Lombardy Region, in order to face the problem, tested for the first time the Operative Protocol for the management of the diffuse pollution of groundwater. The investigated area is named Wide Area (fig. 4), is portion of the FUA and includes the City of Milan and six surrounding municipalities. Its extension is about 286 km^2.

According with the Protocol, the RIG was established with all local institutions involved in the water quality management (Municipalities, Districts, Regional Environmental Protection agencies, Water Service Managers, Regional Agency for health protection) in reason to define the first MP.

The RIG, coordinated by the Region Authorities, performed several monitoring campaigns on a big monitoring network within the FUA. The monitoring data and the recent campaigns (monitoring data between 2003-2014) revealed a presence of diffuse contamination due to chlorinated hydrocarbons especially in the North-Eastern sector of the area.

Based on the results obtained through the investigations, in 2017, Lombardy Region delimited for the first time an area affected by diffuse pollution and, for this area, approved intervention measures and the discipline for remediation procedures.

During the follow-up emerged that several plumes that originate North-Western of Milan have a significant effect on the deterioration of the groundwater quality in Milan and affect some pumping stations used for the water supply services. Within AMIIGA, a new MP will be developed for the Pilot Action area (filled in violet in Figure 2) that covers the surface of 12 Municipalities at North-Western of Milan (including a part of Milan). The groundwater in the Pilot Action area is also affected by diffuse contamination of Chlorinated Hydrocarbons.

3. Diffuse contamination approach: a methodology

A new methodology was developed to manage and assess threshold values representing the diffuse contamination (VDC). More in detail, an integrated approach (statistical and deterministic numerical model) has been adopted to distinguish point sources (hotspots) and multiple-point sources (diffuse contamination). It is a multivariate and K-means statistical approach and a transport numerical modelling (Modflow+MT3DMS) (Alberti *et al.*, 2018, 2016; Azzellino *et al.*, 2019).

The methodology can be divided in three main activities and several sub activities (fig. 3):

1) User data and pre-processing: more than 3477 monitoring points were considered (from private, public network provided by Water Managers, from contaminated sites) thanks to local and regional agencies, covering the period 2003-2014.

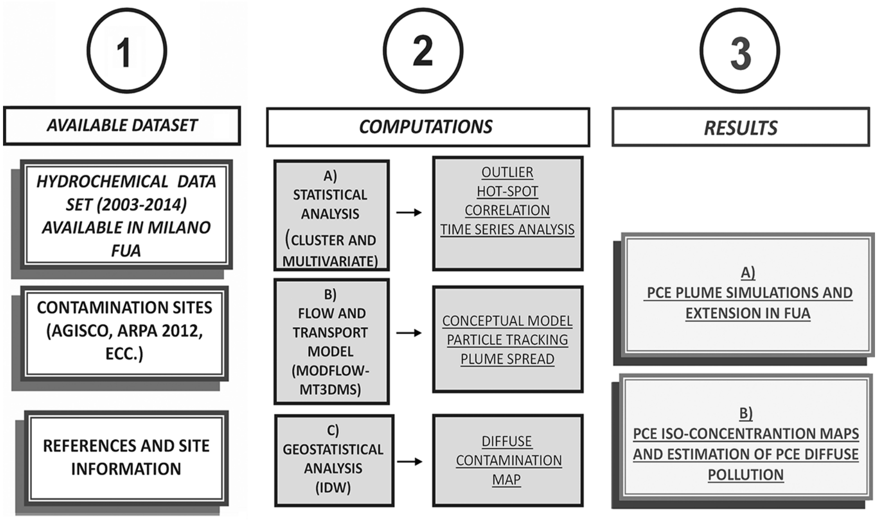


Fig. 3. Roadmap of the methodology for assessing the reference threshold of diffuse contamination (RTDC) in FUA of Milan 1) user data and pre-processing 2) tools used for computations: statistical tools for cluster and multivariate analysis, transport and flow mathematical model and geostatistical interpolator and 3) results in terms of plume extension and diffuse map contamination with estimated threshold values.

Mappa concettuale della metodologia utilizzata per la valutazione dei livelli limite di inquinamento diffuso nella FUA di Milano 1) Fase di pre-processamento e utilizzo dei dati 2) strumenti utilizzati per i calcoli: strumenti statistici per analisi cluster e multivariate, modelli numerici di trasporto e di flusso e interpolatori geostatistici 3) risultati ottenuti in termini di estensione dei pennacchi e di mappe di contaminazione diffusa con rispettivi valori di riferimento.

The overall data were merged into a single database with more than 600,000 records corresponding to 19 parameters (ions mono and bivalent, solvents). Figure 2 shows the spatial distribution of the sampling wells, which covers the entire territory. Data quality were checked by considering: abnormal values, outliers and absence of information into dataset.

2) A) Classification of the sampling point with coordinates, depth and a code indicating the aquifer throughout are screened. Statistical analysis allowed to select few factors able to describe the whole data set with minimum loss of original information (Principal Component and Factor Analysis) whereas k-means Cluster Analysis performed the similarities among the water quality profiles at different monitoring points.

B) Flow and transport model: for the definition of the areas affected by the passage of contamination plumes, the clusters analysis allowed to identify the "hot spots" in the area. These points, considered as point sources, were modeled to define the plumes contamination extension (Dlgs. 152/06). The groundwater model (MODFLOW+MT3DMS developed by (Harbaugh *et al.*, 2000; Zheng and Wang, 1999) was calibrated with PEST (Doherty, 2014, 2003, 1994) with monitored head values in May 2014 and with sampled concentration in 2014.

C) Geostatistical analysis (Inverse Distance Weighted) in order to map the diffuse contamination for perchlroethylene (PCE) and trichloromethane (TCM), not directly influenced by hot spots.

3) Spatial reconstruction of diffused pollution:
   A) the monitoring wells located inside the plume areas were removed from the polluted dataset with the aim to keep just the concentrations representing the diffuse contamination. The new dataset was then used for the geostatistical analysis (Inverse Distance Weighted)

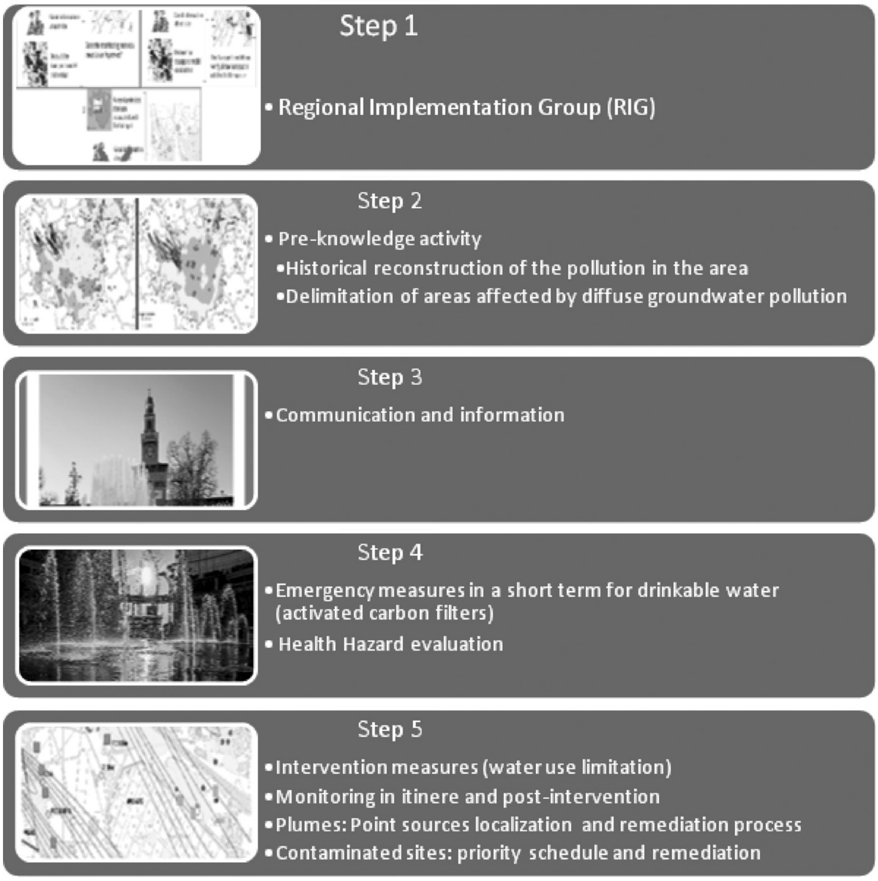
4) definition of reference values of diffuse contamination levels for the areas identified in the maps.

4. Regional management of diffuse contamination

The MP for diffuse pollution, approved with the Decree of the Regional Government (n. 6737/2017) according to the Operative Protocol, contains a series of measures to cope with the presence of diffuse pollution (tab. 1). The measures aim to safeguard the health of the inhabitants, control and contrast the pollution of the groundwater and its effects on the environment. However, the measures do not overtake the central issue of the research of unknown sources.

The Public Institutions involved in remediation measures are in charge for:

- apportion contaminant sources for the application of the polluter pays principle. Recently, the Region has financed the drilling of additional piezometers to find some of these sources
- find resources for the protection of human health and the environment
- control of the correct implementation and the effectiveness of the remediation measures
- substitute the polluters responsible for the remediation in case they refuse to do the remediation (enacting legal actions to recover the costs)



Tab. 1. Scheme of the Operative Protocol of Regional Remediation Program (RRP).
Protocollo operativo per la gestione di bonifica regionale.

- assess risk in contaminated sites.

In addition to these measures, the Region has developed a procedure to assess the potential health risk for population coming from diffuse contamination by Chlorinated Hydrocarbons. It considers many key parameters like concentration of pollutants, lithology, water table, indoor/outdoor exposure, land use, environmental measurement and will be helpful both to exclude health risk and to suggest the opportunity of local investigations to refine risk assessment, to choose the most suitable actions to undertake to decrease the risk to acceptable values.

The tool has been applied for the first time to the Wide Area for the diffuse pollution of PCE and TCM and will be distributed for the use by the local Institutions.

4.1. Step 1: Regional Implementation Group (RIG)

The RIG for the Chlorinated Hydrocarbons diffuse contamination of groundwater was instituted in 2015. The members of the RIG were the Public Authorities that are in charge for the environmental problems (i.e. water management, soil conservation and environment) at local and regional level. Moreover, Regional Environmental Protection Agencies (ARPA), Water Service Managers, university (Politecnico di Milano) were invited to participate to the meeting due to their involvement in the data collection, water management and for the scientific support for modeling the phenomena.

The RIG is in charge for the implementation both of the databases and of the monitoring network, for the circumscription of the areas affected by diffuse pollution based on the Values representative of the Diffuse Contamination (VDC) and of the Reference Threshold for Diffuse Contamination (RTDC). Moreover, it is in charge for the definition and proposal of the measures of intervention. In particular, the RIG tackled the following aspects:

- delimitation of the diffuse contamination within FUA for PCE and TCM
- evaluation of the Health Hazard for the population due to a presence of diffuse contamination and especially linked to the vaporization of PCE and TCM
- definition of the new RTDC for the remediation within the FUA
- definition of the management and interventions measures aimed at control the diffuse contamination evaluation, safeguard the citizens health and mitigate the health risk.

The experiences gained with the RIGs management, previously in the MP of the Wide Area and now applied for the Pilot Action in the North-Western area of Milan for the AMIIGA Project, are showing that this instrument is powerful because of the interdisciplinary of its members, but also that it is not easy to come in to an agreement when many actors are involved in the decisions. Moreover, it is not easy to involve actively members in the activities (only 6 municipalities out of 12 attended to the meeting).

4.2. Step 2: Pre-knowledge activity, historical reconstruction of the area, delimitation of areas affected by diffuse groundwater pollution

The reconstruction of the diffuse pollution distribution of the groundwater in the Wide Area requires an important phase of organization and integration of

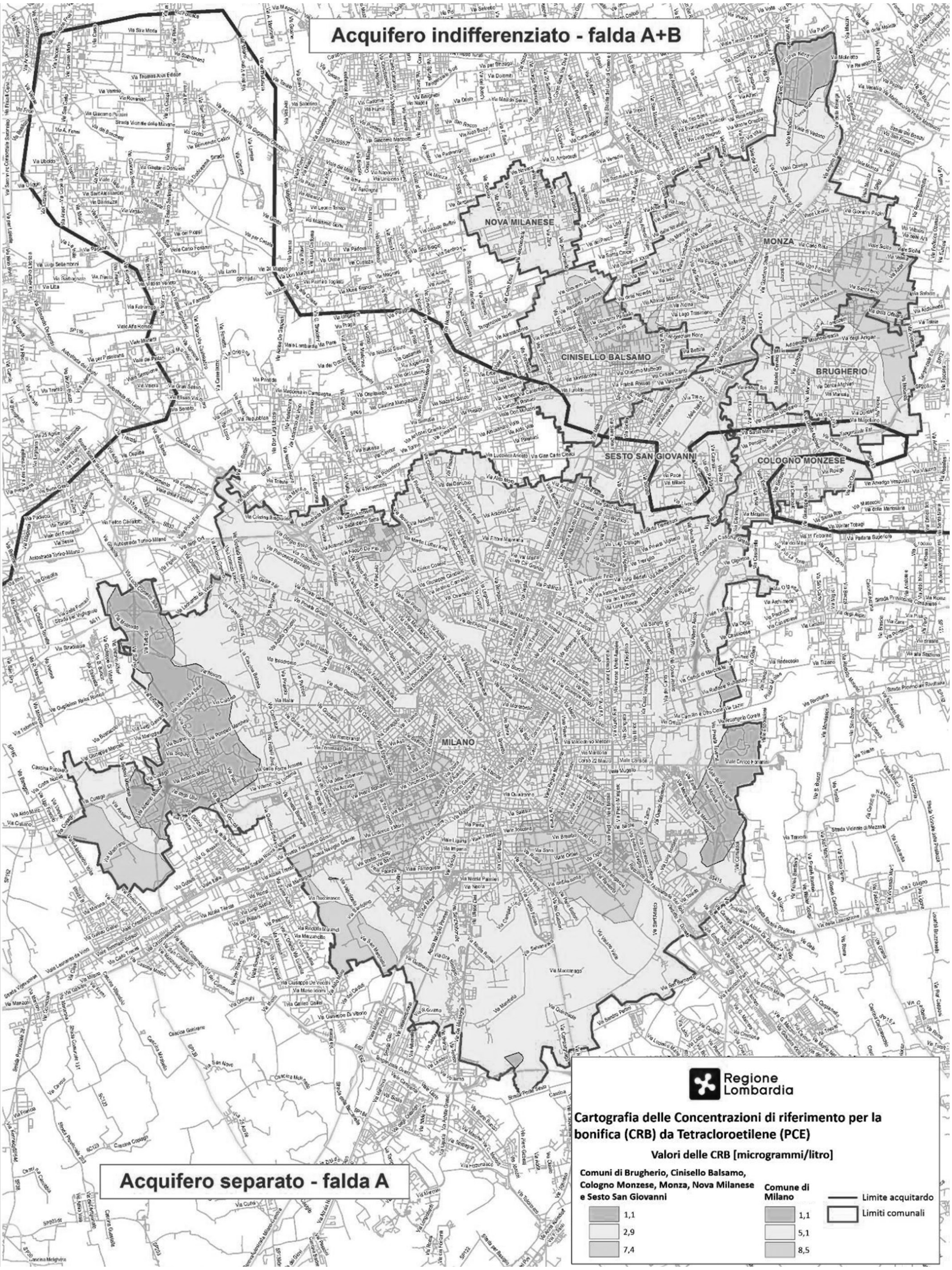


Fig. 4. Map of PCE diffuse contamination and Reference Threshold for Diffuse Contamination (RTDC) for remediation actions.
Mappa di contaminazione diffusa da PCE e valori di concentrazione di riferimento di inquinamento diffuso (RTDC) per la bonifica.

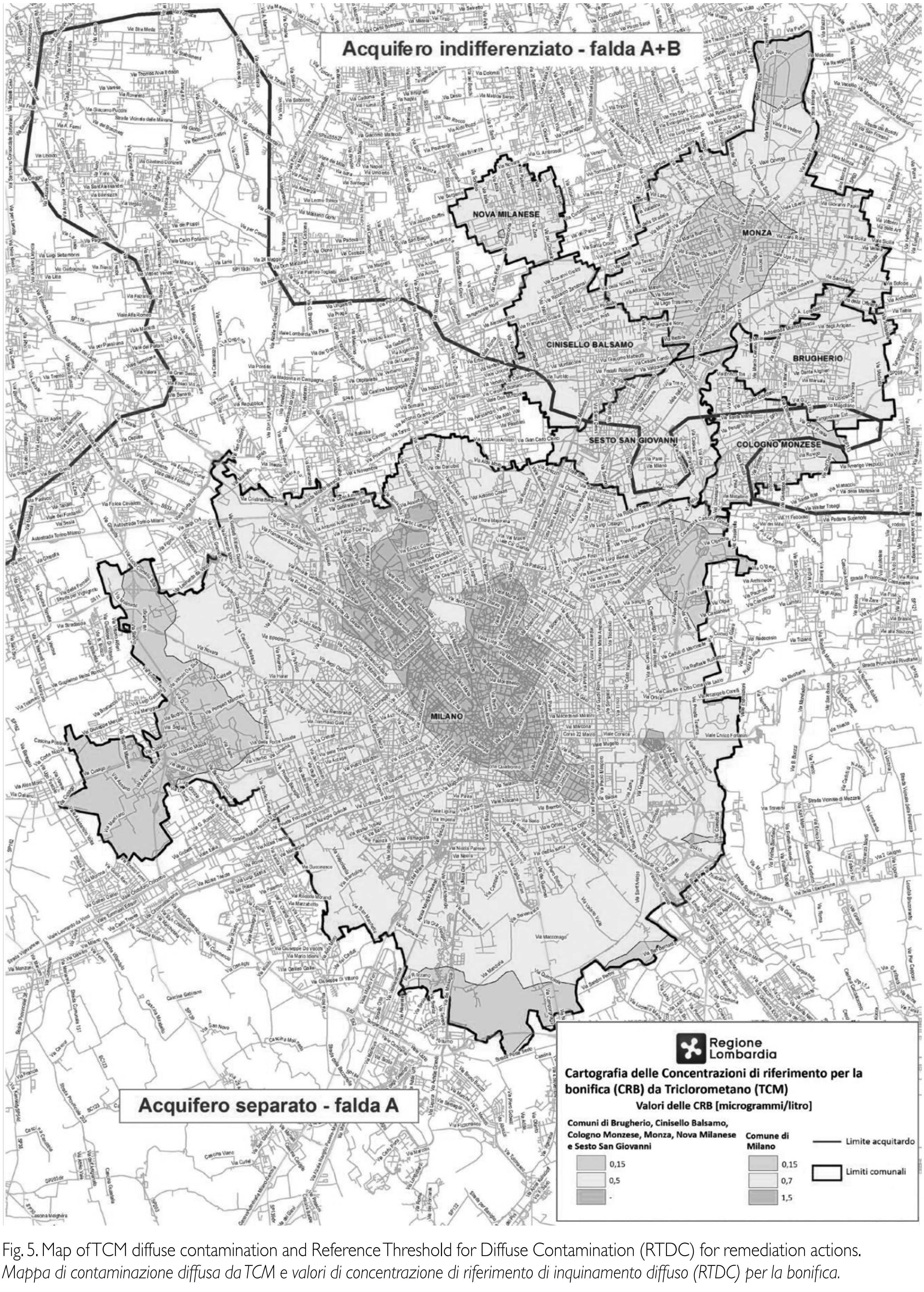


Fig. 5. Map of TCM diffuse contamination and Reference Threshold for Diffuse Contamination (RTDC) for remediation actions.
Mappa di contaminazione diffusa da TCM e valori di concentrazione di riferimento di inquinamento diffuso (RTDC) per la bonifica.

existing dataset. Moreover, a detailed analysis over the time on the typology of activities of companies in the involved area (i.e. sectoral business, types of processing) has to be done. Pre-knowledge activity and historical reconstruction of the pollution in the area have been done by Politecnico di Milano and ARPA (ARPA Lombardia, 2016, 2015) following the new methodology detailed in paragraph 3.

Based on the results of the detailed investigation carried out Lombardy Region, in May 2017 with the Decree of the Regional Government 5590/2017, delimited the areas affected by groundwater diffuse pollution of PCE and TCM. Figure 4 and Figure 5 show the maps, defining the diffuse pollution distribution in the Wide Area for PCE and TCM in the shallow aquifers, that are annexed to the Decree.

Green areas are not affected by diffuse contamination and concentrations are below the National Law Limit (1.1 μg/l and 0.15 μg/l respectively for PCE and TCM: Dgls. 152/06) whereas the yellow areas represent the diffuse contamination with concentrations in the range between the National Law Limit and 10 μg/l (drinkable water Threshold limit (Dgls. 31/01) for the sum of Chlorinated Hydrocarbons). The red areas represent the areas affected by a high level of diffuse contamination (over 10 μg/l).

The methodology applied in this study is able to evaluate the contamination representative of the diffuse pollution for the Wide Area. Lombardy Region, in accordance with national Legislation (Annex 1 –Part IV Dgls. 152/06), adopted these values as Reference Threshold for Diffuse Contamination (RTDC) for the remediation measures. RTDC have been defined for PCE and TCM for the shallow aquifer. Since the aquifer is separated in Milan while undifferentiated in the municipalities Northern Milan, two different RTDC have been defined. Moreover, separated RTDC have been defined also for areas with different concentrations of diffuse contamination (yellow ad red areas). Table 2 and Table 3 contains the RTDC for PCE and TCM with reference to Figure 4-Figure 5. The RTDC was defined with a methodology (presented in the paragraph 3) composed by a numerical transport model (definition of plumes contour due to a presence of known point sources) and multivariate statistical approach (cluster analysis and factor analysis able to evaluate the concentration of diffuse contamination in different areas). For more details about the methodology and the application done to obtain the RTDC, see (Alberti *et al.*, 2016b; Azzellino *et al.*, 2019; Colombo, 2017).

Tab. 2. RTDC values for PCE (μg/l).
Concentrazioni di Riferimento per la Bonifica del Tetracloroetilene (μg/l).

RTDC (μg/l)	Yellow Area	Red Area
Northern Municipalities (Wide Area in the Figure 4)	2,9	7,4
Milan	5,1	8,5

Tab. 3. RTDC values for TCM (ug/l).
Concentrazioni di Riferimento per la Bonifica del Triclorometano (μg/l).

RTDC (μg/l)	Yellow Area	Red Area
Northern Municipalities (Wide Area in the Figure 5)	0,5	Not provided
Milan	0,7	1,5

The RTDC, are less restrictive than National Law Limit and are the new concentration targets for individual remediation procedures in this aquifer.

For the red areas, the RTDC is set as 8.5 μg/l in order to respect the law concentration limit for drinking water (Dgls. 31/01) for the total sum of PCE-TCE.

Within the delimited area, the remediation procedures for point sources remain in charge to the polluters, and have to be managed within traditional administrative procedures, but the concentration limits to be reached for the PCE and TCM in shallow aquifer become the RTDC instead of the National Law limit.

4.3. Step 3: Communication and information

The communication about the groundwater diffuse contamination, because of the high rate of population living in the area and interest of the institutions and municipalities involved in the groundwater quality, needs a coordinate management. In this context, a communication plan to disseminate environmental information and results of the methodology applied will be prepared. The proposal aims to promote knowledge and awareness not only on the presence of diffuse pollution but also on the measures taken to limit the use of impacted resources and on environmental-health issues.

The Plan will also take into account the need to disseminate information to the public, citizens, on the evolution with reference both to implementation of the measures and actions envisaged and to the evolution of the pollution situation. Moreover, stakeholders like Land Owners, Polluters, Remediation Performers and Residents will be involved in the knowledge and progress of the MP in the FUA.

4.4. Step 4: Drinkable water use and hazard evaluation

The use of groundwater for drinking purposes in the studied area is monitored in continuous way from Water Supply Managers and institutions. Moreover, water supplied by distribution networks are treated in order to ensure the complete safety for the population. Concerning the water for human consumption, the Legislation considers control in-house done by Water Supplied Managers or by Regional Agency for Health Protection in order to guarantee the potable water threshold Limit (Dgls. 31/01 –for Chlorinated Hydrocarbons 10 μg/l).

The Water Supply Managers on the investigated area, which are involved in the RIG, have developed and implemented strategy providing drinkable water of high quality, adopting suitable Water Safety Plan based on a risk condition management. In addition, the protection of the population affected by diffuse pollution will be addressed in the most exhaustive way. The provided actions will be developed to get, more complete as possible, a full framework of critical issues associated to water uses. It will be assessed the hazards derived from water affected by diffuse contamination used for irrigation, livestock or recreational use and from sites with excavations in the saturated areas.

4.5. Step 5: Intervention measures

Based on the groundwater modeling (see paragraph 2) and on a sanitary risk assessment (developed by Regione Lombardia), a series of remediation measures have been defined:

a) Limits on the water use
Within the intervention measures, there is the possibility to limit the use of water for the activities concerned in order to avoid risk for the population.

b) Monitoring of groundwater quality
The Regional Environmental Protection Agency will develop a groundwater monitoring plan, it will be funded by the Region. The monitoring activities will be based on the use of the existing network, with a possibility to integrate dataset with the data of Water Services, with a 6-month measurement field campaigns. The monitoring activity will allow to verify and update the mapped RTDC during the years (in a time interval 4-5 years) and evaluate the effects of the measures adopted in a medium-long term.

c) Study and definition of plumes, localization and remediation of point sources
By using groundwater modelling tool, it will be possible to trace the plumes and study their evolution in space and time. An effort will be done for the identification of contaminant sources for the application of the polluter pays principle in order to find resources for the protection of human health and the environment.

d) Contaminated sites
Documentary research and survey plan will be useful to assess the interventions for site-specific contamination problems.

5. Conclusion

Significant contamination affect most of the groundwater bodies of Lombardy Region due to an intense process of historic industrialization. While in some areas the contamination depends on point sources (known or under investigation), in others groundwater presents pollution of diffuse nature.

The management of diffuse pollution represents a difficult challenge for the Public Authorities, as it involves large portions of territory, with low concentrations of pollutants and consequences both on the use of water and on the health of citizens. This problem cannot be managed with the ordinary technical-administrative tools available for the remediation of point sources.

This kind of contamination requires an important systematization and integration of existing data. Therefore, Lombardy Region has defined the diffuse pollution management strategy in land remediation planning.

Since diffuse pollution affects large areas and multiple subjects, the Region has standardized the procedure for its management, including the creation of a RIG (or Technical Panel) to coordinate the procedures and activities among all the involved public bodies.

The regional experience about the management of groundwater diffuse pollution in the Wide Area of Milan (about 2 million inhabitants) represents an innovative procedure in the groundwater protection.

The intervention measures, included in the MP approved by the Lombardy Region in 2017 for this area, aim to protect the health of the population concerned, to control and contrast pollution and its effects on the environment and to raise awareness about it. The monitoring process to assess the evolution of pollution over time have been also established.

Given the importance of protecting human health, new studies have been ongoing to assess, through the application of groundwater models, the potential risks, even cumulated, of the uses of groundwater affected by diffuse pollution.

Because in presence of groundwater diffuse pollution, the remediation procedures admit less restrictive reference values, the issue is sensitive with far-reaching implications and several interested parties. Lombardy is the first region in Italy that is investigating this issue and implementing a new methodology that can be assumed as a test of the national guidelines of diffuse pollution recently issued by the Ministry for the Environment.

This activity will be enhanced thanks to the AMIIGA Project: considering that in Europe there are many areas with similar forms of groundwater pollution, the development of common management modes, focusing on densely populated areas, is strategic to successfully address the complex profile of the problem. At the end of the project, the Plan for the Wide Area and those of the Pilot Action area will be merged in a comprehensive Plan for the whole Milan FUA.

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Strategies for deep aquifers protection at local and regional scale: the Piedmont region example

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Deep aquifers represent a strategic resource because of their quality, generally better than rivers and shallow aquifers. More specifically, in Piedmont Region (Italy) they represent a key source of drinking water and therefore must be protected from qualitative and quantitative degradation. In this paper, the main strategies that can be implemented for the protection of deep aquifers are resumed. Moreover, the current application of these strategies in Piedmont Region is reported, as a virtuous example of management and protection of water resource.

Keywords*: groundwater monitoring, deep aquifers, mixing well, overexploitation, contamination, Italy.*

Strategie per la protezione degli acquiferi profondi a scala locale e regionale: l'esempio della Regione Piemonte. *Gli acquiferi profondi rappresentano una risorsa strategica a causa della loro qualità, generalmente migliore di quella di fiumi e di acquiferi superficiali. In particolare, nella Regione Piemonte (Italia) gli acquiferi profondi rappresentano una risorsa chiave per l'approvvigionamento dell'acqua potabile e pertanto devono essere protetti dalla degradazione qualitativa e quantitativa.*
In questo lavoro vengono riassunte le principali strategie che possono essere adottate per la protezione degli acquiferi profondi. Inoltre, come esempio virtuoso di gestione e protezione delle risorse idriche, vengono riportate le attuali applicazioni di queste strategie nella Regione Piemonte.

Parole chiave*: monitoraggio della falda, acquiferi profondi, pozzi miscelanti, sovrasfruttamento, contaminazione, Italia.*

1. Introduction

Directive 2006/118/EC (European Commission 2006) established that groundwater is a valuable natural resource and should be protected from deterioration and chemical pollution. This is particularly important for the use of groundwater in water supply for human consumption. This Directive was implemented in Italy with Legislative Decree 30/2009 (Gazzetta Ufficiale 2009), in which it is reported that groundwater bodies, used for the extraction of water for human consumption, are subject to protection in order to prevent their quality deterioration.

In the plains subsurface, different aquifers can be recognised, more or less communicating in relation to the geological structure. More specifically, the term "shallow aquifers" refers to aquifers closer to the soil surface, with a local and short groundwater flow system. These aquifers generally have a depth from 20 to 80 m, depending on the hydrogeological structure and the recharge from the surface. Limits are imposed by local topography, hydrographic network and lakes. The influence of climatic zones is significant.

More deeply, groundwater generally belongs to deeper flow systems (Toth 1963) and it is contained in confined or semi-confined aquifers. These systems have an intermediate or regional significance and long flow circuits, where flow conditions are imposed by regional topography (e.g. large axes of the reliefs), large hydrographic axes, great lakes, oceans and inland seas and endorheic depressions of the arid zones. The role of structural geology is, in this case, preponderant.

According to Piedmont Region law 22/1996 (B.U. n.19 del 08/05/1996) and subsequent amendments, the aquifers of Piedmont Region (NW Italy) located underneath a shallow aquifer can be called "deep aquifers". Because deep aquifers typically serve as key sources of drinking water in Piedmont, they have to be mostly protected. Indeed, deep aquifers have generally a better quality than watercourses and shallow aquifers (Lasagna *et al*. 2016) being less vulnerable to contamination. In addition, they are less subject to level fluctuations due to factors such as climate change.

In this paper, the main strategies that can be implemented for the protection of deep aquifers are resumed. Moreover, the current application of these strategies in Piedmont Region is reported, as a virtuous example of management and protection of water resource.

2. Improving the knowledge of hydrogeological systems

Any effective strategy for the deep aquifers' protection must be based on a good knowledge of the hydrogeological setting and the current state of exploitation and use of groundwater resource. Particularly, the main elements to analyse in the study area are: the lithostratigraphic structure, the hydrogeological parameters, the piezometric maps, the recharge features, the water quality, the changes in the piezometric levels over time, the number and type of wells, the withdrawals from the wells.

The water supply in the Piedmont Region plain is mainly linked to the exploitation of the following hydrogeological units (De Luca *et al.* 2004; Bove *et al.* 2005; Forno *et al.* 2018): i) shallow unconfined aquifers consisting of alluvial coarse deposits of the upper Quaternary (outwash and fluvial complex) and glacial Complex); ii) deep confined and semiconfined aquifers represented by a multi-aquifer system (Villafranchian Complex of Upper Pliocene-Lower Pleistocene) and by marine sands (Asti Sands of Middle Pliocene) (fig. 1).

These permeable deposits are followed by predominantly silty-clayey sediments in Piacenziano facies (Lugagnano Clay of Lower Pliocene) and pre-Pliocene marly-arenaceous deposits and conglomerates, mostly impermeable (Complex of marine pre-Pliocene deposits of Turin Hill) (Lasagna *et al.* 2018;)

Piedmont drinking water consumption is over 500 million m^3/year. This supply derives from aquifers (92%), mostly deep. Furthermore, 75% of the Piedmont municipalities have in the deep aquifers the only source of water supply.

3. Qualitative and quantitative monitoring of deep aquifers

An essential source of information about the quali-quantitive status of groundwater derives from an adequate groundwater monitoring network (Alley 2007). The purpose of groundwater qualitative monitoring is to evaluate the long-term changes of the water natural features and to clarify and analyse the extent of natural processes and human impacts on the groundwater system in time and space (Vrba 2003). The quantitative monitoring aims to register changes in groundwater levels, due to groundwater withdrawal or as the effects of climate change. Any monitoring programme needs to be tailored to the hydrogeological and socio-economic context (Jørgensen & Stockmarr 2009).

Groundwater quality monitoring plays an important role in the policy of groundwater protection and quality conservation and effectively supports sustainable groundwater quality management. It provides a valuable base for assessing the current state of and

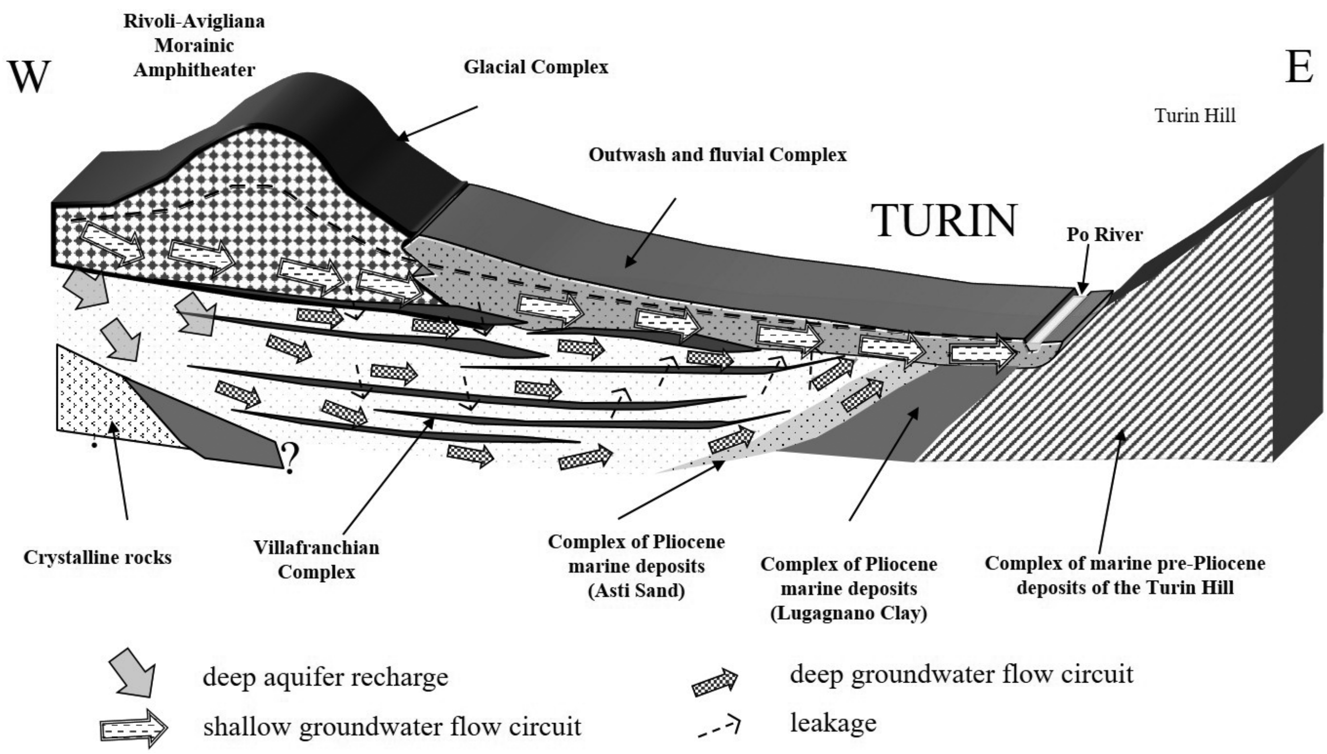

Fig. 1. Hydrogeological conceptual model of Turin plain (Piedmont, Italy) (modified from De Luca and Ossella, 2014). The dotted line represents the piezometric level of shallow aquifer.

Modello idrogeologico concettuale della pianura Torinese (Piemonte, Italia) (Modificato da De Luca e Ossella, 2014). La linea tratteggiata rappresenta il livello piezometrico dell'acquifero superficiale.

forecasting trends in groundwater quality and The Regional Monitoring Network in Piedmont was developed by the Earth Sciences Department (DST) of the University of Turin and is currently managed by Arpa Piemonte. It is composed of: 605 wells, mostly private, for qualitative monitoring and 119 piezometers (automatic network) also used for continuous detection of groundwater levels (fig. 2).

A significant difference in chemistry between shallow and deep aquifers was identified in Piedmont Region through the qualitative monitoring. Indeed, shallow aquifers are very often contaminated and the main pollutants are nitrates, pesticides, chlorinated solvents and hexavalent chromium (De Luca *et al*. 2004; Lasagna *et al*. 2015, Lasagna and De Luca, 2016, 2019; Martinelli *et al*. 2018; Fouchè *et al*. 2019). They are also characterized by a higher salinity and hardness. The deep aquifers, on the contrary, are characterised by rare contamination problems, have a lower salinity and hardness, and sometimes a natural presence of high concentrations of iron and manganese.

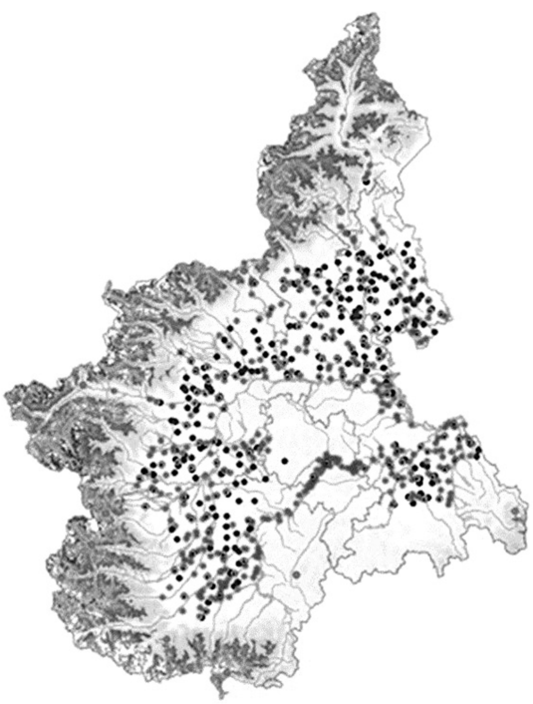

Fig. 2. Piedmont Region groundwater monitoring network (grey point : superficial aquifer monitoring well; black point : deep aquifer monitoring well)
Rete di monitoraggio della falda della Regione Piemonte (punto grigio: pozzo di monitoraggio dell'acquifero superficiale; punto nero: pozzo di monitoraggio dell'acquifero profondo).

The quantitative monitoring network reports a situation of substantial equilibrium of the quantitative status. This means that the amount of water entering or recharging the system is approximately equal to the amount of water leaving or discharging from the system (Alley *et al*. 1999). According to Italian Legislative Decree 152/2006, a groundwater system is in equilibrium when natural recharge and discharge are sustainable for a long time (at least 10 years).

In Piedmont plain, only local problems of nonequilibrium were identified, and among these the most important situation is related to the area of Maggiore Valley (Asti). Here more than 40 wells withdraw approximately 14,000,000 m^3/year of water for drinking purposes (about 50% for the City of Asti) (Lasagna *et al*. 2014). Groundwater is extracted by wells penetrating the deep aquifer, originally artesian, consisting of Pliocene marine sands. As a result of this high withdrawal, a water table lowering of over 50 meters occurred from 1925 to 2015. The lowering trend was about 0.8 m per year.

4. Prevention of deep aquifers qualitative degradation

Shallow aquifers are particularly vulnerable to inappropriate or uncontrolled anthropic activities with spill of pollutants on the ground (heavy metals, hydrocarbons, pesticides, solvents, etc.). Deep aquifers, on the contrary, are more protected from contamination. Moreover, even deeper, semi-confined aquifers will (sooner or later) be affected by relatively persistent contaminants (such as nitrate, salinity and certain synthetic organics), if widely leached into groundwater in aquifer recharge areas (Foster & Chilton 2003). The degradation of shallow groundwater can be the cause of deep aquifers pollution. A natural reason is due to the presence of fine-grained levels, separating shallow and deep aquifers, that are always discontinuous at a regional scale, and create the conditions for a possible passage of the contamination. Anthropic works can also create the conditions of mixing between shallow and deep groundwater (fig. 3). More specifically, the presence of hundreds of mixing wells, with filters in both the shallow and deep aquifers, or defects and voids in the grout of borehole heat exchangers, that represent the main component of the so-called ground source heat pump systems (GSHPs), can lead to inter-aquifer flux (Caviglia *et al*. 2009; Bucci *et al*. 2018). Moreover, the excavation of quarries in the deep aquifers, through the overcoming of the impermeable level that separate shallow and deep aquifers, should be avoided to prevent contamination of deep groundwater (Castagna *et al*. 2015). As a consequence, it is very important to identify all the possible activities that can favour the water mixing, to monitor the si-

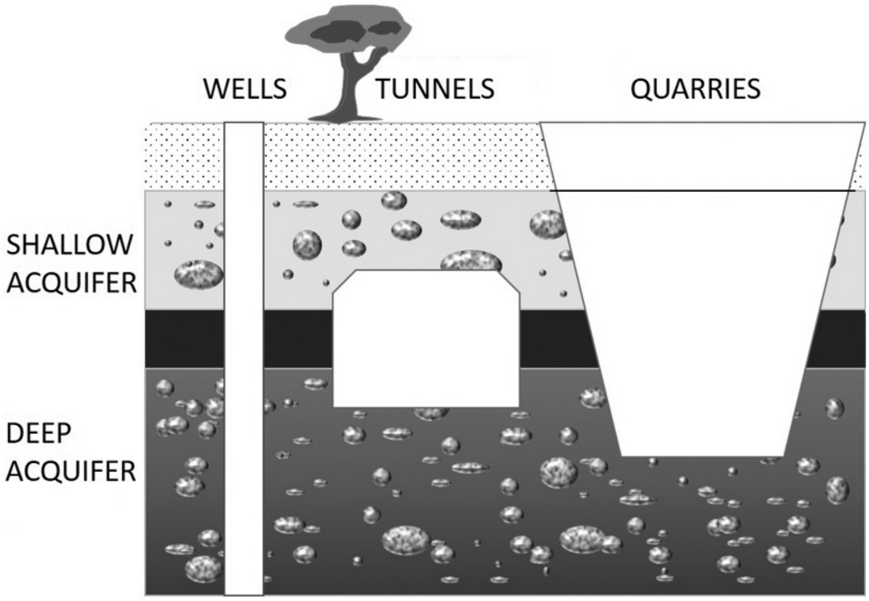

Fig. 3. *Example of anthropic works that can create the conditions of mixing between shallow and deep groundwater.*
Esempio di opere antropiche che possono creare condizioni di miscelamento tra l'acquifero superficiale e quello profondo.

tuation and to intervene with specific safety measures to safeguard the water quality and prevent the development of pollution in deep aquifers. The recharge areas of deep aquifers (RADA) represent portion of territory that must be particularly protected. Indeed, the downward movement of groundwater in RADA can more quickly transfer some pollutants in deep aquifers and thereby contaminate groundwater supplies.

4.1. Reconditioning of mixing wells

A possible direct passage of pollutants from the shallow to the deep aquifers is through the well casing and/or the filter pack, in wells that penetrate deep aquifers and with filters in both the shallow and deep aquifers and/or without impermeable sealing (mixing wells).

A qualitative and quantitative assessment of the mixing wells effects in Piedmont Region was carried out through numerical simulation (Caviglia *et al.* 2009a, 2009b). A mixing well can allow a water passage on average of 250 m^3 per day from the shallow to deep aquifers. Since about 15,000 mixing wells are located in Piedmont plain, a total flow of hundreds of thousands of m^3 per day potentially occurs. In this context the deep aquifer water resources can be seriously damaged. Adequate actions on the mixing wells are a) the ban to drill new mixing wells, b) the closure or reconditioning of existing mixing wells. Reconditioning can occur i) closing the filters in the shallow aquifer and the well casing-soil interspace; ii) closing the filters in the deep aquifers and the well casing-soil interspace.

Piedmont Region has recently published Guidelines, written in collaboration with the DST, for the implementation of reconditioning actions. Furthermore, a map of the shallow aquifer base has been realized in order to facilitate the drilling of non-mixing wells, to accurately and quickly identify the mixing wells, and to avoid contrasts between private citizens and stakeholders.

4.2. Identification and protection of deep aquifers recharge areas (RADA)

The recharge of deep aquifers occurs in the RADA, where the groundwater has a downward flow direction, from the topographical surface to the deep aquifer, passing through the shallow one. Here groundwater can more easily transfer pollutants to deep aquifers. Therefore, the identification and protection of RADA is a very important preventive action against groundwater quality degradation in deep aquifers. More specifically, the identification of the deep aquifers' recharge areas provides the local administration with a management tool to protect groundwater, through the implementation of legislative measures and restrictions for the control over the pollution sources (De Luca *et al.* 2019).

In Piedmont Region, an expeditious method for mapping RADA at a regional scale was proposed by DST, based on easily available data (De Luca *et al.* 2016). It is especially useful to have an estimate of RADA extension in areas where hydrogeological and chemical data are locally insufficient.

5. Prevention of deep aquifers quantitative degradation

Quantitative degradation of deep aquifers is generally connected to water resources overexploitation. If the withdrawal is so high that an equilibrium in the groundwater balance cannot be achieved, a water level decline can realise, also with consequences in surface water levels and ecological resources dependent on streamflow. Thus, it is necessary to prevent these phenomena with a prudent use of deep groundwater or to intervene with safety measures to re-establish equilibrium conditions.

5.1. Deep aquifers use only for human consumption

A sound strategy for deep aquifers protection could be the promotion of the use of deep aquifers for drinking water purposes only. It consists of discouraging the use of deep groundwater for industries or irrigation.

This policy was carried out in the Piedmont Region through: a) the increase of the fees on the groundwater withdrawal from deep aquifers; b) the denial of the permission to build new deep wells for uses different from human consumption.

5.2. Possible actions for mitigation of deep aquifers quantitative degradation

If the groundwater system is in nonequilibrium, it is necessary to identify the causes and to intervene rapidly, so as to avoid damages to human activities, and to the health of the population and the environment.

In case of overexploitation, a different quantitative management of groundwater resources is necessary. Actions may include: a) withdrawals reduction, b) withdrawals redistribution, c) artificial recharge. The choice must be based on a careful analysis of costs and benefits.

A study carried in the Maggiore Valley (Piedmont) by DST on behalf of ATO3 Asti identified as suitable interventions both the reduction of withdrawals (20% of total withdrawal) and the wells redistribution in the territory (De Luca *et al*. 2018). The action program started in 2014 and it is underway, but it already had important positive results with a reversal trend of the piezometric level that raised more than 10 meters.

6. Conclusions

In the subsoil different aquifers are located, in which groundwater is more or less communicating in relation to the geological structure. Among them, deep aquifers represent a strategic resource. Indeed, they generally show a better quality, being less vulnerable to contamination than shallow aquifers and watercourses. In addition, they are less subject to level fluctuations due to factors such as climate change.

However, the restoration of qualitative or quantitative status, after a degradation, can be very difficult. Thus, different strategies can be adopted to avoid the degradation, e.g. to prevent the contamination of shallow aquifers, to avoid anthropic works that can create the conditions of mixing between shallow and deep groundwater, to limit deep groundwater uses other than human consumption, to identify mixing wells, that must be subject to reconditioning, to improve the knowledge of hydrogeological systems also with a quali-quantitative monitoring.

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Aquifer protection from overexploitation: example of actions and mitigation activities used in the Maggiore Valley (Asti Province, NW Italy)

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The groundwater overexplotation is a worldwide problem and it causes serious consequences such as land subsidence, saltwater intrusion, devastating effects on natural streamflow, groundwater fed wetlands and related ecosystems.
The Maggiore Valley (NW Italy) was analysed in this paper because it is considered as a clear example of overexploitation in Italy. In this area a decrease of the piezometric level of more than 40 m and a large reduction of an artesian area were registered, due to a high increase of groundwater withdrawal from the beginning of XX century. Because the exploited confined aquifer is the only source of water for human consumption in the area, Maggiore Valley wellfield is considered of regional importance and numerous actions have been launched to protect and preserve it. After a detailed hydrogeologic reconstruction of the area, a groundwater flow model was implemented. Then, the simulation of new groundwater withdrawal configurations (groundwater extraction decrease, redistribution of the well location and a combination of both of them) were investigated, in order to simulate a different quantitative management of the groundwater resources. The results of all the simulations highlighted a positive impact on the piezometric level. Consequently, a reduction of groundwater withdrawal from Maggiore Valley wellfield and a concurrent supplementary feed (interconnection, 100 L/s) from the Monferrato Aqueduct, were realized. This operation leads to a partial rising of the piezometric level up to 8 m from 2012 and 2016.
In addition, geophysical studies were conducted to identify the best area for some wells relocation. A combined use of Electric Resistivity Tomography (ERT) sections and Time Domain Electromagnetic (TDEM) soundings permitted to depict the depth and lateral continuity of the uppermost part of the Quaternary deposits, hosting the near surface aquifers, and to choose the most suitable zone from a hydrogeological point of view.
Keywords*: overeploitation, groundwater, piezometric level decline, mitigation, Italy.*

Protezione degli acquiferi dal sovrasfruttamento: esempi di azioni e attività di mitigazione utilizzate in Val Maggiore (Provincia di Asti, Italia Nord Occidentale). *Il sovrasfruttamento delle acque sotterranee è un problema molto diffuso e può causare gravi conseguenze come subsidenza del terreno, intrusione salina, effetti negativi sui deflussi superficiali, sull'alimentazione di aree umide e dei relativi ecosistemi.*
In questo lavoro viene analizzata la Val Maggiore (Italia NW) in quanto rappresenta un chiaro esempio di sovrasfruttamento delle risorse idriche sotterranee in Italia. In quest'area sono stati registrati un abbassamento del livello piezometrico di oltre 40 m e una considerevole riduzione di un'area artesiana, dovuti ad un aumento degli emungimenti a partire dall'inizio del XX secolo. Poiché, nella zona, l'acquifero confinato sfruttato rappresenta l'unica risorsa di acqua per il consumo umano, il campo pozzi di Val Maggiore è considerato di importanza strategica e sono state effettuate numerose azioni per proteggere e preservare le acque sotterranee.
Dopo una dettagliata ricostruzione idrogeologica dell'area, è stato implementato un modello di flusso idrogeologico. In seguito, sono state considerate nuove configurazioni dei prelievi delle acque sotterranee (diminuzione degli emungimenti, ridistribuzione dell'ubicazione dei pozzi e una combinazione di entrambi), con lo scopo di simulare gli effetti di una differente gestione delle risorse idriche sotterranee. I risultati di tutte le simulazioni evidenziano un impatto positivo sul livello piezometrico. Di conseguenza, sono state realizzate una riduzione dei prelievi delle acque sotterranee nel campo pozzi della Val Maggiore e un simultaneo apporto supplementare dall'Acquedotto Monferrato ("interconnessione", 100 l/s). Questa operazione ha portato ad un parziale innalzamento del livello piezometrico di circa 8 m dal 2012 al 2016.
Inoltre, sono stati condotti degli studi geofisici per identificare l'area migliore per la rilocaliz-

1. Introduction

1.1. Water needs

Globally, a significant increase in water needs has been recorded in the last century, and thus an intensification of water withdrawal for domestic, agricultural and industrial sectors (FAO, 2016). However, while world population increased 4.4 times, water withdrawal increased 7.3 times over the last century. Thus, global water withdrawal increased 1.7 times faster than world population.

The largest increase in water withdrawal took place between 1950 and 1960 (4.2 percent per year), while it was only just 0.5 percent per year during the period 2000-2010 (fig. 1a).

At global level, the withdrawal ratios are 69 percent agricultural, 12 percent municipal and 19 percent industrial. These numbers, however, are biased strongly by the few countries, which have very high water withdrawals. The water withdrawal ratios, indeed, vary much between regions, going from 91, 7 and 2 percent for agricultural, municipal and industrial water withdrawal respectively in South Asia to 5, 23 and 73 percent respectively in Western Europe (FAO, 2016).

The importance of agricultural water withdrawal is highly dependent on both climate and the place of agriculture in the economy. Figure 1b shows the water withdrawal ratios by continent, where the agricultural part varies from more than

zazione di alcuni pozzi. Un uso combinato di Tomografie Elettriche (ETR) e sondaggi Elettromagnetici nel Dominio del Tempo (TDEM) ha permesso di rappresentare la continuità e la profondità della parte più alta dei depositi quaternari, ospitanti gli acquiferi posti a minore profondità, e di scegliere la zona più adatta da un punto di vista idrogeologico.
Parole chiave: *sovrasfruttamento, acque sotterranee, abbassamento del livello piezometrico, mitigazione, Italia.*

80 percent in Africa and Asia to just over 20 percent in Europe.

1.2. Groundwater resources

Although globally the water demand can be met by surface water availability (i.e., water in rivers, lakes and reservoirs), in regions with frequent water stress and large aquifer systems groundwater is often used as an additional water source (Wada et al 2010). Compared with surface water, groundwater use often brings large economic benefits per unit volume, because of ready local availability, high drought reliability and generally good quality requiring minimal treatment (Burke & Moench 2000).

Some areas are highly dependent on groundwater; in example in Mexico City, one of the world most populated city, there is no nearby surface water and 95% of the population uses groundwater for all the water needs. In Denmark 99% of the drinking water of the entire country comes solely from groundwater (IGRAC, 2018).

Intensive groundwater abstraction commenced from the 1950's following major advances in geological knowledge, waterwell drilling and pump technology. Based on estimates at country level (IGRAC, 2018; Margat, 2008; Siebert *et al.*, 2010; FAO. 2016) the world's aggregated groundwater abstraction as per 2010 is estimated to be approximately 1,000 km^3 per year, of which about 67% is used for irrigation, 22% for domestic purposes and 11% for industry. The global groundwater abstraction rate has at least tripled over the last 50 years and is still increasing at an annual rate of between 1% and 2% (Van der Gun, 2012).

1.3. The concept of overexploitation

If groundwater abstraction exceeds natural groundwater recharge for extensive areas and long time, overexploitation or persistent groundwater depletion can occur (Gleeson *et al.*, 2010). Overexploitation may be defined as the situation in which, for some years, average aquifer abstraction rate is greater than, or close to the average recharge rate (Custodio 2000). However, the rate and extent of recharge areas are often very uncertain, and they may be modified by human activities and aquifer development. In practice, an aquifer is often considered as overexploited when some persistent negative results of aquifer development are felt or perceived, such as a continuous water-level drawdown, progressive water-quality deterioration, increase of abstraction cost, or ecological damage (Custodio 2000).

According to an estimate, 20% of the world's aquifers are over-exploited (Gleeson *et al.*, 2012; WWAP, 2015). Groundwa-

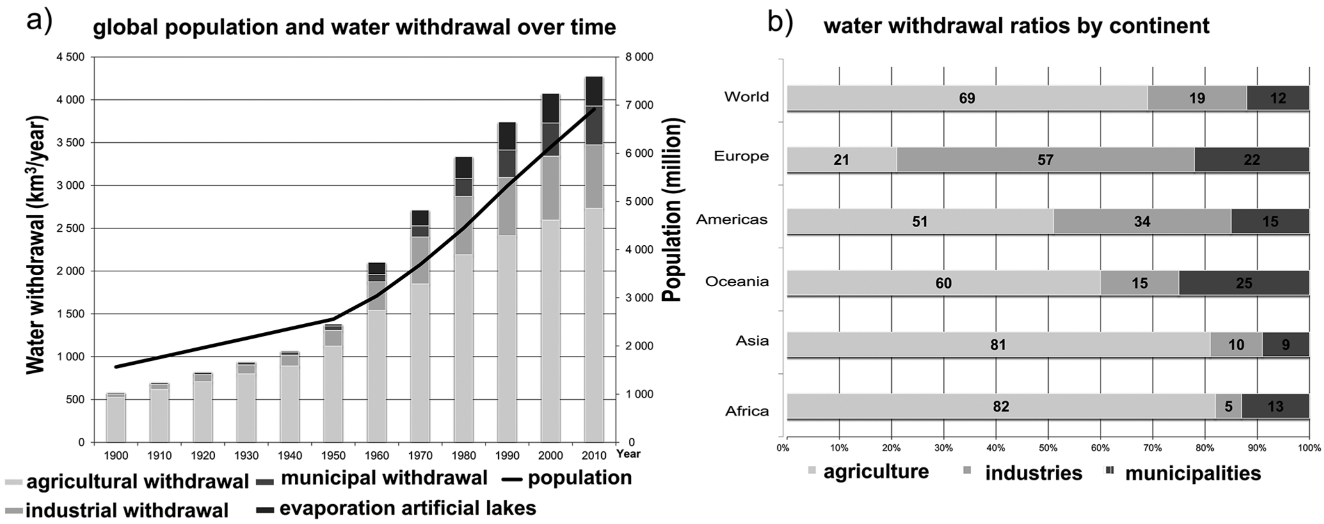

Fig. 1. a) Global population and water withdrawal over time. Three types of water withdrawal are distinguished: agricultural (including irrigation, livestock and aquaculture), municipal (including domestic) and industrial water withdrawal. b) Water withdrawal ratios by continent (FAO, 2016). *Water that evaporates from artificial lakes or reservoirs associated with dams is considered as a fourth type of anthropogenic water use.*
A) Popolazione globale e prelievi d'acqua nel tempo. Sono distinte tre tipologie di prelievi di acqua: agricolo (include irrigazione, allevamento e acquacoltura), civile (incluso uso domestico) e industriale. b) Percentuali di prelievi di acqua per continente (FAO, 2016). Le acque che evaporano da laghi artificiali o bacini associati a dighe sono considerate come un quarto tipo di uso antropico delle acque.

ter overexploitation situation are described in all the continents (Dijon & Custodio 1992, Johnson 1993, Uchuya 1993, Avanzini *et al.* 1997, Bromley *et al.* 2001, Esteller & Diaz-Delgado 2002, Kallioras *et al.* 2010, Ambrosio *et al.* 2009). Overexploitation leads to serious consequences such as land subsidence and saltwater intrusion in coastal areas (USGS, 2013). Land subsidence occurs when groundwater has been over-exploited from porous sediments, such as fine-grained materials. It generally results in substantial damage, including loss of ground surface altitude, cracking of buildings, failure of underground pipelines (Huang *et al.* 2012). Occurrences of land subsidence have been globally reported, such as Italy (Teatini *et al.* 2005; Sappa *et al.*, 2005), Spain (Molina *et al.* 2009), USA (Holzer and Galloway 2005), Mexico (Ortiz-Zamora and Ortega-Guerrero 2010), India (Sahu and Sikdar 2011), Thailand (Phienwej *et al.* 2006), China (Li *et al.* 2006; Shi *et al.* 2007).

Moreover the lowering of groundwater levels can have devastating effects on natural streamflow, groundwater fed wetlands and related ecosystems (WADA *et al.* 2010), with significant impacts on local economies and human well-being (WWAP, 2015).

2. The study area: the Maggiore Valley wellfield

The Maggiore Valley study area was analysed because it was considered as a clear example of overexploitation in Italy. This area is located in Piedmont, NW Italy. It is generally hilly and forms part of the Monferrato Hills range.

The Maggiore Valley wellfield consists of more than 40 wells (De Luca *et al.* 2018), concentrated in a very limited area (fig. 2), and it has a strategic role in Piedmont, because it provides drinking water to more than 43 municipalities. The most important town is Asti, with about 76.000 inhabitants.

Most of the wells are located in Maggiore Valley, but also the Traversola Valley is interested although at a lesser extent. Thus in the following, the wellfields will be defined as Maggiore Valley wellfield.

2.1. Hydrogeologic setting of the study area

The exploited aquifers of Maggiore Valley wellfield are represented by confined and semiconfined aquifers in the Asti Sands (Pliocene) (fig. 4a). This hydrogeologic unit consists of marine sandy sediments, alternated with lenses of fine sand, sandy gravel, clayey sand, silty-sandy and silty-clayey levels with very low permeability. The alternation between sediments with a good permeability and sediments with a scarce permeability creates the conditions for a multi-layered aquifer system. In this system, the various aquifers can intercommunicate through semi-permeable levels.

The thickness of the Asti Sands ranges between 150 and 200 m at Maggiore Valley. This thickness decrease eastward and southward. Under the Poirino Plateau, located westward, the thickness increase (in the Po Plain also more than 400 m). Previous pumping tests indicated a hydraulic conductivity in Asti sands of about 3.10^{-4} m/s (Ajassa *et al.* 2011).

The Asti Sands are located on the top of the Lugagnano Clay unit (Pliocene). It consists of sandy-marly clays and, having a very low or negligible permeability, represents an aquiclude.

The main groundwater flow direction of Pliocene marine aquifer is from west to east. In correspondence to Maggiore Valley wellfield, the piezometric surface highlights a deep cone of depression (fig. 2).

While in the north of the study area the depth of the water table ranges between +6 m above ground level (artesian area), in the

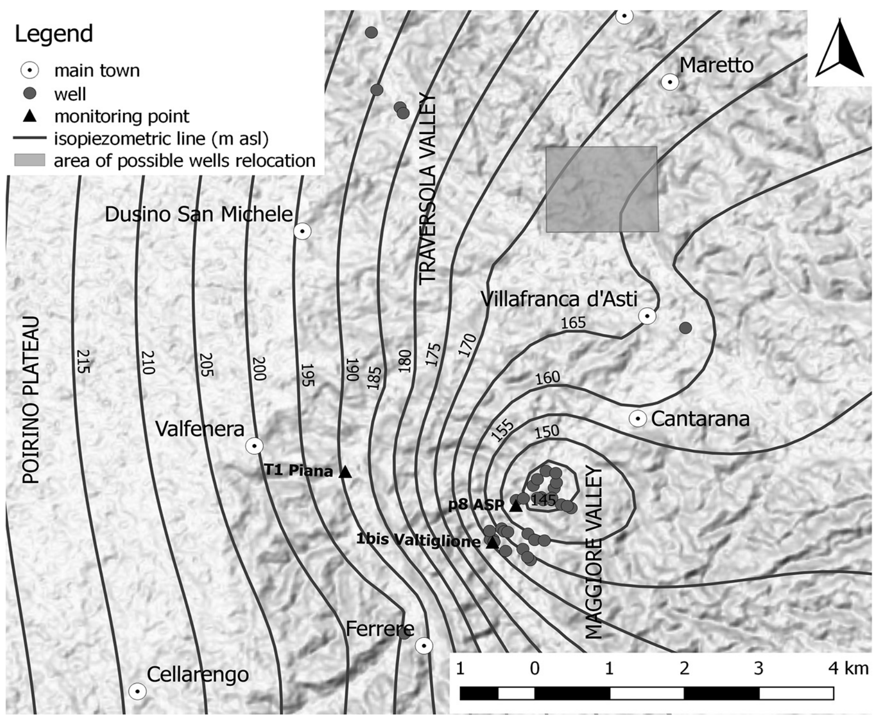

Fig. 2. Location of the study area. The piezometric map is referred to April-June 2013.
Ubicazione dell'area di studio. La carta piezometrica è riferita ad aprile-giugno 2013.

center of the cone of depression the piezometric levels reached –50 m below ground level.

More details about the hydrogeologic setting at a regional scale can be found in Lasagna *et al.* (2014) and De Luca *et al.* (2018).

2.2. Past groundwater withdrawals

The marine Pliocene aquifer was exploited intensively since the early XX century. However, while at the beginning of the 1900 the groundwater withdrawal was about some L/s, it gradually increased up to about 600 L/s (fig. 3). As an example, over the period 1996-2009, the extraction rate increased from 13.4 to 14.4 Mm^3/year (Lasagna *et al.* 2014).

This situation created an overexploitation of the aquifer, revealed by: i) a significant decrease of the piezometric level; ii) a reduction of the artesian area located in the north of the study area.

In the recent years (2000-2010), some monitoring wells in the Maggiore Valley recorded a yearly drawdown of about 0.8 m. From the beginning of the XX century until 2012, the decrease of the piezometric level in some areas was about 50 m (Lasagna *et al.* 2014, De Luca *et al.* 2018).

3. Mitigation activities

The exploited confined aquifer is the only source of water for human consumption in the area. Thus, the Maggiore Valley wellfield is considered of regional importance. These are the reasons why certain actions have been launched to protect and preserve the aquifer. More specifically, the managers of the Integrated Water Service (EGATO5 Astigiano Monferrato), with the advice of the Earth Sciences Department (University of Turin), put into effect the following activities aimed at the protection of groundwater resources.

3.1. Hydrogeology reconstruction of the study area

The hydrogeological reconstruction of the Maggiore Valley and surrounding areas was the first step. Indeed any effective strategy for the aquifers' protection must be based on a good knowledge of the hydrogeological setting and the current state of exploitation and use of groundwater resource. Particularly, the main analysed elements for the study areas were the lithostratigraphic structure, the hydrogeological parameters, the piezometric maps, the recharge features, the water quality, the changes in the piezometric levels over time, the number and type of wells, the withdrawals from the wells. A description of the hydrogeologic setting of Maggiore Valley and surrounding and related information can be found in the previous paragraphs and more in detail Lasagna *et al.* (2014).

3.2. Simulation of new groundwater withdrawal configurations

In order to mitigate the overexploitation situation in the Maggiore Valley wellfield, a different quantitative management of the groundwater resources was necessary. Thus, a groundwater flow model was implemented (fig. 4b), to analyse the aquifer response to various pumping strategies and to determine sustainable solutions.

After the calibration of a preliminary groundwater flow simulation, four different scenarios were simulated to explore the best option to mitigate the problem. The scenarios simulated a groundwater extraction decrease, a redistribution of the well location and a combination of both of them. More specifically, a withdrawal reduction of 110 l/s (20% of current water withdrawal) and 150 L/s were simulated. In Figure 5 two possible scenarios are reported. In Scenario 3 a relocation of 8 wells from Maggiore valley wellfield to northern sectors are simulated. In Scenario 4 a water withdrawal re-

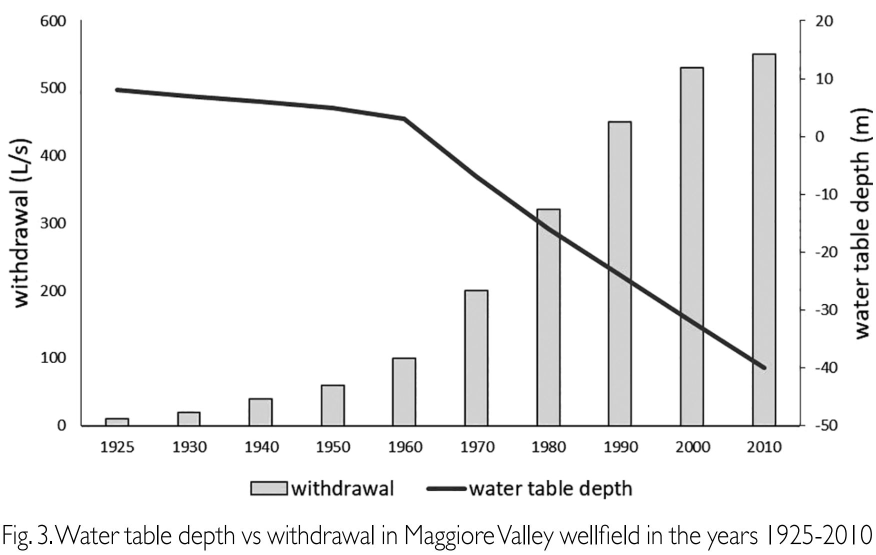

Fig. 3. Water table depth vs withdrawal in Maggiore Valley wellfield in the years 1925-2010 (data from ATO5, 2016).
Profondità della superficie piezometrica e prelievi dal campo pozzi della Val Maggiore nel periodo 1925-2010 (dati tratti da ATO5, 2016).

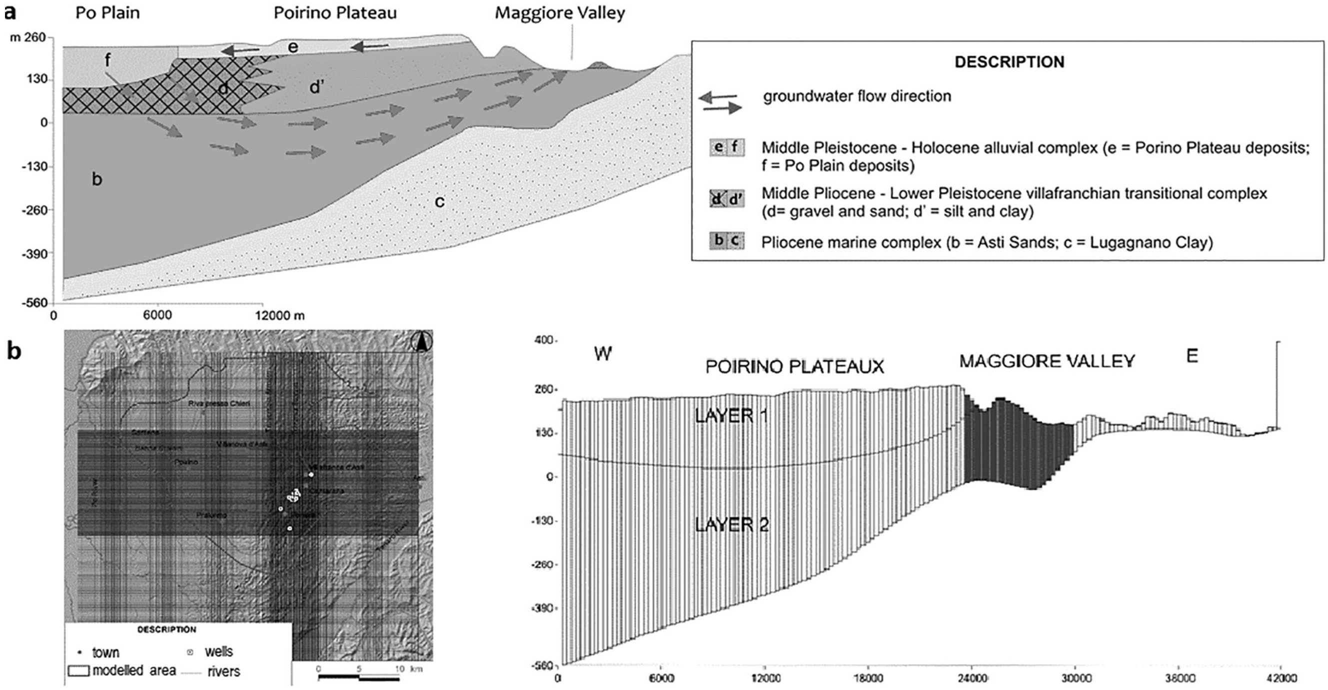

Fig. 4. a) Schematic hydrogeological cross section of the Maggiore Valley and surrounding areas. The aquifer exploited by the Maggiore Valley wellfield is represented by the Pliocene marine sandy complex. b) Discretization of the study area in plant and cross section for the implementation of the mathematical model. A grid mesh refinement was used within the Maggiore Valley wellfield area.

a) Sezione idrogeologica schematica della Val Maggiore e delle aree circostanti. L'acquifero sfruttato dal campo pozzi della Val Maggiore è rappresentato dal complesso delle sabbie marine del Pliocene. b) Discretizzazione dell'area di studio in pianta e sezione per l'implementazione del modello matematico. In corrispondenza del campo pozzi della Val Maggiore è stata utilizzata una griglia più fitta.

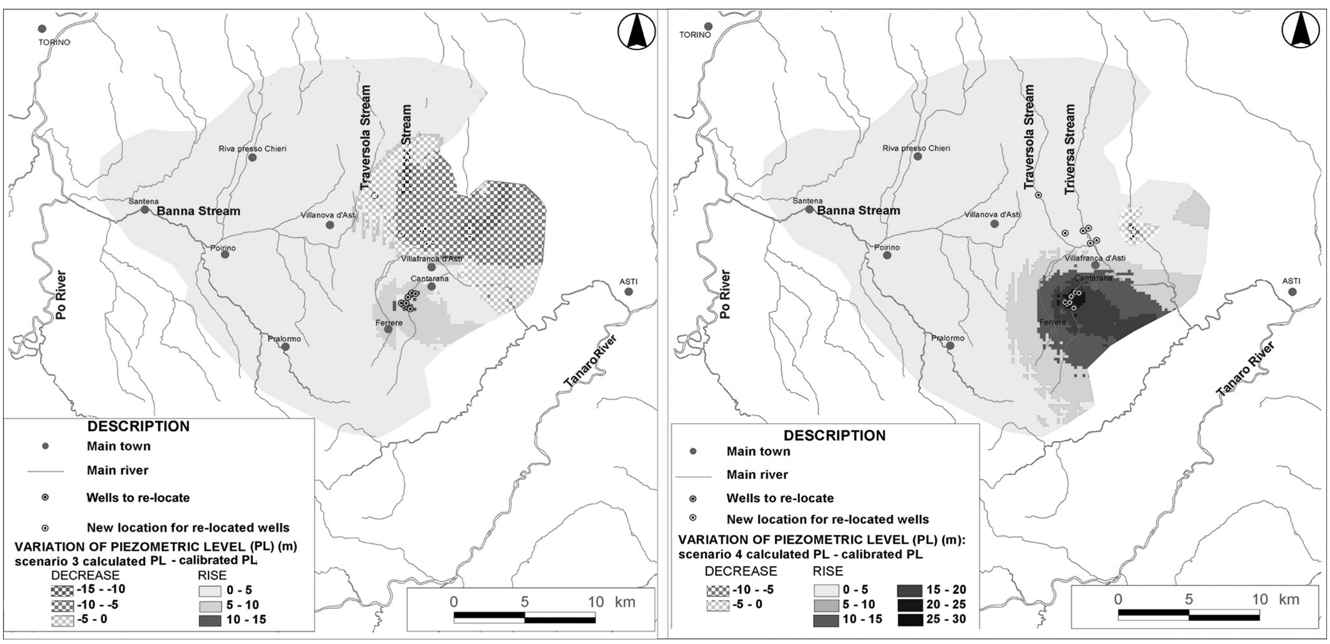

Fig. 5. Piezometric level changes evaluated with a groundwater flow model (modified from Lasagna *et al.*, 2014). Examples of new withdrawal configurations in the Maggiore Valley. Scenario 3 represents the results following a relocation of 8 wells from Maggiore valley wellfield to northern sectors. Scenario 4 analyses a water withdrawal reduction of 110 L/s in the Maggiore Valley wellfield plus a concurrent relocation of 8 wells.

Variazioni del livello piezometrico valutate con un modello di flusso idrico sotterraneo (modificato da Lasagna et al., 2014). Esempi di nuove configurazioni di prelievo in Val Maggiore. Lo scenario 3 rappresenta il risultato dopo la rilocalizzazione di 8 pozzi dal campo pozzi della val Maggiore a settori più settentrionali. Lo scenario 4 analizza una riduzione degli emungimenti di 10 l/s nel campo pozzi della Val Maggiore oltre alla contemporanea rilocalizzazione di 8 pozzi.

duction of 110 L/s in the Maggiore Valley wellfield plus a concurrent relocation of 8 wells are modelled.

The results of all the simulations highlighted a positive impact of the piezometric level, in some instances, up to 30 m. Particularly, the relocation of wells in nearby areas, with a concurrent water withdrawal reduction, proved to be an appropriate solution. The results of the simulation model are more widely described in Lasagna *et al.* (2014).

3.3. Strategies and interventions for groundwater preservation

In order to ensure the water resources necessary for users and to mitigate the overexploitation situation, the following interventions have been planned and/or realised:

- reduction of groundwater withdrawal and concurrent supplementary feed from the Monferrato Aqueduct, located north of the study area (**interconnection**);
- **relocation** of some wells of Maggiore Valley wellfield that involves a decrease of 10-25% of withdrawals in the area of the current wells.

The interconnection of Maggiore Valley aqueduct with the Monferrato aqueduct consists of a 17 km long pipe. It guarantees a regular water supply to the population of about 100 L/s. The interconnection was completed and became operative in 2012. Moreover, a reduction of groundwater withdrawal in the Maggiore Valley wellfield was achieved. These actions led to a partial rising of the piezometric level, up to 8 m from 2012 and 2016. In this period some decreases of the piezometric level were registered, especially in the summertime (i.e. summer 2015) due to climatic conditions that required high water consumption.

In Figure 6 the variation of the water table depth vs groundwater withdrawal is reported. More specifically, it is possible to observe a reduction of groundwater withdrawal in the Maggiore Valley wellfield (blue column) up to about 12 Mm^3/year. Moreover, the additional supply from the interconnection, starting from 2012, is reported (green column). The red line represents the water table depth that decreases starting from 2012 of about 8 m (from –45 m bgl to –37m bgl).

In Figure 7 a detailed trend of the water table depth in three piezometers located in the Maggiore Valley and surrounding areas is reported. More specifically the modification of the groundwater level is described starting from the year of the interconnection with Monferrato aqueduct. In the figure, it is possible to observe a decreasing of the water table depth, with different values in the three piezometers. In the piezometers T1 Piana and p8 ASP, located in the wellfield or in the surrounding, a high increase of the piezometric level can be observed. In the piezometer T1 Piana the decrease is about 12 m from June 2012 and October 2014, while in the piezometer p8 ASP is about 10 m from June 2012 and February 2016. The decrease of the water table depth is less evident in the piezometer 1bis Valtiglione, that is located far from the wellfield area.

In addition to the interconnection, a study was performed to identify the best area for wells relocation. More specifically, geophysical surveys were conducted within the Maggiore and Traversola Valleys, to depict the depth and lateral continuity of the uppermost part of the Quaternary deposits, hosting the near surface aquifers. Combined use of Electric Resistivity Tomography (ERT) sections and Time Domain Electromagnetic (TDEM) soundings allowed obtaining a pseudo-3D representation of the subsurface.

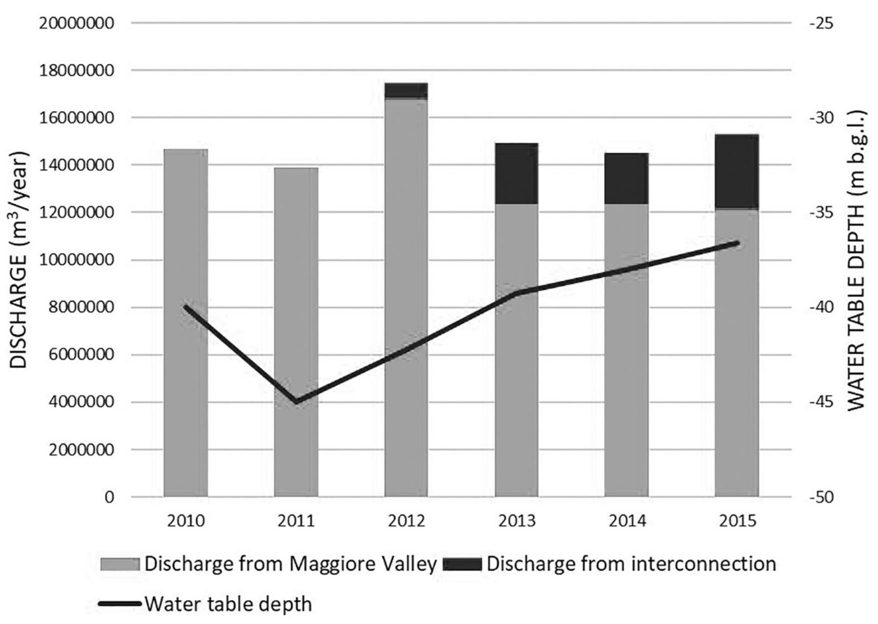

Fig. 6. Variation of the water table depth vs groundwater withdrawal. The total withdrawal is divided according to the source (Maggiore Valley wellfield and interconnection). The water table depth is the average of the entire Maggiore Valley.

Variazione della profondità del livello piezometrico e delle portate di prelievo. Il prelievo totale è suddiviso in funzione della provenienza dell'acqua emunta (campo pozzi della Val Maggiore e interconnessione). La profondità del livello piezometrico rappresenta la media dei livelli piezometrici dell'intera Val Maggiore.

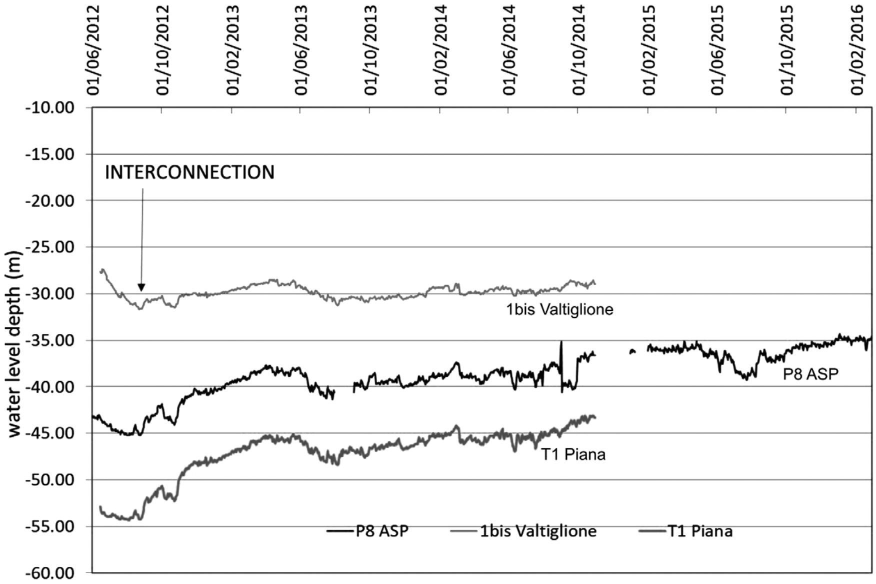

Fig. 7. Modification of the water table depth in three piezometers in the Maggiore Valley and surrounding areas after the interconnection with Monferrato aqueduct. Piezometer P8 ASP represents the reference data of groundwater level, due to its location in Maggiore Valley.
Variazione della profondità del livello piezometrico in tre piezometri della Val Maggiore e delle aree circostanti dopo le interconnessioni con l'acquedotto del Monferrato. Il piezometro P8 ASP rappresenta il livello piezometrico di riferimento ubicato in Val Maggiore.

Two areas were studied with geophysical survey (Villafranca and Dusino San Michele) that represent the most suitable zones from a hydrogeological and logistical point of view. Indeed, there areas are located in the artesian areas, north and west of Maggiore Valley respectively. Moreover they are suitable for a new wellfield because in proximity to existing pipes, with high expansion capabilities, and for the possibility of building a new treatment plant.

In Villafranca area, the aquifer formation is more laterally continuous, whereas in Dusino San Michele area it is discontinuous, laterally less extended and locally missing. Thus even if both of studied areas show a possible aquifer layer, on the basis of geophysical surveys (fig. 8), the Villafranca area was chosen for future relocation of some water wells.

At last, a pilot well will be drilled here in 2019 to verify the hydrogeological features and the productivity of the aquifer identified by the geophysical surveys.

4. Discussion and conclusions

Maggiore Valley wellfield in NW Italy is a typical example of groundwater overexploitation. The increasing water demand from the beginning of the XX century up to now created the condition for a high decrease of the piezometric level (in some areas from + 6 m a.g.l. to – 50 m b.g.l.) and a large reduction of an artesian area, located at the north of the study area.

Because the exploited aquifer is the only source of water for human

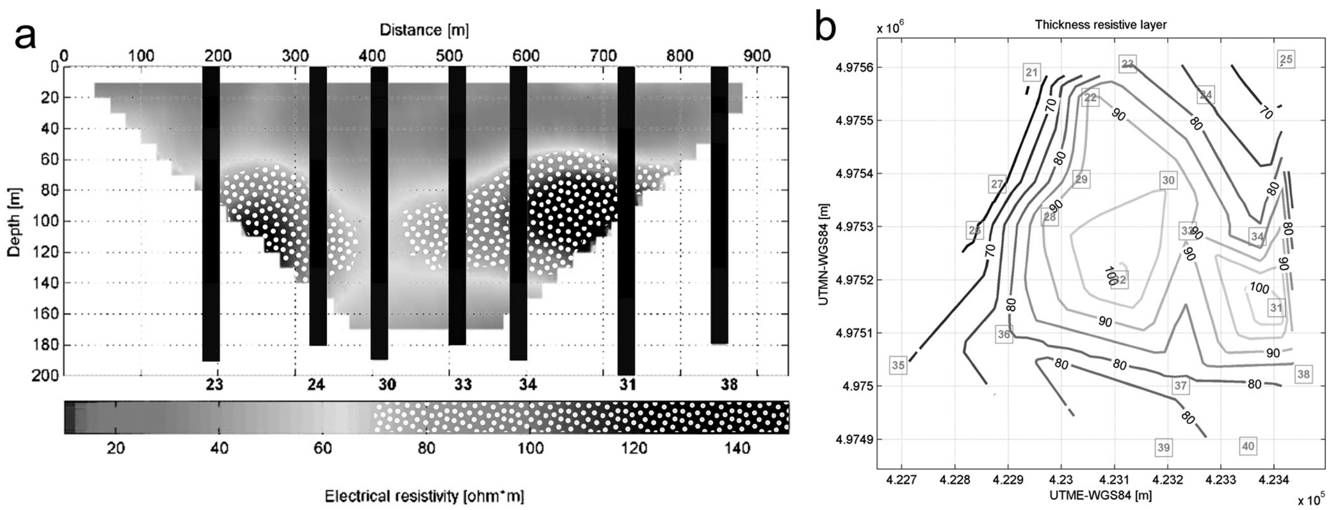

Fig. 8. a) ERT results in Villafranca area and location of the TDEM soundings nearest to the resistivity section (number at the bottom of each column indicates the name of the sounding). b) Maps of the thickness of resistive layer, identified as the aquifer formation in the Villafranca area (modified from De Luca *et al.*, 2018).
a) Risultati di una tomografia elettrica (ERT) nell'area di Villafranca e ubicazione dei TDEM più vicini alla sezione di resistività (il numero alla base di ogni colonna indica il nome del sondaggio). b) Carta degli spessori dei livelli resistivi, identificati come la formazione acquifera dell'area di Villafranca (modificato da De Luca et al., 2018).

consumption in the area, numerous actions have been launched to protect and preserve it.

The main activities concerned the reduction of groundwater withdrawal, with a concurrent supplementary feed from the Monferrato Aqueduct, located north of the study area, and a relocation of some wells of Maggiore Valley wellfield.

To study the consequences of a different quantitative management of the groundwater resources, a groundwater flow model was implemented. It permitted to analyse the aquifer response to various pumping strategies and to determine the most sustainable solutions.

The reduction of groundwater withdrawal plus the interconnection with Monferrato aqueduct led to a partial rising of the piezometric level, up to 8 m from 2012 and 2016.

Moreover, a geophysical study was performed to identify the best area for wells relocation. The Villafranca area, located north to Maggiore Valley wellfield, was chosen for future relocation of some water wells, because it is located in the artesian areas and the aquifer formation is resulted more laterally continuous respect to other studied areas. Additionally this area is suitable also for logistic reasons (in proximity to existing pipes and with high expansion capabilities).

The creation of a new wellfield represents a guarantee for the continuity of the water service distribution in a medium-long term context. Moreover, it is essential because it allows to the piezometric level of Maggiore Valley wellfield to rise. A further decrease of the water table, indeed, would have rendered some of the wells unusable.

At last, a pilot well will be drilled here in 2019 to verify the hydrogeological features and the productivity of the aquifer identified by the geophysical surveys.

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Evaluation of risk to groundwater due to extractive waste in abandoned mine site: Case study of Gorno, NW Italy

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Extractive waste (EW) from abandoned mines can pose serious pressure to natural water systems. The harmful effects of EW such as deterioration of water sources by allowing leaching of potentially toxic elements (PTE) into groundwater make it necessary to carry out careful, scientific and comprehensive studies on this subject. The present research used risk analysis approach to study the effect of presence of PTE to groundwater in abandoned mine site in Gorno, Lombardy (NW Italy). Results indicated that the groundwater was at risk due to Cd and Zn when point of compliance (POC) was at zero m and decreased to no risk at distance of 1500 m from waste dumps.
***Keywords**: mining waste, risk analysis, abandoned mine, extractive waste, groundwater, hydrogeology.*

***Valutazione del rischio per le acque sotterranee a causa dei rifiuti minerari in una miniera abbandonata: caso studio di Gorno, NW Italia.** I rifiuti estrattivi (EW) provenienti da miniere abbandonate possono rappresentare un serio problema per sistemi idrici naturali. Gli effetti dannosi dei EW, come il deterioramento delle risorse idriche derivanti dalla lisciviazione di elementi potenzialmente tossici verso le acque sotterranee, rendono indispensabile effettuare studi accurati su questo argomento. La presente ricerca ha utilizzato un approccio di analisi del rischio per studiare l'effetto della presenza di PTE nelle acque sotterranee in un sito minerario abbandonato a Gorno, in Lombardia. I risultati hanno indicato che le acque sotterranee sono a rischio per Zn e Cd nel caso di un punto di conformità (POC) pari a zero mentre si riduce zero a una distanza di 1500 m dalla discarica di rifiuti.*
***Parole chiave**: rifiuti minerari, analisi del rischio, miniera abbandonata, rifiuti di estrazione, acque sotterranee, idrogeologia.*

1. Introduction

Italy has a long history of mining activities. Classical authors have pointed out that some of the mining sites were in operation since Phoenician-Punic times in Sardinia region (Caro *et al.*, 2013). The mining industry contributed strongly to economy of the Sardinia region from Roman times. The mining was carried out for producing metals (Sardinia), mercury and iron (Tuscany), talc, asbestos, and mixed metallic sulphides (north of Italy). Most of the mining activities in Italy are closed now, leaving behind a legacy of about 3000 abandoned mines (APAT, 2006).

These abandoned mine sites, consisting of mining waste (also referred as extractive waste) provide obvious sources of contamination in the surface environment. As, it acts as source of potentially toxic metallic and metalloid elements to the earth's surface environment for a long time (Hudson-Edwards and Edwards, 2005).

Potentially toxic elements (PTE) are of major concern because of their persistent and bio-accumulative nature which may pose threat to groundwater (GW) in the vicinity of abandoned mine areas (Abraham and Susan, 2017). The present study focuses on calculating risk to GW due to extractive waste (EW) in abandoned mine site of Gorno, Lombardy (NW Italy).

2. Methodology

2.1. Study site

The Gorno mining district is located within the Seriana, Riso and Brembana valleys (Lombardy, Northern Italy). It belongs to the Alpine type zinc-lead-silver stratabound ore deposits, associated with the middle Triassic carbonatic series, as shown in Figure 1. The mineralization (Zn-Pb ± Ag ± baryte ± fluorite) mostly occurs within the "Metallifero" (i.e., "ore-bearing") formation of upper Ladinic – lower Carnian age (Rodeghiero and Vailati, 1977; Jadoul *et al.*, 2012).

Important minerals present in the area are sphalerite (ZnS) and galena (PbS) (average Zn/Pb ratio= 5:1), with minor pyrite (FeS_2), marcasite (FeS_2), chalcopyrite ($CuFeS_2$) and argentite (Ag_2S). The dominant gangue minerals are calcite, dolomite and quartz (± ankerite). The industrial exploitation for Zn and Pb started in the 1837 and continued until 1982.

In the investigated site, Riso creek represent the main watercourse of the Riso valley, which flows to reach the Serio river, the main water artery of the Val Seriana. From the hydrogeological point of view, the area is located in recharge area of Nossana spring (Gattinoni & Francani, 2010). This is a very important spring, used for the water supply of Bergamo city. The groundwater circulation takes place along discontinuity planes (tectonic lines, cracking/fracturing or stratification/schistosity) and karst cavities. Due to the presence of dolomites and limestones outcrops, groundwater flows in fractured karst media with high permeability and high hydraulic conductivity, thus transferring contaminants away from source at high speed (De Luca *et al.*, 2019).

2.2. Sampling and analysis of extractive waste

Site investigation was performed to collect information about waste typology and location, in order to ensure that the facilities were suitable for characterisation and sampling. The sampling site at Gorno, consisted of different WR facilities. One of the important waste facility is located in Mt. Arera, where sampling was conducted. The WR dumps in Arera are spread uniformly with thickness of approximately 2 m.

The location and number of sampling points are often site-specific, however a systematic sampling strategy was adopted in order to obtain representative data of the whole waste facility. Consequently at the site, the WR material was sampled using hand shovel and a hammer (where necessary). Each sample (8-10 kg) was collected in an area of 2m × 2m, after cleaning from organic residues. In total 10 samples of WR were collected at the site (fig. 1). The waste rock samples collected from the site were digested using *aqua – regia* and were analysed for PTE concentrations using Inductively Coupled Plasma – Optical Emission Spectrometry (ICP-OES). The detailed methodology followed for the measurement has been reported in Mehta *et al.* (2018).

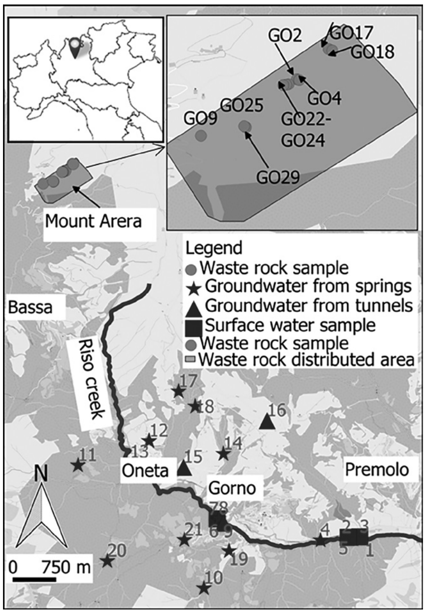

Fig. 1. Geomorphological setting and sample locations.
Inquadramento geomorfologico e ubicazione dei campioni.

2.3. Sampling and analysis of water sources

In Gorno two sampling campaigns were conducted in September and October 2016. Groundwater samples were collected from springs and mine tunnels. Surface water (SW) was sampled in Riso creek and other creeks. During the two sampling campaigns, a total of 17 GW samples and 4 SW samples were collected. It should be noted that, due to limited site access and the lack of spring and wells in the area, the water samples were not collected near to WR dumps in Arera, but at distance varying from 3500 m-8000 m from the dumps.

The physical-chemical parameters, like temperature, pH, and electrical conductivity (EC), were measured *in situ* for all samples. Water samples were measured for total alkalinity (sum of CO_3^{2-} + HCO_3^-), bicarbonate and carbonate alkalinity using potentiometric method. Anions (NO_2^-, F^-,SO_4^{2-},-NO_3^-,Cl^-) were measured using 761 Compact IC Metrohm Ion chromatography The major and minor metal cations (Ca^{2+}, Mg^{2+}, Na^+, K^+, P, Al, Ag, Fe, Hg, Ni, Mn, B, Ti, Mo, Sb, As, Be, Cd, Co, Cr (total), Cr (VI), Pb, Cu, Se, Tl, Zn, Sn were measured using ICP-OES. The detailed methodology followed for the measurement has been reported in Mehta *et al.* (2018).

2.4. Risk analysis

The potential risks to GW due to the presence of contaminants in WR were evaluated using Risk – Net software, in accordance with the provisions of Risk Based Corrective Action (RBCA) (ASTM, 1995; ASTM, 2015). It indicates that sites should be managed to have low and acceptable risk levels rather than bringing them to pristine levels. The permissible limits for the chemical elements for the risk calculations were taken from the Italian Legislative Decree 152/06 and risk analysis guidelines (Ministero dell'Ambiente e della tutela del territorio, 2006; APAT, 2008).

The risk was calculated under following conditions: (1) site characteristics and exposure parameters at Gorno, and (2) considering the point of compliance (POC) at varying distance from the WR. To account for the most conservative risk analysis results, the following aspects were considered for source, receptor and pathway:

1) Source: the contaminated WR dumps were considered as source. The concentrations of contaminants at source (CRS) were considered as 95% upper confidence limits for the concentrations of PTE at fractions <20 mm of WR.
2) Receptor: the superficial aquifers present in detritic cover were considered as receptor. Consequently, the karstic au-

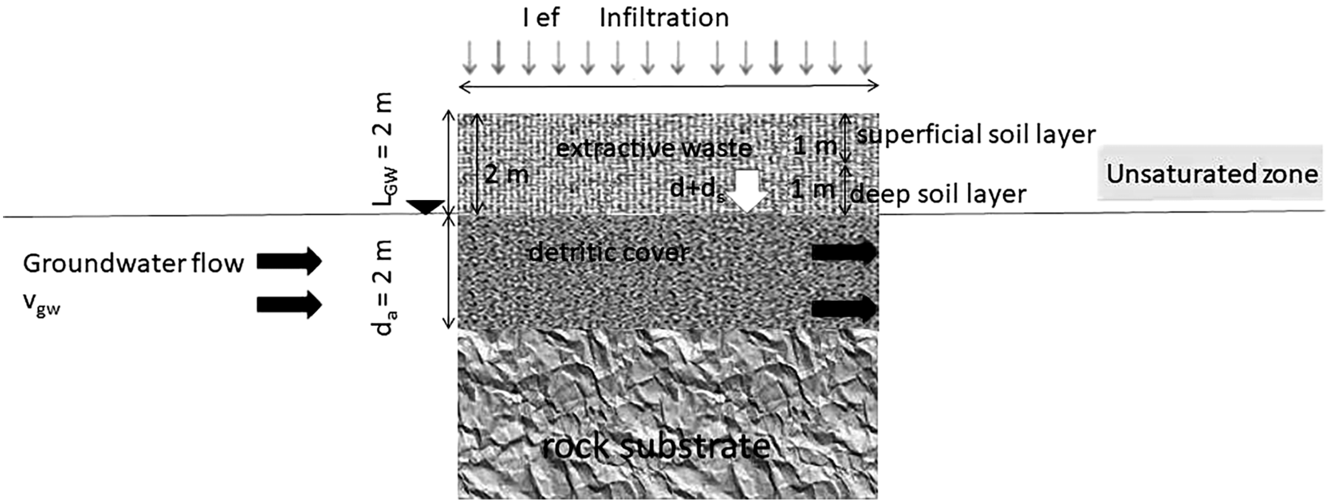

Fig. 2. Schematization of the modelled scenario for risk analysis.
Schema dello scenario modellizzato per l'analisi di rischio.

qifer, that is present below detritic cover, was not taken into account in the risk analysis procedure (fig. 2).

3) Pathway: the contaminants considered at site are inorganic in nature, hence, the only migration pathway of contaminants from the WR was leaching to the underlying water.

2.5. Site characteristics

Observations collected from the general site setting, field surveys, and previous hydrogeological and climatic studies led to the development of the site characteristics used in the risk analysis (tab. 1). The study site is almost completely covered by WR at Gorno. These characteristics are explained in detail as follows.

- The natural soil has been replaced by WR in a rectangular manner, with 900 m and 450 m as the dimensions of sides.
- The total thickness of the on-site waste deposits was 2 m, thus leading to superficial soil with a depth of 1 m and deep soil with a depth of 1 m in the waste distributed area, as shown in Figure 2.
- The groundwater flow through the detritic cover and WR was considered to be predominant. The depth to the GW level from the top was 2 m, and thus the thickness of the unsaturated zone was 1.9 m, considering that a thickness of 0.1 m became saturated due to capillary action.
- The hydraulic gradient was approximately equal to the slope

Tab. 1. Unsaturated zone, saturated zone and outside environment properties at Gorno.
Zona insatura, zona satura e caratteristiche ambientali esterne (Gorno).

Parameter		Units	Gorno
$L_{s(SS)}$	Depth of top of source in the surface soil relative to the surface level	m	0
$L_{s(SP)}$	Depth of the top of the source in the deep soil relative to the surface level	m	1
d	Thickness of source of contamination in the surface soil (unsaturated)	m	1
d_s	Thickness of the source of contamination in the deep soil (unsaturated)	m	1
L_{GW}	Depth of the groundwater level (total from the top) (phreatic level)	m	2
h_v	Thickness of the unsaturated zone	m	1.9
pH	pH		7.72
I_{ef}	Effective infiltration	cm/year	49.6
P	Precipitation	cm/year	166
W	Extension of the source in the direction of groundwater flow	m	900
S_w	Extension of the source in the direction perpendicular to the groundwater flow	m	450
d_a	Aquifer thickness	m	2
K_{sat}	Hydraulic conductivity of saturated soil	m/s	50×10^{-4}
i	Hydraulic gradient		0.3
v_{gw}	Darcy's velocity	m/s	1.5×10^{-3}
v_e	Average effective rate in the aquifer	m/s	4.25×10^{-3}
$\theta_{e\ sat}$	Effective porosity of the ground in the saturated zone		0.353
POC	Distance of the receptor (off-site) (DAF)	m	0
δ_{gw}	Thickness of the mixing zone in the aquifer	m	2
LDF	Dilution factor in groundwater	calculated	213

of the mountains and was thus 0.30.

- Out of all the types of soil in the software, the physical properties of the WR within the fractions less than 20 mm most closely resembled those of sand. Thus, the effective porosity of the source, volumetric air content and volumetric water content of sand were used.
- The infiltration capacity was measured considering an average precipitation of 166 cm at Gorno (the average annual precipitation for the period of 1961-1990 for the site).

2.6. Risk calculation

To evaluate the risks to GW the concentrations expected in the groundwater at the POC were compared with drinking water quality criteria set by legislation (Ministero dell'ambiente e della tutela del territorio, 2006). This is one of the approaches most widely adopted in European countries (Di Gianfilippo *et al.*, 2018). The risks to GW due to elements being leached from the soil are calculated using Eq. (1), (2) and (3) by calculating $R_{SS.\,LF}$ and $R_{DS.\,LF}$. There is presence of risk to GW due to a contaminant if the summation of $R_{SS.\,LF}$ and $R_{DS.\,LF}$ i.e. RGW exceeds 1, with the potential risks increasing with increase in RGW.

$$RGW = R_{SS\cdot LF} + R_{DS\cdot LF} \quad (1)$$

$$R_{SS\cdot LF} = \frac{CRS \cdot LF_{SS}}{DAF \cdot CSC \cdot 10{-}3\ mg/\mu g} \quad (2)$$

and

$$R_{DS\cdot LF} = \frac{CRS \cdot LF_{DS}}{DAF \cdot CSC \cdot 10{-}3\ mg/\mu g} \quad (3)$$

Where

RGW = Risk to groundwater

$R_{SS\cdot LF}$ = Risk to groundwater due to the contaminant in superficial soil,

$R_{DS\cdot LF}$ = Risk to groundwater due to the contaminant in deep soil,

CRS = Concentration of contaminant at source (mg/kg),

LF_{SS} = Leaching in groundwater from the contaminant in superficial soil,

LF_{DS} = Leaching in groundwater from the contaminant in deep soil,

DAF = Factor of dilution in groundwater (for on-site exposure, DAF =1), and

CSC = Permissible limit of a particular element in groundwater (Ministero dell'ambiente e della tutela del territorio, 2006, legislative decree 152/06).

2.7. Risk calculation with variation in point of compliance

To assess, wider span of possible scenario conditions, potential risks to GW were calculated at varying distance of POC from source of contamination. The effect due to superficial soil layer and sub soil layer, were analysed. This was done, to see the effect of distance on the GW quality. This is a key aspect to consider, as the variation of POC can lead to changes in concentration of contaminants due to attenuation during transport from the source to the underlying groundwater. The dilution attenuation factor (DAF) in groundwater (Eq. 2 and 3) to be considered will change with the placement of POC. The DAF takes into account the dispersive phenomenon in all directions (i.e. x, y, z).

3. Results and Discussion

3.1. Analysis of extractive waste

The concentration of PTE in waste rock samples and pH values are shown in Table 2. The pH values were found to be in slightly alkaline range varying from 7.4 to 7.9, with an average of 7.7. The results also indicated that Zn was present at very high levels, with an average concentration of 37,193 mg/kg, whereas the concentrations varied from 179 mg/kg to 98,706 mg/kg. Cadmium was found to vary from

Tab. 2. Potentially toxic elements concentrations (mg/kg) in WR samples with sizes less than 20 mm from Gorno.

Concentrazioni di elementi potenzialmente tossici (mg/kg) in campioni WR con dimensioni inferiori a 20 mm (Gorno).

Sample	pH	Sb	As	Be	Cd	Co	Cr	Ni	Pb	Cu	Tl	V	Zn
Limit 1		**10**	**20**	**2**	**2**	**20**	**150**	**120**	**100**	**120**	**1**	**90**	**150**
Limit 2		**30**	**50**	**10**	**15**	**250**	**800**	**500**	**1000**	**600**	**10**	**250**	**1500**
GO2	7.9	7.5	9.9	0.1	**28.1**	0.4	1.4	1	6	21	0.4	15.1	**12,169**
GO4	7.8	**11.2**	10.0	0.2	**133.0**	0.5	2.3	1	9	50	0.6	21.0	**50,678**
GO9	7.8	3.6	15.2	0.5	**21.2**	1.2	3.1	3	26	13	**1.2**	12.7	**12,669**
GO17	7.8	4.5	**23.7**	0.4	**28.6**	0.3	1.6	1	9	15	0.6	9.5	**14,505**
GO18	7.8	1.6	3.7	0.0	**18.8**	0.1	0.5	0	2	9	0.2	2.5	**6,626**
GO22	7.8	**16**	**37.2**	0.5	**167.3**	1.3	4.1	4	12	77	**1.4**	29.9	**76,243**
GO23	7.7	**32.3**	**45.1**	0.8	**210.8**	3.1	9.4	7	24	110	**3.8**	54.9	**98,706**
GO24	7.7	**49.9**	**28.6**	0.4	**167.9**	1.4	4.4	3	40	91	**1.5**	30.5	**69,077**
GO25	7.5	8.0	15.6	0.2	**37.3**	0.5	1.8	2	11	17	0.7	24.7	176
GO29	7.4	8.3	16.2	0.3	**59.0**	0.7	2.7	3	17	25	0.8	20.7	**31,081**

* Legislative limits currently adopted in Italy for PTE concentrations in the soil (Ministero dell'ambiente e della tutela del territorio, 2006), limit 1 is intended for green and residential areas, while 2 for commercial and industrial areas.

19 mg/kg to 211 mg/kg, with an average concentration of 87 mg/kg. High concentrations of Zn and Cd, can be explained by the fact that the site is rich in Zn as the exploitation activities also were performed for Zn.

Antimony was found to vary from 2 mg/kg to 50 mg/kg, with an average concentration of 14 mg/kg. Arsenic was found to vary from 4 mg/kg to 45 mg/kg, with an average concentration of 20 mg/kg. It should be noted that the samples from the site were analysed for their concentrations of PTE in size fractions of less than 2 mm. However, the concentrations used in risk analysis were calculated from fractions of less than 20 mm following risk analysis guidelines (Ministero dell'ambiente e della tutela del territorio, 2006; APAT, 2008).

3.2. Analysis of water samples

The results of the analyses performed on water samples are shown in Table 3. With regard to physical parameters, GW from mine tunnel showed temperature varying from 8.2°C and 12.6°C. Surface water showed a wide range of temperature, between 14.2°C and 25.3°C (registered in a secondary creek near Ponte Nossa). The pH values varied from 7.39 and 8.40 in GW. In SW the values of pH were quite constant from 8.40 to 8.52 and were in alkaline range which could be due to presence of carbonate minerals like calcite and dolomite.

The surface water samples collected at Gorno showed no parameter exceeding the limits, according to Italian Law Decree 152/06. Although there was presence of mine activities for the extraction of sphalerite and calamine, water samples showed no contamination of Zn in both groundwater and SW (fig. 1). The SW samples collected in the Riso creek in the lower part of the valley shows concentration of Zn, respectively 14.8 μg/l and 7.6 μg/l. The water samples also showed no contamination due to Cd. Table 3, gives the values of Cd and Zn only, as the major elements present in waste rock were Cd and Zn (mentioned in Section 3.1). These could potentially leach to GW and cause contamination. However, the concentrations of other parameters can be found in Mehta (2019).

The absence of contamination in water samples (GW and rivers) could be due to several concomitant factors: 1) higher pH of groundwater, which facilitates the precipitation of PTE, 2) presence of sampled water sources at distance from the WR dumps, which leads to attenuation of contaminants due to dispersion and transfer phenomena, and 3) increased flow velocity in the karst limestone rocks.

Tab. 3. Physical-chemical properties of the water samples. Limit: Legislative limits adopted in Italy for PTE concentrations in water (Ministero dell'ambiente e della tutela del territorio, 2006).
Proprietà fisico-chimiche dei campiodi d'acqua. Limite: limiti legislativi adottati in Italia per le concentrazioni di PTE nell'acqua (Ministero dell'ambiente e della tutela del territorio, 2006).

Sample	Type	pH	Temp	EC	Cd	Zn
Unit			°C	μS/ cm	μg/l	μg/l
Limit					5	3000
1	GW	7.9	18	770	0,3	38.2
2	SW	8.45	16.4	320	<0,2	14.8
3	SW	8.52	25.3	348	0,2	19.4
4	GW	7.78	21.2	232	<0,2	<1.0
5	SW	8.35	16	326	<0,2	7.6
6	GW	8.35	12.6	335	<0,2	<1.0
7	SW	8.47	14.2	308	<0,2	<1.0
8	GW	8.31	14.3	275	<0,2	<1.0
9	GW	7.89	11.3	380	<0,2	<1.0
10	GW	7.39	10	289	<0,2	<1.0
11	GW	7.95	10.2	289	<0,2	<1.0
12	GW	8.07	11	289	<0,2	<1.0
13	GW	8.35	10.6	259	3,1	260
14	GW	8.27	10	258	<0,2	<1.0
15	GW	8.24	10.05	299	1,0	327
16	GW	8.21	8.2	244	0,3	25.8
17	GW	7.92	11.1	190	0,3	69.0
18	GW	8.03	9.8	277	<0,2	<1.0
19	GW	7.89	11.9	247	<0,2	<1.0
20	GW	8.31	8.3	256	<0,2	<1.0
21	GW	8.22	11.3	256	<0,2	<1.0

3.3. Risk analysis

For POC positioned in the groundwater under the source of contamination, the GW was at risk due to the presence of Cd and Zn (tab. 4). This can be attributed to the fact that the WR were rich in Cd and Zn. Moreover, the potential risks to groundwater due to Cd and Zn were very similar in values. The possible reason could be that Cd concentrations in WR were associated with Zn concentrations. This happens due to strong geochemical associations between these two metals because of similar physical and chemical properties. Similar phenomenon has been observed in lead-zinc mines in Upper Silesia (Poland) and Zawar (India) (Ullrich *et al.*, 1999; Anju and Banerjee, 2011). Metals like Be, Co, Cr and Se were present in very low concentrations compared to the permissible limit of metals in GW in Italy and thus causing low level of potential risks.

3.4. Risk analysis with variation in POC

The total risks to groundwater due to Zn at POC placed at zero distance was 2.16 (0.72 due to superficial layer and 1.44 due to deep layer). The potential risks due to Cd, it was observed that the value was 2.44 for groundwater under the source of contamination. The total risks to GW decreased to 1 due to both Cd and Zn at about 1500 m, i.e. at POC = 1500 m. Thus there was no risk to GW, for aquifers at distance equal to and/or greater than 1500 m from WR. The detailed values of potential risks to GW due to superficial soil layer and deep soil layer can be found in Figure 3.

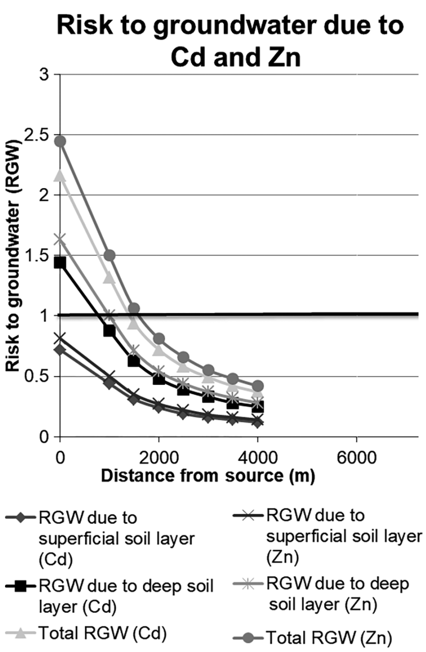

Fig. 3. Graph showing variation of RGW due to Cd and Zn with respect to distance of POC from source of contamination at Gorno.
Grafico della variazione di RGW dovuta a Cd e Zn rispetto alla distanza di POC dalla sorgente di contaminazione (Gorno).

Tab. 4. Risks to groundwater in Gorno. CRS is concentration of contaminant at source. There is presence of risk when RGW (Risk to GW) exceeds 1.
Rischi relativi alle falde acquifere (Gorno). CRS è la concentrazione di contaminante alla fonte. Esiste una presenza di rischio quando RGW (Risk to GW) supera 1.

		Superficial layer	Deep layer
Contaminant	CRS (mg/kg)	Risk to GW	Risk to GW
Antimony	30.38	0.32	0.63
Arsenic	28.09	0.22	0.45
Beryllium	0.47	3.49×10^{-4}	6.98×10^{-4}
Cadmium	130.20	**0.814**	**1.63**
Cobalt	1.46	0.001	0.003
Chromium	4.60	1.2×10^{-7}	2.40×10^{-7}
Nickel	3.67	0.006	0.01
Lead	22.22	0.006	0.012
Copper	83.08	0.006	0.01
Selenium	0.02	9.32×10^{-4}	1.86×10^{-3}
Thallium	1.72	0.03	0.06
Zinc	5,70,79.00	**0.72**	**1.44**

3.5. Possible solutions

The risk analysis calculations using the software shows presence of potential risks at POC = 0 m, according to the used parameters in most conservative cases for concentration of contaminants and position of aquifers. However, it is difficult to confirm these results at site, as the aquifers sampled in the study showed no contamination. It should be noted that, the water samples were collected away from WR dumps and not directly beneath the dumps, due to limited site access.

The future efforts and intervention activities to reduce any potential risks to GW can include: (1) placing of low permeability layer on WR dumps to reduce the leaching of contaminants, (2) transporting the WR and reusing it, such as for recovery of raw materials, and (3) use of signage and boards in the area to communicate to the local public, about presence of elements in WR. These activities can be carried out on the basis of the interests of local public and government and using cost-benefit and life-cycle analysis (Mehta *et al.*, 2018; Dino *et al.*, 2018; Mehta 2019).

4. Conclusions

Risk analysis studies can be used to determine potential risks to GW. To calculate risks to GW elemental analyses of WR were performed. The WR samples at Gorno indicated that Zn was present at very high levels, with an average concentration of 37193 mg/kg, whereas the concentrations varied from 179 mg/kg to 98,706 mg/kg. Cadmium was found to vary from 19 mg/kg to 211 mg/kg, with an average concentration of 87 mg/kg.

Risk analysis studies at Gorno depicted that GW was at risk due to Cd and Zn contamination for POC at zero m and there was no risk to groundwater at POC placed at distance equal to and/or greater than 1500 m from WR dumps. These risk analysis calculations were performed according to the parameters in most conservative cases for concentration of contaminants and position of aquifers. In reality, the sampled GW in the area collected not directly beneath the dumps, did not show any contamination, possibly due to dilution of contaminants.

The studies noticing the effect of distance of POC provides necessary information about the extent of the impact on water sources due to waste and thus can provide guidance towards application of mitigation measures to source of contamination. Factoring in the natural attenuation of contaminants during transfer, leads to more robust risk analysis calculations. This risk analysis approach can form the basis towards understanding, evaluating and assessing GW contamination.

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Groundwater heat pump systems diffusion and groundwater resources protection

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Geothermal Energy, being a clean and sustainable source of energy, is gaining importance worldwide due to various reasons. Geothermal power can be generated throughout the year on twenty four hour basis as it's not much dependent on ambient temperature and weather conditions.
Recently there is an increased interest in exploitation of low enthalpy geothermal resources for other applications such as geothermal space heating and cooling for domestic, industrial and commercial applications.
GroundWater Heat Pump systems (GWHPs) extract water from one or more wells, pass it through a heat exchanger or a heat pump, which either extracts heat from, or rejects heat, and discharge water back into the aquifer or nearby surface water.
This reinjection disturbs the natural aquifer temperature, producing a local temperature anomalies (cold or heat plume) known as the thermal affected zone (TAZ).
Moreover, it is important to know if the TAZ can interfere with downgradient pre-existing plants or subsurface infrastructure or with the plant itself (thermal feedback). It is then important to know, even before constructing a GWHP system, the future TAZ extent around the planned injection point.
Due to these risks, the increasing number of GWHP systems enforces the need for new criteria to develop subsurface energy policies that allow planning their spatial distribution. To obtain these sustainability criteria, the results of different dedicated studies are here proposed, in order to optimize the design and operation of GWHP systems.

Keywords: *geothermal energy, thermal feedback, groundwater heat pumps system, groundwater protection, thermal affected zone modeling.*

Diffusione dei sistemi di pompa di calore per acque sotterranee e protezione delle risorse idriche sotterranee. *L'energia geotermica, essendo una fonte di energia pulita, sta guadagnando importanza in tutto il mondo a causa di varie ragioni. L'energia geotermica può essere generata durante l'anno su ventiquattro ore perché non dipende molto dalla temperatura ambientale e dalle condizioni meteorologiche.*
Recentemente si registra un maggiore interesse nello sfruttamento delle risorse geotermiche a bassa entalpia per altre applicazioni come il riscaldamento ed il raffrescamento di edifici sia ad uso domestico che industriali e commerciali.
I sistemi a pompe di calore (GWHPs) estraggono acqua dal primo acquifero attraverso l'uso di pozzi, tale acqua passa attraverso uno scambiatore o una pompa di calore dove poi viene estratto calore e/o reimmesso calore a seconda della stagionalità ed infine l'acqua viene scaricata o in acquifero superficiale tramite un pozzo o in corpo idrico superficiale. Questa immissione di acqua in acquifero superficiale provoca un'anomalia termica (a seconda che la plume sia più calda o più fredda rispetto alla temperatura indisturbata dell'acquifero) la plume viene anche detta Thermal Affected Zone (TAZ). Inoltre è importante sapere se la TAZ rischia di interferire con impianti preesistenti o infrastrutture superficiali posti a valle rispetto allo stesso impianto oppure può interferire con l'impianto stesso tra pozzo di presa e pozzo di immissione a causa della troppa vicinanza (Thermal feedback – cortocircuitazione termica). È importante quindi sapere, soprattutto in fase di progettazione di un impianto, la futura estensione della TAZ.
A causa di questi rischi ed il crescente numero di sistemi GWHP si viene a creare la necessità di sviluppare nuovi criteri nelle politiche energetiche per le acque sotterranee che consentano di pianificare e distribuire tali impianti soprattutto in un territorio urbano. Vengono infatti qui proposti i risultati di diversi studi dedicati al fine di ottimizzare la progettazione ed il funzionamento dei sistemi GWHP.
Parole chiave: *energia geotermica, thermal feedback, impianti a pompa di calore geotermica, protezione risorse idriche, thermal affected zone*

1. Introduction

Energy is actually one of the central topics of the European development policies: the main issues are related to the reduction of emissions and the mitigation of climate change, which put human health and quality of life of citizens at risk (Regione Piemonte, 2015).

The objective concerning the de-carbonization of the European energy system is corroborated in the 2020 Climate and Energy Package and the following 2030 climate and energy framework which contain and outline the medium-long term objectives which consist of: i) downsizing 40% of emissions from so-called greenhouse gases compared to 1990 reference values; ii) electricity production for a share of 27% from renewable sources; iii) 27% improvement in energy efficiency (European Commission, 2014). These ambitious goals have further strengthened in the agreements signed during the last Paris climate conference (COP21), with the three general options based on: safety, environmental sustainability and economic sustainability. (ONU, 2015)

According to REN2018 (2018) modern renewable energy supplied approximately 10.3% of total global energy consumption for heat in 2015. Another 16.4% was supplied by traditional biomass, predominantly for cooking and heating in the developing world. While additional bio-heat, geothermal direct use and solar thermal capacities were added, growth was very slow. A large portion of energy use in buildings is related to heating and cooling. Energy demand for cooling is growing rapidly, and access to cooling is an issue for health and well-being. Renewables currently play a small role in providing cooling services, although there is considerable potential.

Geothermal energy is a reliable and constant source of energy. Despite the high capacity factor of traditional geothermal technologies, which exploit high enthalpy geothermal energy, the use of this energy is usually limited due to the local distribution of geothermal fields and the high up-front costs of drilling exploratory (Taddia *et al.*, 2018). However a notable contribution to the growth of this renewable energy is related and is expected to Ground Source Heat Pump systems (GSHP) which use the form of energy stored below the surface of the solid earth (low enthalpy geothermal energy). Low enthalpy geothermal energy, called also shallow geothermal energy is in fact available almost in every place and can be applied in various ways such as space heating and cooling. Depending on the use mode, energy can be extracted (heating) or injected (cooling).

Ground-source heat pump systems can then represent an important potential technology for mitigating greenhouse gas emissions related to space heating and cooling. Markets for heat pumps expanded around the world during 2017. Primary policy drivers for increased deployment of heat pumps include air pollution mitigation. The scale of the global heat pump market is difficult to assess due to the lack of data and to inconsistencies among existing datasets. It is estimated that air-source heat pumps make up the largest share of the global market, followed by ground source heat pumps. As of 2014 (latest data available), the global stock of ground-source heat pumps represented 50.3 gigawatts-thermal (GWth) of capacity, producing approximately 327 petajoules (91 TWh) of output (Lund and Boyd, 2016).

Based on historical growth rates, global ground-source heat pump capacity may have reached 65 GWth in 2017. The largest markets for heat pumps are China, the United States and Europe as a whole, where (in order of scale) France, Italy, Spain, Sweden and Germany were the most significant national markets in 2017 (REN21, 2018).

Two major types of ground-source heat pumps exist: closed loop heat pump systems (ground-coupled) or open loop heat pump systems (groundwater source) (Rafferty, 2000). Closed loop heat pump system also called ground-coupled system uses a buried earth coil with circulating fluid in a closed loop of horizontal or vertical pipes to transfer thermal energy to and from the ground. Open-loop heat pump system also called groundwater heat pump system (GWHP) need the presence of an aquifer as a heat source or sink.

GWHP systems extract groundwater from one or more wells, pass it through a heat exchanger or a heat pump, which either obtain heat from, or rejects heat, and discharge water back into the aquifer or nearby surface water. A typical open loop system scheme is represented by a well-doublet system which comprises three elements: an abstraction well, a heat-transfer system and one (or more) reinjection well(s) (Banks, 2009).

This reinjection disturbs the natural aquifer temperature, producing a local temperature anomalies (cold or heat plume) known as the thermal affected zone (TAZ). Such a thermal plume may pose an external risk to downstream users and environmental receptors or an internal risk to the sustainability of the well doublet, due to the phenomenon of thermal feedback.

Groundwater represents the world's largest and most important source of potable water. It is also an important resource for many of the world's larger cities. Urban and industrial development can impose major stresses on this resource on quality and on quantity, by increasing water demand (Howard, 2002). A balance between its use and protection has then to be found: to avoid detrimental environmental impacts, it is necessary to define groundwater temperature limits for heating and cooling and minimum distances between such geothermal systems. A long term effects of GWHP systems have also to be considered carefully in order to find a balance between system utilization and groundwater protection. (Haehnlein *et al.*, 2010).

Moreover, it is important to know if the TAZ can interfere with downgradient pre-existing plants or subsurface infrastructure or with the plant itself (thermal feedback). It is then important to know, even before constructing a GWHP system, the future TAZ extent around the planned injection point.

Due to these risks, the increasing number of GWHP systems enforces the need for new criteria to develop subsurface energy policies that allow planning their spatial distribution. Well-designed GWHP systems can optimize thermal energy extraction from the aquifers without causing undue environmental effects. To obtain these sustainability criteria, the results of different dedicated studies are here proposed, in order to optimize the design and operation of GWHP systems. The studies refer mainly to GWHP systems located in the outwash plain of Turin (Piemonte).

2. GSHP Systems basic principles

GSHP systems are environmentally friendly and energy efficient technologies that exploit the relatively constant temperature of the ground, or a medium thermally coupled to the ground, versus outside air temperature.

Air-source heat pumps have been used for many years for both space heating and cooling; however, their efficiency is influenced by the variation in outside air temperature. In winter, when heat is most needed, the outside air is cooler, thus often requiring backup electric resistance heating during the coldest days. Similarly, cooling is most needed during the hottest days, requiring the equipment to work at low efficiencies.

Ground-source heat pumps, overcome the problem of resource variations, as ground temperatures remain fairly constant throughout the year. Depending upon the soil type and moisture conditions, ground (and groundwater) temperatures experience little if any seasonal variations below about 10 m (fig. 1).

The ground-source or geothermal heat pump systems (GSHP or GHP), thus have several advantages over air-source heat pumps. These are: (1) a more stable energy source than air which implies good energy performances over the entire heating season, even with very low air temperatures when the performance of air source heat pump is poor; (2) they use less refrigerant and (3) do not require the unit to be located where it is exposed to weathering. The main disadvantage is the higher initial capital cost, being about 30 to 50% more expensive than air source units.

In particular, groundwater heat pumps (GWHPs) utilize the natural thermostability of groundwater. The diffusion of this kind of system is favored by different factors including plant and aquifer characteristics. Two main aquifer characteristics, which make GWHP diffusion attractive, are high productivity and good saturated thickness, which ensure good heat dispersion in a restricted area around the injection wells.

3. Groundwater heat pump system potential in Piemonte

Geothermal resources are abundant in Italy, ranging from resources for shallow applications (including heat pump technology), through to medium (> 90 °C) to high (> 150 °C) temperature systems at depths accessible only by wells (usually within 3-4 km) (Santilano *et al.*, 2015).

Geological bodies and groundwater in the Piemonte plain could represent an important source of clean geothermal energy and seemed particularly suitable for a wide implementation of GWHP direct open-loop systems (Lo Russo *et al.*, 2009). The average groundwater temperature ranges from 13.2 °C (minimum) to 15.5 °C (maximum), with a mean of 14.0 °C on a regional scale (Regione Piemonte, 2007).

3.1. Hydrogeological setting

Regione Piemonte (2005, 2007) studies documented the hydrogeology of the plain area with a high degree of confidence based on a large number of wells in the Turin area. As well known, an unconfined high-productivity aquifer connected to the surface water drainage network is found across the entire Piemonte plain and in the major valleys in the mountain sector. This unconfined aquifer is constitute by various continental units results of different exogenous processes linked to Quaternary glacial and alluvial dynamics (fig. 2). Generally, these units are lithologically represented by coarse gravel and sandy sediments (locally cemented) with limited amounts of thick clayey-loamy horizons related to lacustrine facies. Confined productive aquifers are also widespread they represent the main regional source of water for human consumption (Civita *et al.*, 2004). The vertical separation between the unconfined and deeper confined aquifers varies from a few meters to several tens of meters depending on local hydrogeological conditions. (Lo Russo *et al.*, 2009).

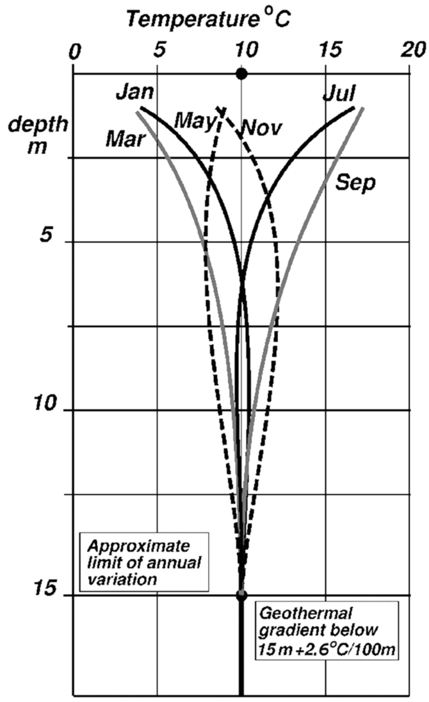

Fig. 1. Seasonal variation of the near-surface temperature profile respect the progressive depth (Busby *et al.*, 2009).
Variazione stagionale della temperatura con la profondità (Busby et al., 2009).

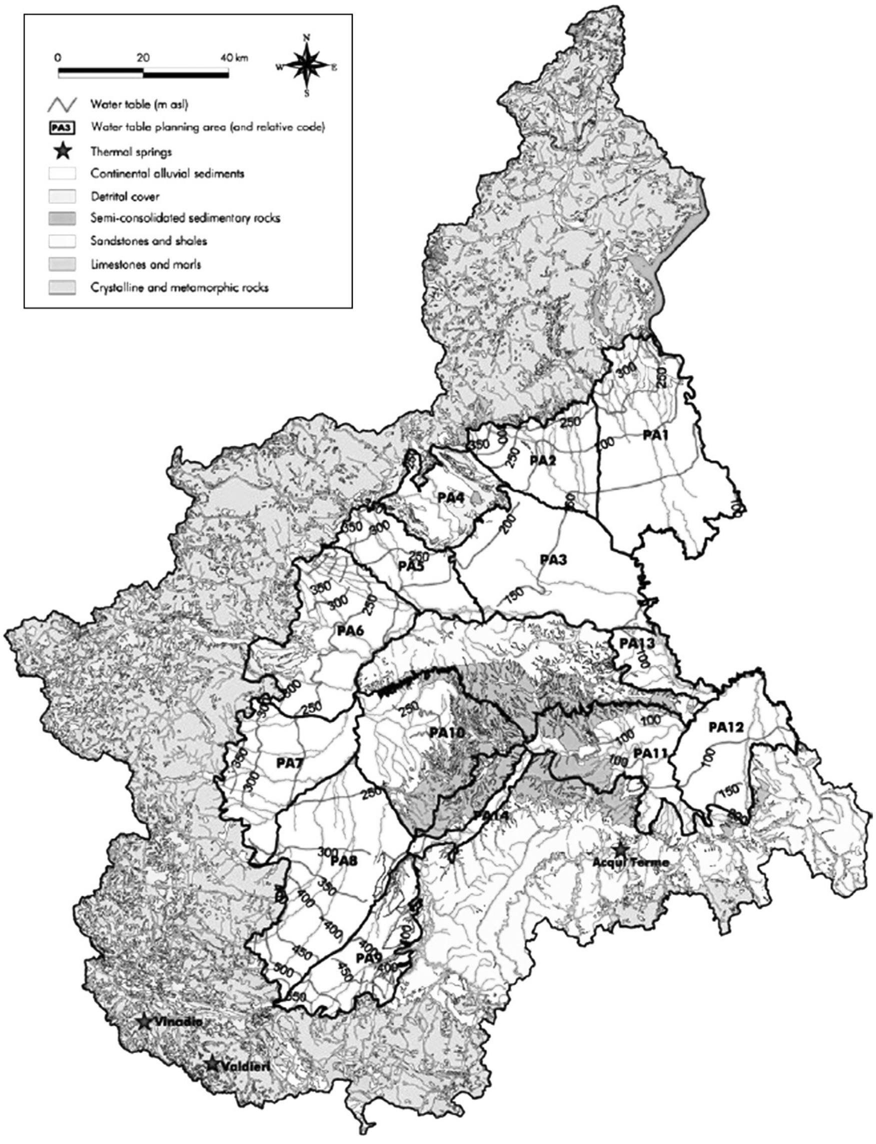

Fig. 2. Hydrogeologic map of Piemonte (modified after Civita *et al*., 2004).The unconfined aquifer is indicated by white color (Continental alluvial sediments) while grey line indicates the water table elevation.
Mappa idrogeologica del Piemonte (modificata dopo Civita et al., 2004).
L'acquifero non confinato è indicato con il colore bianco (sedimenti alluvionali continentali) mentre la linea viola indica la piezometria.

3.2. Water quality

An open loop system does not necessarily require water of high quality otherwise depending upon its specific chemistry, it can promote scaling, corrosion or both. If the water has a tendency to be scale forming, fouling of the heat exchanger may occur. The fouling reduces the effectiveness of the heat exchanger and compromises the performance of the heat pump. In most cases, the formation of scale is a slow process occurring over months or years. As a result, the impact of the reduced heat pump or desuperheater performance on the utility bill is gradual. This slow erosion of the savings the system would otherwise produce may be imperceptible to the system owner (Rafferty, 2000).

According to Lo Russo *et al.* (2009) which examined the chemical analyses of the waters derived from the shallow aquifer, performed twice a year since 1990 through the regional groundwater-monitoring network, in general, water quality at the regional scale is good enough to be used without the need for secondary exchangers in the heat pump systems. In exceptional cases (i.e. in the more polluted sites) groundwater quality is unsuitable to be used directly and secondary exchangers are recommended.

This technical option would significantly affect both the capital and running costs of the heat pump plant. For this reason, the characteristics of a prospective site (including water chemistry) should be carefully studied before choosing the heating system in order to verify the real economic benefit of installing a GWHP system.

4. Main constrain in development of GWHP systems

4.1. Groundwater protection

It is known that changes in groundwater temperature can influence its physical properties, chemical reactions, microbiology of the aquifer (Hanlein *et al.*, 2010). However, the risks have not been widely concerned and comprehensive studies are needed (Zhu, 2017).

Proper regulations to guarantee groundwater protection are in place in the countries with a developed GWHP market. In Piemonte deep, high-quality groundwater bodies are legally preserved for human consumption. To avoid potential pollution GWHP could be used only with shallow groundwater. Nevertheless, where the local hydrogeological conditions are such that no confined aquifer is present below the water table or the top of the confined aquifer is below 60m depth, it may be appropriate to consider 60 m as the maximum depth for injecting GWHP discharges. (Lo Russo *et al.*, 2009).

4.2. Planning of GWHP in urbanized area

The integration of GWHP systems into urbanized area will depend on a series of factors that should be taken into account to determine the feasibility of the installation. In particular, if compared to less anthropized areas, some elements require particular attention as underground availability and building restrictions, which play a determinant role for the installation of this type of system. This interaction between the buildings, the city's framework and the underground infrastructures (garages and parking areas, cellars, and communication, and transport systems such as tunnels, metros, and trains) has to be examined as they could influence the choice of the most suitable type of plant and then development of such kind of low enthalpy geothermal systems.

Due to the high concentration of buildings, the extensive use of ground and consequently the limited free ground, two important issues to be considered are:

- the interference that could occur between different GWHP plants
- the risk of thermal feedback in a well-doublet system.

Considering a well-doublet system if the designed distance between abstraction and rejection well is not enough there is in fact a risk that a proportion of the discharged warm water will flow back (against the regional hydraulic gradient) to the abstraction well, resulting in a reduction of the provided energy performance. This phenomenon is called thermal feedback. Thermal feedback risks can be avoided by a relatively large separation between the abstraction well and re-injection tool. This distance is typically unrealistically large for many densely inhabited urban areas. The temperature of the abstracted water will thereafter rise over time, towards a value described by Gringarten and Sauty (1975). At best, this gradually compromises the efficiency of the cooling scheme and at worst it can result in system failure or environmental non-compliance. In other words, far from being a "renewable" cooling source, the system can eventually become unsustainable (Banks, 2009).

Thermal feedback problem that has been widely described in literature (Ferguson and Woodbury, 2005; Banks, 2009; Milnes and Perrochet, 2013). To avoid this problem Lo Russo *et al.* (2016) proposed the use of gabiondrains as alternative reinjection systems to reduce the distance to the abstraction well and avoid thermal feedback in cases where abstraction withdrawal through the well occurs in deeper regions of the aquifer.

5. Modelling of the thermal affected zone: best practice

Different authors suggested that the thermal plume dimension around an operating well is site-specific and can critically affect neighboring injection or production wells. In addition, the environmental impact can be notable, particularly where open-loop plants are located adjacent to each other. Thus, GWHP systems are recommended to be installed in areas, where the interference can be avoided, or rigorous and proactive management of multiple adjacent GWHP systems is warranted (Pophillat, 2018).

Quite apart from building design considerations, proper installation and effective maintenance of GWHP plants requires an appropriate characterization of subsurface heat transport processes such as conduction and convection. (Hecht-Mendez *et al.*, 2010).

Numerical modeling studies should be carried out to analyze the behaviour of the aquifer during the design phase of an installation of GWHP system. This would assist in the correct evaluation of the subsurface environmental effects and avoid interferences with previously existing groundwater uses (wells) and subsurface underground structures or the thermal feedback phenomenon. Here are presented the results of some previous studies, which analyses the steps that should be considered when approaching a numerical modelling. These case studies refer to some plant located in Turin plain which interest the unconfined aquifer. The numerical modelling were performed using the finite-element FEFLOW® package developed by Diersch (2005).

A sensitive analysis of the subsurface hydrogeological and thermal parameters affecting the TAZ was performed by Lo Russo *et al.* (2012). The parameters subjected to sensitivity analysis are: hydraulic conductivity (vertical and horizontal), natural hydraulic gradient, porosity, storativity, volumetric heat capacity of fluid (water) and solid (aquifer matrix), heat conductivity of the fluid and solid and longitudinal and transversal thermal dispersivity.

The parameter sensitivity was performed by recalculating the TAZ for variations of each parameter (10% or 20% reduction and 10% or 20% increase with respect to the initial value) one at a time. In order to compare the results of the sensitivity analysis, TAZ was defined by the maximum extent of

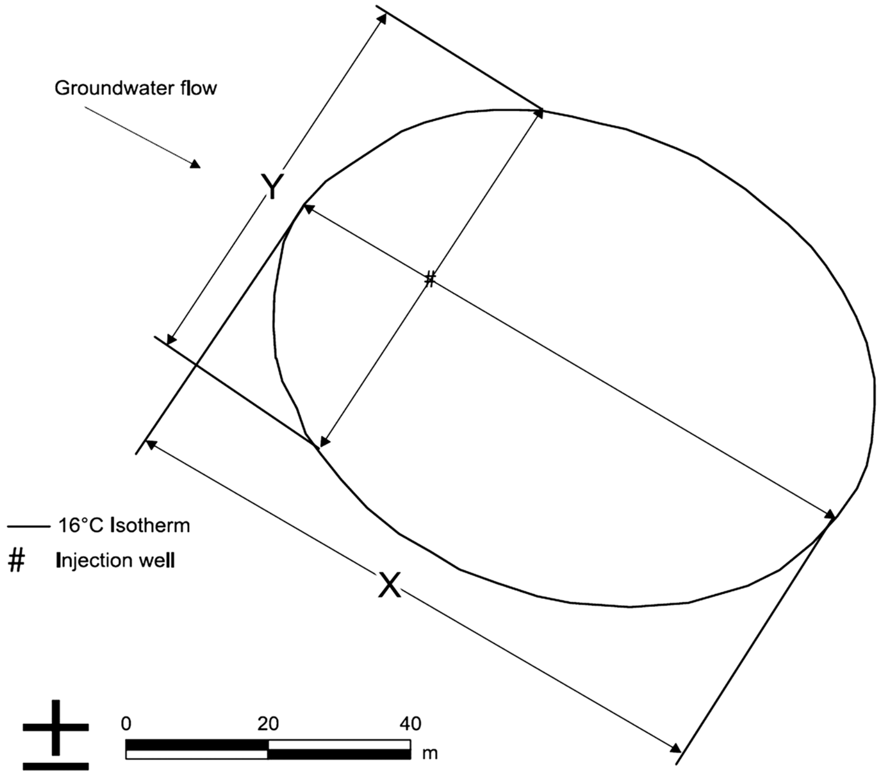

Fig. 3. Geometric parameters of the TAZ. The X axis was measured along the groundwater flow direction, and the Y axis is the normal axis passing over the injection well (Lo Russo *et al.*, 2012).
Parametri geometrici della TAZ. La lunghezza X è misurata lungo la direzione di flusso dell'acquifero e la lunghezza Y è misurata perpendicolarmente alla direzione di flusso passante per il semiasse maggiore dell'ellisse (Lo Russo et al., 2012).

the 16 °C isotherm in the ellipsoid thermal plume (fig. 3). The total surface area enclosed by the 16-°C isotherm was computed and the length of each ellipsoid axis at the injection well was also measured.

The results of the analysis indicate that the hydrodynamic parameters correlated with groundwater flow such as the hydraulic conductivity and the gradient are highly important. The size of the TAZ is also most sensitive to variations in volumetric heat capacities of the fluid and the solid while the effects of variations in the storativity and the thermal conductivities of the fluid and solid seem to be almost negligible.

In order to accurately predict the TAZ, another important issue which has been analyzed is the introduction of parameters time variability. As the actual flow rate and injection temperature are highly time-variable and follow changes in building energy requirements, it is then necessary to consider this time variability. Lo Russo *et*

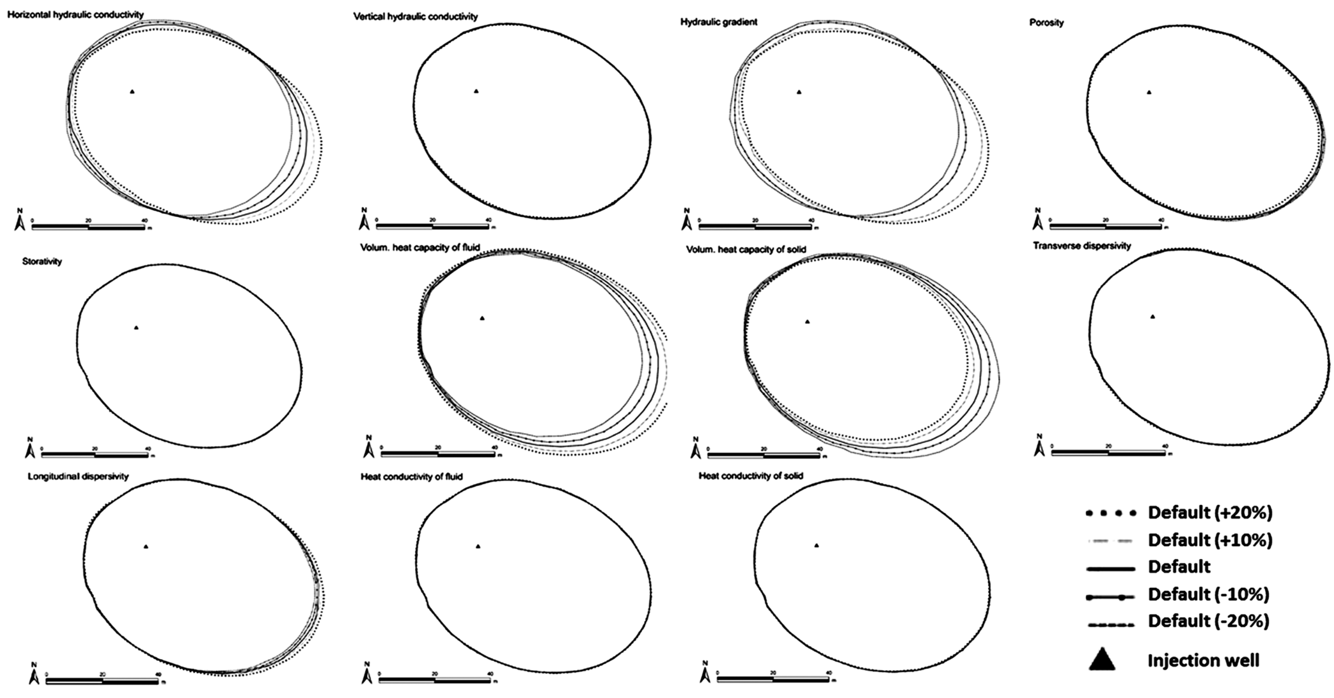

Fig. 4. Location of 16.0 °C isotherms after 60 days of injecting warmer water for various values of subsurface hydrogeological and thermal parameters (modified from Lo Russo *et al.*, 2012).
Isoterma 16°C dopo 60 giorni di immissione di acqua calda in acquifero in stato transitorio con parametri termici e idrogeologici variabili (modificato dopo Lo Russo et al., 2012).

al. (2014) verified whether the time-averaged values of flow rate and temperature can be suitable substitutes for hourly values. Even in this case the TAZ extension has been conventionally indicated by the 16.0 °C isotherm (fig. 4). It was determined the extent to which these simplifications modify the reliability of TAZ predictions: if the use of average hourly (T1), daily (T2), monthly (T3) or seasonally (T4) injection flow rate and temperature data produced good quality simulation results. To confirm the reliability of the simulations the four simulation results were then compared with groundwater temperature data measured using a downgradient piezometer in order to assess the reliability of the simulations (fig.5).

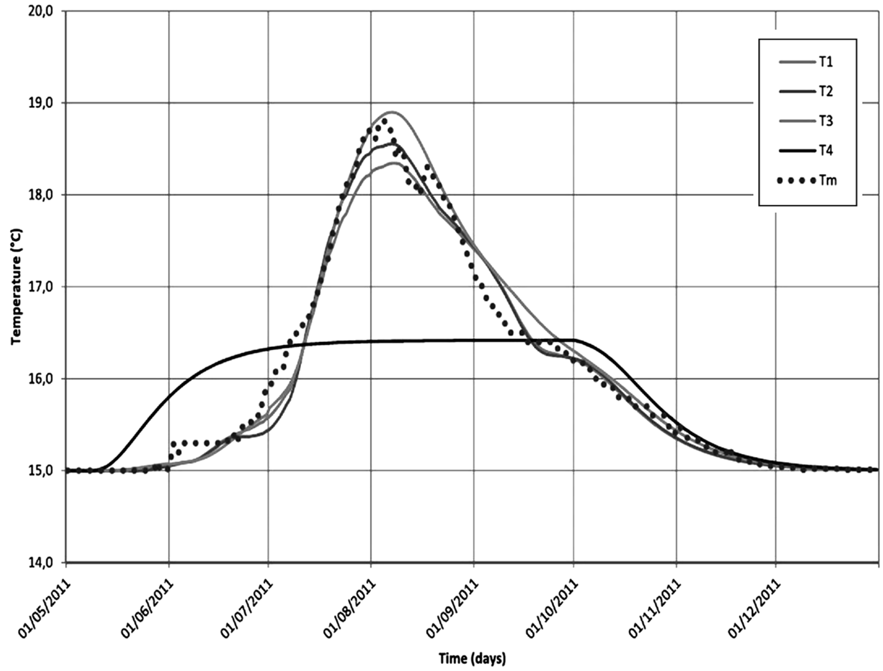

Fig. 5. Temperatures in piezometer S2. The dotted line corresponds to the measured data.
Temperatura nel piezometro S2. La linea puntinata corrisponde ai dati misurati.

Simulations T1, T2, and T3 were statistically tested to quantitatively evaluate their reliability. Scenario T4 was not tested because the results were clearly too far from the measured data for meaningful statistical comparison.

The quality of the simulation was satisfactory when hourly, daily, or monthly flow rate and injection temperature data were used, whereas the seasonal averages were not suitable for reliably assessing TAZ development (Lo Russo *et al.*, 2014).

Another important parameter which can influence the TAZ extension is the dynamic viscosity. As known hydraulic conductivity has a major influence on heat transport because plume propagation occurs primarily through advection. Hydraulic conductivity is, in turn, influenced by water reinjection because the dynamic viscosity of groundwater varies with temperature. Lo Russo *et al.*, 2016 evaluated then how the thermal-affected zone (TAZ) is influenced by the variation in dynamic viscosity due to reinjected groundwater in a well-doublet scheme. A computational analysis using FEFLOW software have been conducted.

Usually the dynamic viscosity of groundwater is set at a constant value. This scenario of constant condition (FEFLOW program default) is used as a reference setting (scenario SC2) for comparison with TAZ calculations determined when dynamic viscosity varies with reinjected groundwater temperature.

The TAZ area was graphically

Tab. 1. Geometric parameters of the TAZ calculated for each case study and comparison between SC1 and SC2 (Lo Russo *et al.*, 2018).
Parametri geometrici della TAZ calcolati per ogni caso studio e confrontati tra SC1 e SC2 (Lo Russo et al., 2018).

Parameter	K value	SC 1 variable dynamic viscosity			SC 2 constant dynamic viscosity			Comparison between SC1 and SC2		
		$\Delta T = +$ 5 °C	$\Delta T = +$ 10 °C	$\Delta T = +$ 15 °C	$\Delta T = +$ 5 °C	$\Delta T = +$ 10 °C	$\Delta T = +$ 15 °C	$\Delta T = +$ 5 °C	$\Delta T = +$ 10 °C	$\Delta T = +$ 15 °C
Area [m^2]	K_{xy} 1×10^{4}	6,962.25	8,479.67	9,280.52	6,961.11	8,447.95	9,264.16	ΔTAZ[a] = −0.02%	ΔTAZ = −0.4%	ΔTAZ = −0.2%
	K_{xy} 1×10^{3}	6,895.90	8,501.98	9,696.49	6,872.01	8,478.98	9,449.19	ΔTAZ= −0.3%	ΔTAZ = −0.3%	ΔTAZ = −2.6%
	K_{xy} 1×10^{2}	5,662.53	18,286.86	27,796.96	5,543.00	17,150.89	25,114.42	ΔTAZ = −2.1%	ΔTAZ = −6.2%	ΔTAZ = −9.7%
X	K_{xy} 1×10^{4}	94.48	104.41	109.25	94.46	104.23	109.22	$\Delta X = 0.02$	$\Delta X = 0.18$	$\Delta X = 0.03$
	K_{xy} 1×10^{3}	123.33	138.29	149.58	121.68	135.76	143.97	$\Delta X = 1.65$	$\Delta X = 2.53$	$\Delta X = 5.61$
	K_{xy} 1×10^{2}	279.24	525.51	610.97	276.75	505.86	578.10	$\Delta X = 2.49$	$\Delta X = 19.66$	$\Delta X = 32.87$

[a] ΔTAZ is equal to TAZ_{SC2} variation with respect to TAZ_{SC1} [%]

defined as the maximum plant extent of the 16°C isotherm in the thermal plume. The total surface area enclosed by that isotherm was computed. The length of the TAZ area along the groundwater flow direction (X) was also measured (fig. 3).

For both scenarios (SC1 and SC2), nine different cases have been considered using combinations of three conductivity classes and three different injection temperatures values. For each conductivity class, three injection temperatures were considered (tab. 1). The temperatures were set to explore the real potential functioning conditions of the heat pump (Lo Russo *et al.*, 2016).

The modeling results demonstrate non-negligible groundwater dynamic viscosity variation that affects thermal plume propagation in the aquifer. This influence on TAZ calculation was enhanced for aquifers with high intrinsic permeability and/or substantial temperature differences between abstracted and post-heat-pump-reinjected groundwater.

6. Conclusions

Global energy demand is going to grow in the next decades. Distribution and typology of energy demand is rapidly changing. Fossil conventional sources consumption will grow as well as renewables. In this context low-enthalpy geothermal resources represent a very promising technology to provide cooling and heating needs for buildings. Groundwater can be used directly to such aims by ground water heat pump systems.

Their use has to be taking into account especially where unconfined aquifers have high productivity characteristics as most of the flood plain areas. Turin plain represents a good chance for the potential exploitation of this technology. However, groundwater has to be considered not only a potential source of energy but also an important source to be protected. In this regard numerical modelling is an important modern tool that can predict environmental effects prior to construction of the plant and to assess the effects of warmer (or colder) water injection.

The parameters connected with the groundwater flow influence the TAZ development, particularly those connected with the advective component of heat flow. Consequently, the hydrodynamic subsurface parameters are of major importance to reliable modelling of the TAZ, and on-site investigations should concentrate determining these parameters (hydraulic conductivities and gradient, porosity, etc.) (Lo Russo *et al.*, 2012).

For significant GWHP plant projects, in order to obtain a good match between simulated and actual groundwater temperatures during modeling of the TAZ produced by a GWHP plant, suitable pumping tests and a potentiometric surface determination appear necessary in all cases.

Also the variation in dynamic viscosity with groundwater temperature can have a significant influence on the geometry and extension of the TAZ, especially when high aquifer hydraulic conductivity and/or relatively warm injected water are involved. Therefore, at least in these modeling contexts, dynamic viscosity variance should be taken into account to enable accurate assessment of subsurface thermal perturbation (Lo Russo *et al.*, 2018).

Moreover, Lo Russo *et al.*, (2014) demonstrated that in order to obtain a good match between simulated and actual groundwater temperatures during modeling of the TAZ produced by a GWHP plant, it is necessary to model the injection using realistically variable flow rates and injection temperature data. As well-known time-averaging reduces the computational effort required in modelling routines and is therefore extensively used in professional practice for TAZ prediction. Otherwise, only the use of average hourly, daily, or monthly injection flow rate and temperature data produced good quality simulation results. In contrast, the use of seasonal average values did not produce good estimates of the TAZ. Simulations employing seasonal average data might produce unreliable results, underestimating the peak temperature reached by the groundwater in the neighbourhood of the injection well, and therefore should be avoided if possible. Instead, the use of hourly, daily, or monthly data may be considered a good option for TAZ modelling (Lo Russo *et al.*, 2014).

The knowledge of the hydrodynamic parameters and the plant running functioning conditions are requirements to provide reliable results. These issues should be taking into account when developing technical guidelines for the wide implementation of the technology.

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The role of the airborne asbestos fibers measurement in the classification of working environments: the case of Large Public Facilities

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The residual presence of critical components (e.g. Asbestos Containing Materials – ACMs) still represents one of the main criticalities for the Occupational Safety and Health – OS&H in many large public facilities (Lee and Van Orden, 2007).
Since the areas characterized by ACMs in good conditions are the most crucial to manage, due to the presence of the Hazard Factor in dormant conditions, an effective assessment and management of the related risk is pivotal. The Italian regulation (D.M. 06/09/94) provides general information on the approach for the analysis, stating the possibility to adopt two criteria: 1. examination of the artefacts condition, to detect possible deteriorations resulting in airborne fibers release, 2. indoor airborne fibers concentration measurements. The same Decree specifies that the airborne measurements alone cannot be a valid criterion to detect the possible fibers release from the pre-identified ACMs deterioration .
The paper discusses the actual contribution that airborne asbestos measurements can provide to the Risk Management, in particular in the identification of incipient deteriorations of ACMs. The research work was performed by implementing a special measuring strategy, in a real scenario, to increase the method sensitivity and collect data useful to relate the indoor pollution to the ACMs deterioration.
***Keywords**: occupational safety and health, asbestos risk assessment and management, quality approach to OS&H, asbestos containing materials, data uncertainty evaluation, airborne fibers measurements, dissemination of culture of safety.*

***Il ruolo della misurazione di fibre aerodiserse di amianto nella classificazione degli ambienti di lavoro: il caso delle Grandi Strutture Pubbliche.** La presenza residua di componenti critiche (e.g. Materiali Contenenti Amianto – MCA) è ancora oggi una delle maggiori criticità nell'ambito della Sicurezza e Salute sul Lavoro – OS&H in molte grandi strutture pubbliche (Lee and Van Orden, 2007).*
Poiché le aree caratterizzate da MCA in buone condizioni risultano essere le più cruciali da gestire, a causa della presenza di un Fattore di Pericolo dormiente, una efficace Valutazione e Gestione del Rischio correlato alla presenza di Amianto risulta essenziale. La normativa (D.M. 06/09/94) fornisce informazioni generali riguardo al metodo di analisi, indicando la possibile adozione di due differenti approcci: 1. accurato esame delle condizioni dei manufatti per individuare possibili deterioramenti potenzialmente in grado di liberare fibre, 2. misurazione indoor della concentrazione di fibre aerodisperse. Il medesimo Decreto specifica che le sole misurazioni di fibre aerodisperse non costituiscono un valido criterio per l'identificazione del possibile rilascio dovuto al deterioramento dei MCA. Il presente lavoro è stato sviluppato per investigare sul reale contributo che le misurazioni di fibre aerodisperse possono fornire nella Valutazione e Gestione del Rischio Amianto, in particolare nella identificazione di incipienti fenomeni di degradazione dei prodotti che lo contengono. Lo studio è stato condotto tramite implementazione di una speciale strategia di misurazione, appositamente messa a punto ed applicata in un reale scenario lavorativo, al fine di migliorare la sensibilità del metodo e raccogliere dati utili per correlare l'inquinamento indoor con il deterioramento dei MCA preventivamente identificati.
***Parole chiave**: sicurezza e salute sul lavoro, valutazione e gestione del rischio amianto, approccio in qualità all'OS&H, materiali contenenti amianto, valutazione dell'incertezza di misura, misurazione di fibre aerodisperse, disseminazione della cultura della sicurezza.*

1. Introduction

In line with the D.M 06/09/94, indoor air dispersed asbestos fibers measurements could periodically confirm the good conditions of the pre-identified ACMs (Borchiellini et al. 2016), along the time. In no other situation the environmental pollution measures are necessary, since the presence of asbestos containing deteriorated artefacts or of damaged sealings/enclosures pertains to a scenario where the area involved is no more considered a workplace.

The same Decree specifies that the airborne measurements alone cannot be a valid approach to detect the possible ACMs deterioration. It is important to evaluate the role, the contribution and the effectiveness of airborne measurements in the identification of incipient deteriorations of asbestos containing products in good conditions, as collateral support to Quality Risk Management of the involved areas. Even more given the common, but not exhaustive, practice to monitor the artefacts condition evaluating the airborne fibers concentrations collected by occasional airborne fibers samplings – assuming a direct correlation between pollution and ACMs conditions, without any consideration on the factors affecting the indoor pollution (mainly in terms of boundary conditions). This approach can be debated since it is affected by different criticalities and difficulties:

1. the collection of a limited number of indoor asbestos airborne fibers concentration measures inside the areas containing ACMs can provide only a "snapshot" of the pollution in a limited time span;
2. the extent of possible fibers release due to incipient artefacts deterioration results in an increase of concentration barely measureable (comparable with the outdoor background), as confirmed by some research works on the evaluation of fibers release from artefacts subject to stress conditions (Paustenbach *et al*., 2004). Therefore, the indoor pollution variability due to artefacts deterioration can be heavily influenced by the outdoor concentration fluctuations (e.g. outdoor pollution variability);
3. the method uncertainly (sampling and analysis) should be carefully defined: in some cases, (e.g. in the Phase Contrast Microscopy – PCM analysis) the measure expanded uncertainty becomes important and comparable to the numerical value of the measured concentration (NOHSC, 2005); the decision making becomes then difficult, in particular in very low concentration conditions.

Hence, a presumed prompt identification of the ACMs even slight alteration by means of indoor airborne measurements presents not negligible lacks.

The target of the study entails the possibility to detect very low concentrations: hence, the method sensitivity was increased by selecting a peculiar sampling context, adopting a special sampling and analysis strategy, and implementing an approach for the data interpretation characterized by a well-defined logical (metrology-based) structure.

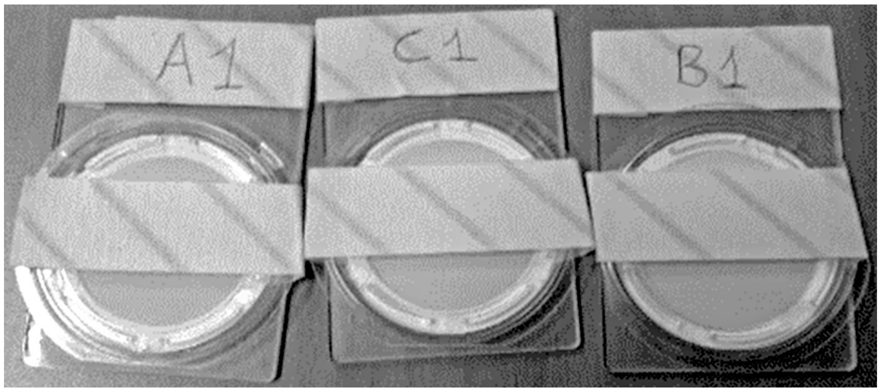


Fig. 1. First sampling session filters.
Membrane utilizzate nella prima sessione di campionamento.

2. Materials and methods

2.1. The sampling and measuring strategy

The context designated to perform the measurement campaigns pertains to window fixtures removal operations due to the presence of asbestos in mastic sealant in many areas of a large public facility. The removal yard, involving consecutively different parts of the buildings (e.g. single floors) can reproduce a context of ongoing deterioration of materials containing asbestos in limited amount. The situation is certainly worse, and most critical (just think to mechanical stresses on the window fixtures due to the removal operations) than a context where ACMs in compact matrix are exposed to stress actions due to natural deterioration and/or operative causes[1]. Therefore, this scenario could contribute to overcome the problems related to barely detectable airborne fibers concentrations, considering the mechanical wearing actions on artefacts producing potentially higher fibers releases.

In this context, the sampling campaign was designed and carried out following a special strategy, based on sessions of three simultaneous (matching starting sampling times) indoor/outdoor samplings, involving three different areas at a time:

1. the remediation working area (indoor environment), labelled as *area A;*
2. an indoor nearby area (*area B*) with the same criticalities (window fixtures with asbestos containing mastic sealant, to be successively removed);
3. the external environment (*area C*) close to the removal yard.

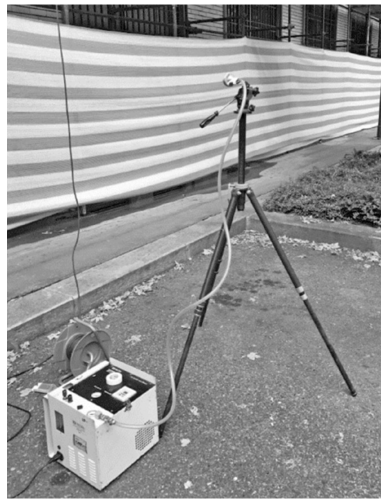
The identification of each zone typology by a specific letter simplified also the management of sampling operations, tagging the used membranes with the same letter of each sampling area, together with the progressive number of sampling session (fig. 1 shows the membranes related to the first sampling session).

The concurrent indoor/outdoor measurements can provide useful information to evaluate the potential effect of external pollution on the indoor measurements, considering that the expected indoor fibers concentrations could be comparable with the outdoor ones. The entire sampling campaign lasted from October 2016 to May 2017, in six "ordinary" and four "special" sampling stages.

The sampling phase and loca-

[1] Mechanical actions on the ACMs due to working/operational causes (e.g. maintenance or cleaning activities) are managed through a careful design of both the intended use and allowed activities.

Tab. 1. Sampling equipment used in the measuring campaign.
Attrezzatura di campionamento utilizzata nella campagna di misurazioni.

Sampling area	Area A	Area B	Area C
Sampling pumps	 *Zambelli 5000*	 *Zambelli ZB2*	 *Tecora Bravo R*
Sampler	Open face samplers, positioned approx. 1,5 meters above the floor, using Mixed Cellulose Ester – MCE filters (47 mm diameter, 0,8 µm pore size).		

tion of the sampling stations were organized taking into account the parameters conditioning the quality of measures (e.g. microclimatic conditions in the three different sampling areas) and the peculiarities of the pollutant, in particular the negligible aerodynamic resistance of fibers.

The three simultaneous samplings were carried out using three high-flow/flow-controlled area sampling pumps equipped with open face samplers[2] (tab. 1).

According to the measuring processes and equipment setup in System Quality (Bisio et al. 2016), the used sampling equipment and analytical instrumentations fulfil the metrological confirmation condition, ensuring the quality of the results. Moreover, the three sampling pumps were calibrated by means of a flowmeter, before and after each sampling session, to verify the flowrate within the required interval: ± 5% of the set flowrate (UNI EN ISO 13137: 2015).

Action tested to increase the method sensitivity – sampling

Regarding the sampling phase, the improvement to increase the method sensitivity concerned the sampled air volume: the minimum volume suggested by the D.M 06/09/94 (3000 liters) was increased to 5000 liters, drawn in 200 minutes (sampling duration), with a reference flowrate Q_{ref} = 25 l/min, maintaining unchanged the ratio flowrate/membrane surface (0,35 m/s required for SEM analyses).

The entire campaign was completed in six sampling sessions, resulting in 18 membranes. During the collection of the three concurrent samplings, a multifunction measuring device monitored and recorded (every 30 minutes) the significant parameters potentially conditioning the sampling results (temperature, pressure, relative humidity and air velocity and direction).

The analytical method adopted conforms to the Italian regulation DM 06/09/94, Attachment 2: the analyses were carried out by means of a Hitachi TM 3000 SEM, equipped with SwiftED 3000 device for micro-analysis, working at 2000x magnification, with 15 kV acceleration voltage. The respirable fibers (complying the geometric requirements: length greater than 5 µm, cross dimension smaller than 3 µm, and length/diameter ratio equal to or greater than 3:1) are definitely recognized as asbestos fibers through micro-analysis.

Action tested to increase the method sensitivity – analysis

As for the sampling phase, one of the analytical parameters was improved to increase the method sensitivity. In particular, a larger filter section (1,27 mm2) was analyzed, this resulting in 400 reading fields of 0,0032 mm2, with an increase of approx. 22% of the routine value suggested by the already quoted D.M. 06/09/94.

2.2. The method implementation (data analysis)

To draw some considerations about the results of the above-described measuring strategy, based

[2] Both defined in UNI EN ISO 13137:2015 standard

on the comparison of the simultaneous concentration measures, the approach implementation followed three consecutive steps:
1. *determination of concentration and Limit of Detection*;
2. *evaluation of the measurement uncertainty*;
3. *data interpretation*.

2.2.1. Airborne fibers concentration and Limit of Detection

The starting point is the definition of the *mathematical model* (eq. 1) to calculate the airborne fibers concentration from the samplings and analysis parameters (tab. 2).

Table 3 summarizes the "nominal" values of the parameters, set in sampling and analysis stages, except for the variable N_f, whose value changes depending on the analytical results.

The concentration mathematical model (eq. 1) lays at the basis of the calculation of the *Limit of Detection* – LoD based on relationship (eq. 2) in Table 4: the number of fibers count (N_f) is replaced by the upper 95% confidence limit: the detection limit considers the confidence interval of the fibers count due to the Poisson distribution of fibers on the filter.

The *Limit of Detection* of a method specifies the smallest detectable quantity obtainable by the used method. In the case of SEM analysis, the Limit of Detection is defined as the numerical asbestos fibers concentration below which, with the 95% probability, the real concentration shall lie when no asbestos fibers are identified during the analysis (UNI EN ISO 16000 – 7 standard). Hence, this limit shall be determined for each single analysis, and in the case of a no fibers count, the outcome of the analysis will denote "below the LoD".

To verify the possibility of getting a higher fibers count, with a more reduction of the LoD, four additional samplings were carried out, with a further increase of the sampled air volume up to 10.000 liters, using the same membrane in two consecutive samplings of the usual 200 minutes sampling duration. The inlet airflow was monitored systematically to verify the minimum capturing velocity (0,35 m/s in the case of SEM analysis), taken into account the increased aerodynamic resistance due to the progressive filter obstruction.

2.2.2. Measurement uncertainty

The measuring processes aimed to define pollutant airborne concentrations (or in general for the quantification of a Hazard Factor) should take into account the sources of variability conditioning the results (fig. 2), with the goal to reduce the final expanded uncertainty affecting the measures (Barbato et al. 2013).

Even if, as suggested by literature, in the case of low fibers counts, the intrinsic uncertainty due to

Tab. 3. Values of parameters.
Valori dei parametri.

Parameters and "nominal" values					
N_f [ff]	A [mm²]	N_c [n.]	a [mm²]	Q [l/min]	t [min]
x	962	400	0,0032	25	200

Tab. 2. Airborne fibers concentration formula and parameters.
Formula e parametri per il calcolo della concentrazione di fibre aerodisperse.

Concentration mathematical model:

$$C[\text{ff/l}] = \frac{N_f \cdot A}{N_c \cdot a \cdot (Q \cdot t)} \qquad \text{(eq. 1)}$$

where:
- N_f is the number of fibers identified in the analyzed membrane section;
- A is the effective area of the filter [mm²];
- N_c is the number of reading fields;
- a is the area of each reading field [mm²];
- Q is the flowrate of the sampling pump [l/min];
- t is the sampling duration [min].

Multiplying Q and t results in the sampling volume (V) referred to the normal conditions (T = 25 °C, P = 1013 mbar).

Tab. 4. Limit of Detection and Confidence Limits.
Limite di Rilevabilità e Limiti di Confidenza.

Limit of Detection formula:

$$LoD = \frac{UCL \cdot A}{N_c \cdot a \cdot (Q \cdot t)} \qquad \text{(eq. 2)}$$

In general, the 95% confidence interval of a measurement, as function of the number of asbestos fibers counted, can be obtained from the two equations (eq. 3 and eq. 4):

$$x_{UCL} = d \cdot \left[1 - \left(\frac{1}{9 \cdot d}\right) + z \cdot \sqrt{\left(\frac{1}{9 \cdot d}\right)}\right]^3 \qquad \text{(eq. 3)}$$

$$x_{LCL} = x \cdot \left[1 - \left(\frac{1}{9 \cdot x}\right) - z \cdot \sqrt{\left(\frac{1}{9 \cdot x}\right)}\right]^3 \qquad \text{(eq. 4)}$$

where x is the fibers count, d = (x + 1) and z = 1,960 the standard normal deviate for the two-sided limits at the 95% probability level. The same data are available in the UNI EN ISO 16000 – 7 standard, Table 3.

The considered 95% confidence interval of a zero fibers count ranges from 3,69 [ff] Upper Confidence Limit – UCL, to 0 [ff] Lower Confidence Limit – LCL.

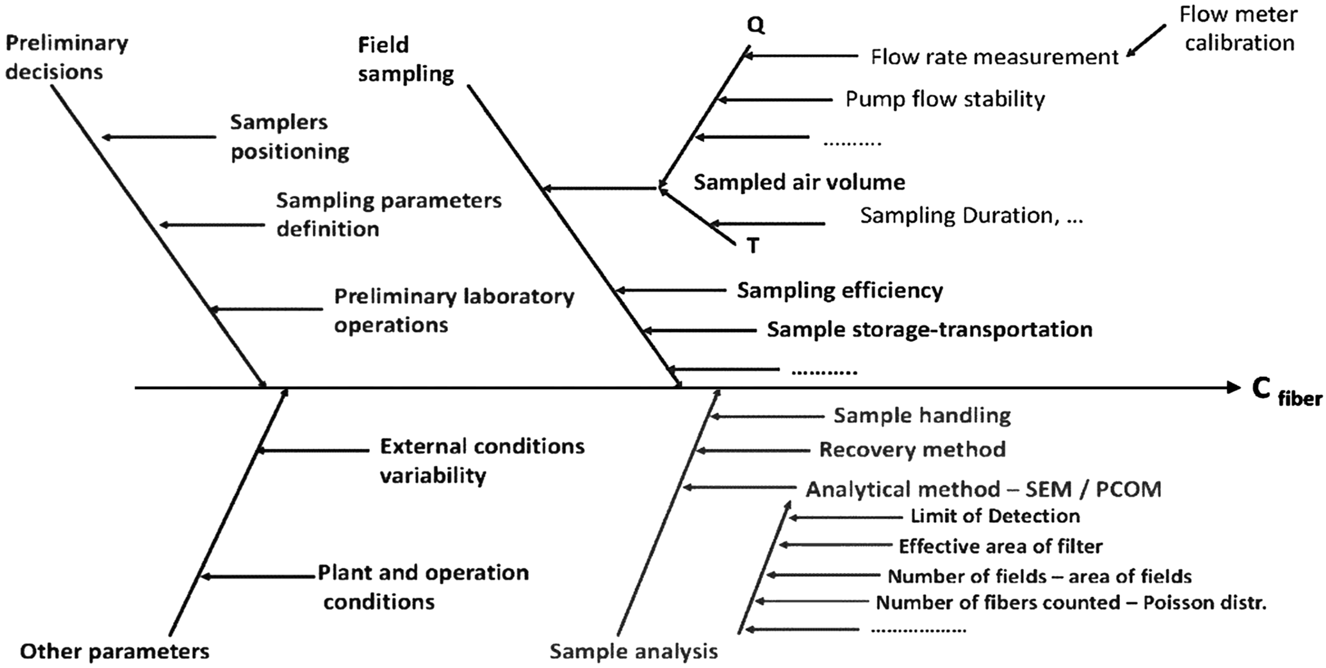


Fig. 2. Example of the Cause Effect – Hishikawa diagram (Center for Chemical Process Safety, 2008) of the main variability sources conditioning the fibers concentration data.
Esempio di diagramma di Hishikawa (Center for Chemical Process Safety, 2008) sulle principali sorgenti di variabilità che condizionano i dati di concentrazione.

the statistical Poisson distribution of fibers on the filters can make negligible the contribution of the remaining uncertainty sources, the experimental nature of the sampling and analytical method adopted made necessary to investigate whether the adjustments aimed to increase the method sensitivity introduce significant variability causes. The analysis was planned in three steps:

1. evaluation of *a-priori uncertainty* of the analytical method (predicted variability obtained by combining the various uncertainty components that characterize the measurement);
2. *a-posteriori assessment of uncertainty* of the method implementation, using measured data accurately processed to identify systematic effects/tendencies, outliers, etc.;
3. *conclusion* about the three set of concurrent measures in terms of both values and experimentally observed variability.

Typically, the a-priori uncertainty is evaluated previously to any measurement, and is based on the knowledge of influence factors mainly producing non-statistical uncertainty contributions. The adopted strategy of three simultaneous samplings results comparable to *three distinct processes*, carried out by means of comparable sampling equipment (with their own metrological characteristics), and same analytical instrument. The a-priori uncertainty assessment should provide indication on:

1. the predicted variability associated to each of the three processes;
2. the ranking of the uncertainty contributions, useful to make decisions about the sources to act upon to reduce the expanded uncertainty in the method implementation, identifying the most critical factors;
3. the effect of such decisions (point 2) in terms of expanded uncertainty reduction.

The knowledge of sampling and analysis activity/equipment made possible the identification of the uncertainties sources for each parameter, as summarized in Table 5.

The uncertainty contributions were estimated as suggested in the Procedure for Uncertainty MAnagement – PUMA: non-statistical information were transformed in statistical characteristics, in terms of variance, to be composed with statistical information, assessing the relevant statistical distribution, e.g. rectangular or triangular, for passing to variance. The determination of both the a-priori and a-posteriori uncertainties, and their comparison, makes possible to understand if the measurement system is correct.

2.2.3. Data interpretation

Assuming that data are correctly collected (Bisio et al. 2017), a possible approach for the data interpretation can be based on the ratio between the situation in areas where ACMs have been

Tab. 5. Parameters and their relevant variability sources.
Parametri e loro fonti di variabilità.

Parameters	Uncertainty source
N_f	- *Poisson distribution* of fibers on the membrane - *Resolution*
A	- *Caliper uncertainty* (zero error) - *Reproducibility* - *Reading uncertainty*
N_c	- *Bias*
a	- *Micrometer calibration*
Q	- *Reproducibility* - *Resolution* (sampling equipment characteristic) - *Accuracy* (sampling equipment characteristic)
t	- *Reproducibility* - *Resolution* (chronometer characteristic) - *Accuracy* (chronometer characteristic)
NOTE: the following definitions of the terms used in the table are drawn from JCGM 200:2012: ***Resolution***: smallest change in a quantity being measured that causes a perceptible change in the corresponding indication; ***Reproducibility***: measurement precision under reproducibility conditions of measurement (condition of measurement, out of a set of conditions that includes different locations, operators, measuring systems, and replicate measurements on the same or similar objects); ***Bias***: estimate of a systematic measurement error; ***Accuracy***[1]: closeness of agreement between a measured quantity value and a true quantity value of a measurand.-	

[1] For the purpose of this research work, we still make reference to the term accuracy, even if the last updates of International Vocabulary of Metrology – VIM introduced some amendments on the term.

identified, but no activities involving emission are present, or situations where some activities can be expected to cause asbestos fibers release, and the common environment pollution, expressed in the relationship eq. 5:

$$K = \frac{\text{concentration in the indoor polluted area}}{\text{concentration in the external nearby area}} \qquad \text{(eq. 5)}$$

3. Results and discussion

3.1. Concentration and LoD

Regarding the pollutant concentration data, the SEM analysis of the 18 membranes, from the six "ordinary" samplings, resulted in *no asbestos fibers detection* (only few artificial or organic fibers were identified). Therefore, laboratory reports gave concentration values, for the all membranes analyzed, below the LoD, calculated according to eq. 6, from data of Table 4:

$$LoD = \frac{3{,}69[\text{ff}]\cdot 962[\text{mm}^2]}{400\cdot 0{,}0032[\text{mm}^2]\cdot(25\ [\text{l/min}]\cdot 200[\text{min}])} = 0{,}56[\text{ff/l}] \qquad \text{(eq. 6)}$$

No background fibers were detected in the field blank analysis, proving the absence of membrane contamination.

3.2. Uncertainty evaluations

According to the analytical results, the measurement uncertainty evaluation was carried out by replacing the fibers count parameter (N_f) with the 95% upper confidence limit for a zero fibers count (3,69 [ff]).

The PUMA method adopted to perform the a-priori uncertainty analysis pointed out that the variability sources of the three processes resulted equivalent, except for the sampling pumps: the three used devices, even differing for producer and model, had very similar characteristics in terms of resolution, accuracy and reproducibility.

The predicted variability, achieved from the a-priori uncertainty calculation sheets, resulted similar for the three measuring processes/conditions (tab. 6).

On the basis of the standard uncertainty values $u_i^2(y)$ (values of the estimated variances associated with the output y – concentration generated by the estimated variance associated with each input estimate x_i.) it is possible to identify the most important uncertainty sources affecting each process. In

Tab. 6. A-priori expanded uncertainty in the three investigated situations.
Incertezza estesa a-priori per le tre situazioni esaminate.

A-priori uncertainty results			
	area A	*area B*	*area C*
Confidence level	0,95	0,95	0,95
Coverage factor (tStudent)	2	2	2
Expanded uncertainty U(y)	**0,093 ff / l**	**0,092 ff / l**	**0,092 ff / l**

Tab. 7. Ranking of the standard uncertainties in the three situations.
Ordinamento gerarchico nelle incertezze standard nelle tre situazioni.

Indoor work – A					Indoor not work – B			Outdoor – C		
Factor x_j					Factor x_j			Factor x_j		
Symbol	Value	Remarks	$u_j^2(y)$	Rank	Symbol	$u_j^2(y)$	Rank	Symbol	$u_j^2(y)$	Rank
Nf	3,7E+00	Poisson distr	1,1E-04	2	**Nf**	1,1E-04	2	**Nf**	1,1E-04	2
		resolution	1,9E-03	1		1,9E-03	1		1,9E-03	1
A	9,6E+02	caliper uncertainty (zero)	1,1E-11	13	**A**	1,1E-11	13	**A**	1,1E-11	13
		reproducibility	1,0E-10	12		1,0E-10	12		1,0E-10	12
		reading uncertainty	2,8E-08	8		2,8E-08	8		2,8E-08	8
Nc	4,0E+02	bias	2,6E-06	6	**Nc**	2,6E-06	7	**Nc**	2,6E-06	6
a	3,2E-03	microm calibr	1,0E-04	3	**a**	1,0E-04	3	**a**	1,0E-04	3
Q_{IW}	2,5E+01	reproducibility	4,1E-05	5	Q_{INW}	1,5E-05	5	Q_{OU}	2,6E-05	5
		resolution	1,6E-06	7		6,6E-06	6		1,6E-06	7
		accuracy	8,0E-05	4		2,6E-05	4		5,9E-05	4
t	2,0E+02	accuracy	4,1E-09	9	**t**	4,1E-09	9	**t**	4,1E-09	9
		reproducibility	1,6E-09	10		1,6E-09	10		1,6E-09	10
		resolution	1,8E-10	11		1,8E-10	11		1,8E-10	11

our case, the uncertainty contributions are almost in the same ranking between the three situations (tab. 7) and the fibers count represents the first important contribution to the final combined standard uncertainty $u_c(y)$[3].

Even if in our case the three rankings show limited differences, the result confirms the importance of hierarchical ordering of variability sources as key decision tool for the allocation of resources for sampling, analysis and measuring devices. The results of a-priori uncertainty analysis makes possible some significant considerations:

1. the original modifications implemented to increase the method sensitivity (i.e. higher air volume sampled and larger filter section analysed) do not introduce significant sources of uncertainties;
2. the three measuring systems (samplings and analysis) show a comparable variability degree; the variability related to the fibers count (resolution and Poisson distribution) remains the major uncertainty source.

The *a-posteriori uncertainty* requires to replace the estimated variability contributions (by PUMA method) with uncertainties statistically defined, in order to achieve the expanded uncertainty affecting the collected measures in specific operating conditions.

In the case under exam, the a-posteriori analysis would be ineffective owing to the preponderance of variability related to N_f on the remaining uncertainty sources, the difficulty to collect data on the third source of uncertainty (the reading field area – *a*), and the reduced contribution of the remaining sources[4].

3.3. Data interpretation

The accurate determination of concentration values in the three considered contexts, together with the associated variability range for each resulting measure, makes possible a reliable estimate of the K-ratio.

In our case, the concentration data resulted below the LoD of the method, in the three analysed situations, this leading to the estimate of concentration values of 0,56 [ff/l] plus 18% (expanded uncertainty), i.e. 0,66 [ff/l]. This result confirms that, even during the window fixtures removal the measurements in the operating area did not put into evidence a significant environmental pollution, and that there is no possibility of Risk Assessment for the three situations on the basis of airborne fibres samplings.

A quite different result is obtained in the case of important emissions of fibers from asbestos containing rock masses during tunnel driving operations (Poma and Puma, 2016): in proximity of the face the concentration values can result certainly high, and in some cases close (or higher) to the technical threshold limit (100 ff/l). In such a scenario, indoor/outdoor simultaneous airborne measurements become pivotal: the raising of indoor pollutant concentration attributable to the excavation activities could be detected by identifying significant

[3] The *combined standard uncertainty* is an estimated standard deviation characterizing the dispersion of the values that could reasonably be attributed to the measurand *y* (JCGM 100:2008)

[4] in the case of a-posteriori uncertainty calculation, it is necessary to consider also the uncertainty contribution of the measuring devices for temperature and pressure determination, needed in particular to normalize the sampled volume whilst these uncertainty contributions are not introduced in the a-priori uncertainty evaluations, since the variability related to flowrate is estimated on the basis of non-statistical information (e.g. samplers characteristics).

differences between indoor / outdoor concentrations. However, clearly this context is very far from the management of environments characterized by residual presence of Asbestos containing artefacts in good conservation conditions.

4. Conclusion

On the basis of the achieved results in a rigorous metrological approach, it is confirmed the impossibility to characterize the environments containing ACMs on the basis of airborne fibers concentration measurements, since, taken into account the uncertainty values related to such determinations, the concentrations result hardly comparable with the measures collected in areas with verified presence of ACMs without ongoing stresses, or in outdoor environments close to the abovementioned areas.

Very different is the situation in operative contexts where the quantities of asbestos containing materials and the involved stressing actions cause important pollution levels.

Hence, according to the D.M.06/09/94 indications, the importance of rigorous direct inspections is confirmed, both to localize ACMs in compact matrix (Hazard Factor dormant), and to identify transition situations from dormant to active Hazard Factor. Such a result cannot be achieved by means of airborne fibers measurements, except in the case of important fibers releases.

Future research developments will focus on the set up of rigorous instrumental techniques to support the direct investigations, reducing the impact of judgment subjectivity, thanks to the implementation of formalized methodologies of Canvassing, based on assisted image interpretation techniques.

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Annotazioni di Sicurezza e Salute sul Lavoro – OS&H

Costituzione della Repubblica Italiana
art.41: "L'iniziativa economica privata è libera. Non può svolgersi in contrasto con l'utilità sociale o in modo da recare danno alla sicurezza, alla libertà, alla dignità umana...."

OS&H
Occupational Safety and Health

Mario Patrucco, Docente di Valutazione dei rischi industriali e nella cantieristica, Università degli Studi di Torino
Rebecca Nebbia, Dottoranda, Gestione, Produzione e Design – Course curricula OS&H, Politecnico di Torino

Con questo primo numero del 2019, si riprende – e ne sono ovviamente grato a GEAM per la rinnovata stima e fiducia – la consueta gestione delle pagine destinate agli aspetti di Sicurezza e Salute del Lavoro.

Il tema è trattato secondo la consolidata impostazione, caratterizzata da Annotazioni con considerazioni non scevre di aspetti scientifici su questioni di attualità, nell'ambito delle quali sono presentate anche le successive note curate da esperti e verificate da autorevoli studiosi della materia facenti parte del Comitato Scientifico di GEAM sin dalla introduzione delle tematiche securistiche nella rivista, nel n. 1 del 2016.

Nel rispetto degli spazi concessici, tenuto conto che come già accennato in precedenti occasioni *soggettività* e *semplificazione arbitraria* possono inficiare gravemente l'azione di prevenzione, ho reputato preferibile limitare alle righe che precedono queste mie considerazioni, per lasciare spazio ad una sintesi curata dall'ing. Rebecca Nebbia sulla "delicatezza" di un corretto approccio alla fase di identificazione e quantificazione delle criticità in materia di OS&H, primo ed essenziale passo non solo per una corretta Gestione tecnologica dei Rischi, ma anche per l'impostazione di efficaci programmi di Sorveglianza Sanitaria.

Una valutazione del rischio non critica e, di conseguenza, una gestione del rischio priva di un approccio rigoroso è ancora un problema ricorrente nell'ambito della OS&H (De Cillis et al., 2018). Una delle cause che conducono ad una cattiva Valutazione dei rischi può essere una raccolta di dati incompleta o non di qualità a causa di semplificazioni errate. Semplificare non è certamente sbagliato in assoluto, ma poiché a monte delle semplificazioni ci sono sempre delle ipotesi, è necessario verificare in ogni contesto la validità delle stesse, soprattutto in fasi lavorative caratterizzate da elevata variabilità di conduzione e di contesto. Un esempio, nell'ambito OS&H, è il non attribuire importanza a pressione e temperatura in fase di valutazione di esposizioni ad agenti chimici e in particolare a particolato aerodisperso. Tuttavia, questi parametri sono importanti perché possono causare un aumento della dose inalata dell'inquinante (The Japan Society for Occupational Health, 2018) e sono anche componenti di incertezza associate alle procedure di campionamento (Standard ASTM D4532).

Sono oggi reperibili sul mercato campionatori personali per le frazioni inalabile e respirabile che effettuano direttamente la normalizzazione dei dati in temperatura e pressione senza la necessità di successive elaborazioni, il che li rende particolarmente adatti per campionamenti ad alta quota, o in cantieri anche a grande profondità (ad esempio in miniere profonde) in cui i suddetti parametri possono raggiungere valori estremi.

Le semplificazioni possono coinvolgere non solo le misurazioni, ma anche altri aspetti come la definizione di gruppi simili di esposizione (SEGs), approccio utile per ridurre durate ed oneri dell'indagine (UNI EN 689: 2018). Tuttavia, la norma stessa segnala la possibilità che due lavoratori addetti alla medesima mansione non risultino esposti allo stesso modo (variabilità tra lavoratori) e che si verifichino variazioni di esposizione da turno a turno (variabilità all'interno del lavoratore). Ne deriva che la valutazione dell'esposizione di un lavoratore non può essere tout court estesa ad altri che eseguono nominalmente la stessa mansione, e che i SEGs dovrebbero essere costituiti soltanto <u>dopo</u> una prima valutazione dell'esposizione di ogni singolo lavoratore, sulla base di dati dimostratamene significativi.

Concludendo, le semplificazioni nell'ambito della OS&H rispetto all'impiego esclusivo di criteri di rigore scientifico e metrologico sono di per loro certamente consentite, purché caso per caso giustificate senza mai perdere di vista il processo logico che le ha rese possibili.

Ci si ripromette di tornare su questo tema in forma estesa in una prossima nota.

In coerenza con l'approccio generale di Disseminazione della Cultura della Sicurezza alla base delle pagine sulla Sicurezza del Lavoro, verrà in particolare discusso, nella nota

The role of the airborne asbestos fibers measurement in the classification of working environments: the case of Large Public Facilities

il contributo che le misurazioni di fibre aerodisperse possono fornire nella Valutazione e Gestione del Rischio Amianto. Lo studio è stato condotto tramite implementazione di una strategia dedicata di misurazione, applicata in uno scenario reale, al fine di migliorare la sensibilità del metodo e raccogliere dati utili per correlare l'inquinamento indoor con il deterioramento dei MCA preventivamente identificati.

Ben ritrovati e buona lettura!

Mario Patrucco, Rebecca Nebbia

Bibliografia essenziale sulla "delicatezza" di un corretto approccio alla fase di identificazione e quantificazione delle criticità in materia di OS&H

De Cillis, E., Demichela, M., Fargione, P., Maida, L., Nebbia, R., Patrucco, M.: "Education: an essential tool for the dissemination of the culture of safety". Chemical Engineering Transactions, Vol. 67, 313-318 DOI: 10.3303/CET1867053, 2018, ISSN 2283-9216

Standard ASTM D4532 "Standard Test Method for Respirable Dust in Workplace Atmospheres Using Cyclone Samplers".

The Japan Society for Occupational Health. Recommendation of Occupational Exposure Limits (2018-2019). J Occup Health, 2018; 60: 419-452.

UNI EN 689: 2018 "Atmosfera nell'ambiente di lavoro – Misura dell'esposizione per inalazione agli agenti chimici – Strategia per la verifica della conformità coi valori limite di esposizione occupazionale".

OCCUPATIONAL SAFETY AND HEALTH

Tips on Occupational Safety and Health – OS&H

Costituzione della Repubblica Italiana
art.41: ***"L'iniziativa economica privata è libera.***
Non può svolgersi in contrasto con l'utilità sociale o in modo da recare danno alla sicurezza, alla libertà, alla dignità umana...."

OS&H
Occupational Safety and Health

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This first issue of 2019 resumes – I am grateful to GEAM for its renewed esteem and confidence – the usual organization of the pages dealing with the scientific aspects of Occupational Safety and Health.

The theme is treated according to a consolidated approach, characterised by Tips with scientific content discussing some topical issues, and introducing the following papers verified by experts belonging to the Scientific Committee of GEAM since the introduction of the OS&H issues in the journal, in n. 1, 2016.

Considering that, as already mentioned in previous occasions, subjectivity and arbitrary simplification can affect the action of prevention, I thought it appropriate to limit the lines preceding these my considerations, to leave room for a synthesis curated by Ing. Rebecca Nebbia on the "delicacy" of a correct approach to the phase of identification and quantification of criticalities in the field of OS&H. This is the first and essential step not only for the correct technological management of risks, but also for the setting of effective Health Surveillance programs.

Uncritical Risk Assessment, and consequently a Risk Management without a rigorous approach, is still a recurring problem within the OS&H (De Cillis et al., 2018). One of the causes that lead to poor Risk Assessment can be an incomplete or non-quality data collection due to erroneous simplifications. Simplifying is not wrong, but because upstream of the simplifications there are assumptions, it is necessary to verify in every context the validity of the same, especially in working phases characterized by high variability of conducting and context. An example, in the context of OS&H, is not to attach importance to pressure and temperature during the exposures' evaluation to chemical agents and in particular to airborne particulate. However, these parameters are important because they can cause an increase in the inhaled dose of the pollutant (The Japan Society for Occupational Health, 2018) and are also components of uncertainty associated with sampling procedures (Standard ASTM D4532).

Nowadays, personal samplers for inhalable and respirable fractions, that normalize data in temperature and pressure without the need for subsequent calculations, are available on the market. These samplers are suitable for high-altitude sampling and in deep yards (e.g. in deep mines) where the aforesaid parameters can reach extreme values.

Simplifications may involve not only measurements, but also other aspects such as the constitution of similar exposure groups (SEGs), that is a useful approach to reduce the duration and the costs of the survey (UNI EN 689: 2018). However, the standard itself indicates the possibility that two workers involved in the same job are not exposed in the same way (variability between workers) and that changes occur in exposure from shift to shift (variability within the worker). It follows that the assessment of the worker's exposure can't be extended to others who perform the same job nominally, and that the SEGs should be constituted only after a first exposure's assessment of each individual worker, and so on the basis of significant data.

In conclusion, the simplifications within the OS&H are certainly allowed, as long as case by case justified without losing sight of the logical process that made them possible.

A promise is to come back on this subject in extended form in a next paper.

In coherence with the theme of Dissemination of the Culture of Safety of the OS&H pages, the paper

The role of the airborne asbestos fibers measurement in the classification of working environments: the case of Large Public Facilities

discusses the actual contribution that airborne asbestos measurements can provide to the Risk Management, in particular in the identification of incipient deteriorations of ACMs. The research work was performed by implementing a special measuring strategy, in a real scenario, to increase the method sensitivity and collect data useful to relate the indoor pollution to ACMs deterioration.

Welcome back and enjoy your reading!

Mario Patrucco, Rebecca Nebbia