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# Shallow groundwater temperature in the Turin area (NW Italy): vertical distribution and anthropogenic effects

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1	Urban groundwater warming in Turin area (NW Italy)
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7	ABSTRACT
8	This study investigated the thermal regime of shallow groundwater in the Turin area (NW
9	Italy), where the large energy demand has driven a new interest for ground-source heat
10	pumps (GSHPs). The strongest vertical variability of groundwater temperature is found
11	within 10-20 m below ground surface. In spring, deeper temperatures are higher than
12	shallow temperatures, while in autumn the trend is reversed. These variations are
13	connected with the heating and cooling cycles of the ground surface due to seasonal air
14	temperature oscillation, propagating into the aquifer.
15	The areal temperature distribution shows an increase from the foothill sectors close to the
16	Alps towards the central Po Plain, driven by the progressive warming along the flow path.
17	In the Turin city aquifer temperatures are 0.6 $\div$ 1.6 °C higher than rural sectors. This
18	groundwater warming is linked to the urban heat island effect, mainly driven by the typical
19	artificial land use. Sparse warmer outliers (16-20 °C) are in some cases connected to
20	documented point heat sources, such as GSHP systems, industrial districts and landfills.

KEY WORDS: groundwater temperature; seasonal oscillation; anthropogenic heat sources;
 ground-source heat pumps

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### INTRODUCTION

As many other countries in Europe, Italy is trying to reduce its dependence to non-25 renewable fossil fuels. NW Italy is one of the most densely populated and industrialized 26 areas and concerns are rising for the great thermal energy demand, especially in its large 27 conurbations (Turin, Milan). Among the renewable sources, low temperature reservoirs are 28 being increasingly regarded worldwide as promising thermal energy suppliers via the use 29 of heat pumps. A similar trend has been characterizing Italy in the last decades: geothermal 30 heat pumps have doubled their contribution to the final consumption of renewable energies 31 (EC, 2015). 32

In NW Italy the Po Plain is a very promising area for the large-scale dissemination of geothermal heat pumps: the relatively thick alluvial body forming the plain hosts many productive groundwater systems, making possible the installations of geothermal heat pumps in the above mentioned cities (Sparacino et al., 2007; Baccino et al., 2010; Beretta et al., 2014; Alberti et al., 2017; Emmi et al., 2017; Piga et al., 2017).

The Turin area is located in such a favourable geological context, but it still lacks a cityscale thermal characterization of aquifers. The present study thus investigated the temperatures of the shallow groundwater in the Turin area, considering both the urban and the rural areas adjacent to the city. Another reason to study the Turin case is that several studies, carried out in many cities worldwide, reveal an over-heating of urban shallow aquifers (Ferguson and Woodbury, 2004; Zhu et al., 2010; Menberg et al., 2013; Benz et al., 2015).

#### **STUDY AREA**

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The area investigated is located in Piedmont Region (NW Italy) and includes both the 48 narrow sector of the western Po Plain between the Western Alps (W) and Turin Hill (E) 49 and the internal plain sector of the Ivrea Morainic Amphitheatre. The regional climate is 50 51 driven by the orographic component (ARPA 2007): air temperatures show a regular decrease with elevation in western direction towards the alpine chain and can be changed 52 53 by local conditions, such as urban areas. The average annual temperature of Piedmont Po Plain ranges between 10°C and 12.5°C, with higher average monthly values in autumn 54 than in spring (Table 1). 55

56

57 Table 1

58

From a hydrogeological point of view, the Quaternary alluvial sediments of the Po Plain 59 represent a continuous highly permeable porous medium that hosts many groundwater 60 systems. Conventionally, one shallow and various deep aquifers have been described in 61 Piedmont Region (Bortolami et al., 1988; Bove et al., 2005; De Luca et al., 2014; Lasagna 62 and De Luca, 2017). The shallow aquifer, hosted in late Pleistocene and Holocene units, is 63 mostly unconfined and supplied by the infiltration of rainfall and secondarily by rivers in 64 the high plain sectors. Due to the mainly sandy-gravelly texture, many quarry activities are 65 exploiting this complex (De Luca et al. 2007; Castagna et al. 2015a, 2015b). The 66 maximum aquifer thickness is 50 m and the water table generally has depths between 1 and 67 50 metres below ground level, with minima located in the high plain sectors. In most of the 68 wells (78%) the water table depth is found between 1 and 20 metres b.g.l. (Bucci et al., 69

2017). The low plain sectors, far from the Alpine chain, are generally discharge areas and
the Po River represents the main regional discharge axis for the groundwater flow
(Debernardi et al., 2008; Lasagna et al., 2016a, 2016b).

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#### **TEMPERATURE MODEL AND METHODS**

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The shallow subsurface temperature is mainly controlled by the temperature at the ground 77 surface, which strictly depends on the local climate and on the land use conditions. The 78 temperature temporal oscillation in the unsaturated zone, solved by a 1D heat diffusion 79 model for a semi-infinite medium characterized by homogeneous properties and negligible 80 81 vertical water movements (Banks, 2008; Taylor and Stephan, 2009), consists of an oscillating temperature around the average annual ground temperature. The fluctuations 82 83 undergo a decay and an increasing time lag with depth. This means that longer temperature cycles -decades, centuries- are, the more they penetrate the subsurface, whereas the short 84 cycles -days, months- but their amplitude is increasingly damped and lagged by the heat 85 dissipation within the geologic medium. The heat transfer processes become more complex 86 87 when the ground temperature inputs reach the groundwater: the flow of the water in the porous medium, the inertial effects and eventual turbulence enlarge the apparent thermal 88 diffusivity until it reaches several orders of magnitude greater than the molecular thermal 89 diffusivity (Taylor & Stephan 2009). This means an increased rate of heat transport due to 90 hydrodynamic effects that are highlighted by distortions in borehole temperature logs. 91

92 The aquifer depth interval affected by temperature oscillations, known as the "surficial 93 zone", is generally 10 to 20 m deep; it is followed by the so-called "geothermal zone", in

which the geothermal gradient drives a constant increase in temperature (Anderson 2005).
However, previous works in NW Po Plain alluvial aquifers (e.i. Barbero et al., 2016)
revealed a "homoeothermic zone" with no temperature oscillations in time. The
temperature below the surficial zone is usually 1 to 2 °C higher than the average annual
temperature at the ground surface (Anderson 2005).

The mean annual average temperatures and the amplitude of temperature oscillations in the 99 vadose zone and in the aquifers strictly depend also on the local land use: variations in 100 reflectance and porosity of soil are able to influence the transmission of solar radiation and 101 water infiltration. Consequently, temperatures are affected by anthropogenic elements 102 103 found at ground surface: buildings, roads, paved surfaces and so on. The temperature rise varies depending on the type of element: for example, Taylor and Stefan (2009) observed 104 increments of up to 3°C linked to isolated roads. The most evident thermal footprints occur 105 beneath urban areas: Menberg et al. (2013) estimate a temperature difference between rural 106 and urban areas equal to +1.9 °C to +2.4 °C in some German cities. Warmer temperatures 107 below cities are also linked to the global warming (Taniguchi et al., 2007; Bayer et al., 108 2016). 109

Thermal logs, the typical survey method for aquifer temperature detection (Taniguchi, 110 1993; Pasquale et al., 2011), were carried out throughout the water column of around 50 111 observation wells of Turin area, all wells are screened in the shallow aquifer. Temperature 112 acquisition interval was 1 to 5 m (depth-wise increase) and an electronic water level metre 113 equipped with a thermometer (±0.1 °C accuracy) was used. For assessing possible city-114 related effects, temperatures were collected in rural and urban (Turin city) sectors. A multi-115 116 temporal approach was used to detect the seasonal fluctuations. The largest part of the wells was surveyed in 2014 in a spring-autumn survey. In 2016 further observation points 117 were added with measurement frequency equal to 1 month. The depths of monitored wells 118

have the following ranges: <10 m (2.4%), 10 to 20 m (42.9%) and >20 m (54.7%).

According to the afore mentioned temperature model and to air temperatures, the maximum expected groundwater temperature below the surficial zone with climatic variations is between 12 and 14.5 °C in the Turin plain.

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#### **RESULTS AND DISCUSSION**

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The most evident feature of the temperature profiles measured in the observation wells of 126 the area investigated is the vertical variability in the shallow portion of the aquifer, 127 according to the afore mentioned models. The temperature delta along the water column of 128 the well, obtained by the difference between top and bottom well temperature, indicates the 129 warming/cooling of very shallow groundwater; as expected, the temperature variation 130 along the well water column diminishes significantly with the depth of groundwater level 131 (Fig. 1). This trend is season-driven: in spring deep values are higher than the shallow ones 132  $(\Delta T < 0)$ , while in autumn a decrease of temperature with depth occurs ( $\Delta T > 0$ ). Such depth 133 and time variations are connected to the heating and cooling seasonal cycles of ground 134 surface temperatures, propagating into the shallow portion of the aquifer. Furthermore, the 135 seasonal amplitude reduction with increasing depths means that the vadose zone plays a 136 major role in damping the oscillations, according to similar studies by Burns et al. (2016). 137

138

139 Figure 1

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Underneath the seasonal oscillation zone, groundwater temperatures are approximately constant in most wells, according to Barbero et al. (2016): in Fig. 1, below 10 m the residual changes (less than  $\pm$  1 °C) can be connected to other processes, such as advective heat transport within the aquifer. Deviations from constant temperature in the thermal profiles can be read as either upward or downward water movements, in recharge and discharge areas, or as lithological heterogeneities in areas with nearly horizontal flow. The groundwater temperature in Turin plain, averaged on spring and autumn values extracted from Bucci et al. (2017), is 14.1 °C, that is within the expected temperature range (see previous paragraph).

Lateral variations of aquifer temperature in autumn 2014 are displayed by plotting the bottom well temperatures, not affected by seasonal oscillations (Fig. 2), that were measured at the average depth of 25 m. There is a gradual groundwater warming from high plain sectors close to the Alps towards the Po River. This feature is consistent with the main groundwater flow direction, meaning that colder aquifer temperatures of recharge areas -due to colder air temperatures in high plain sectors- warm up during their pathway.

The second most evident feature is the high concentration of warm temperatures below the 156 Turin city: compared to rural values, the urban aquifer is 14-16 °C and rural aquifer is 12-157 14 °C. More precisely, the urban warming intensity can be calculated with the difference 158 between the average temperatures in the city area and rural area: in the Turin case in 2014 159 it is +1.6 °C in spring and +0.6 °C in autumn. This feature is likely linked to the 160 groundwater warming caused by the large urbanized area of Turin: the extensive cover of 161 roads and buildings warms up the land surface and then this heat is transferred to the 162 underlying aquifer. 163

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165 Figure 2

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Sporadic high temperatures (>16 °C) have local significance and may be related to point
heat sources. In the case of La Loggia observation well (Fig. 2), located few kilometres

south of the Turin city, groundwater reaches a temperature of around 17 °C. In this case the 169 groundwater heating is likely linked to the presence of an industrial district that may be 170 171 responsible of intense heat fluxes due to the huge volumes of warm indoor air and/or to industrial exothermic processes. Other outliers are: a well in Turin city close to an open-172 loop geothermal system working in heat injection mode, which displayed temperatures up 173 to 23 °C -not in figure- and the Caselle T.se observation well (N of Turin), which showed a 174 high maximum temperature in autumn (18.6 °C) and a marked difference with the spring 175 value (13.4 °C). Without any further knowledge on heat sources in the surroundings and 176 lithological variations at the site, such behaviour may be related to a significant seasonal 177 178 effect on groundwater: the small groundwater table depth ( $\leq 5$  m) and the limited well depth (20 m) make the groundwater at that site largely influenced by the seasonal 179 oscillations, even at the bottom of the observation well, where the plotted measurement 180 was taken. Furthermore, the land use of both sites is constituted by large paved parking 181 areas that might have amplified the heat accumulation during summer, with consequent 182 high temperatures in autumn. 183

Fig. 3 and 4 show the typical urban thermal logs from the 2016 survey and their evolution 184 in time. The 4 monitoring points (green dots in Fig. 2) were grouped in 3 sites: PZC1 and 185 PZE6 (Site 1), are in the same site, a former illegal landfill; PZ3 A is in Turin city 186 neighbourhood with early urbanization (Site 2); PZ34 is located in an industrial waste 187 landfill (Site 3). Site 1 and 3 have less dense urbanization. The strongest vertical variability 188 is evident in the wells of Site 1 with shallow water table depth, whereas in Site 2 and 3 the 189 groundwater temperatures are approximately constant in depth because the water table is 190 below 20 m b.g.l., where the seasonal effects are supposed not to influence the 191 groundwater temperatures. The huge differences between PZC1 and PZE6 of Site 1 are 192 mainly due to the position with respect to the landfill (PZC1 is downstream, PZE6 is 193

194	upstream) and, secondarily, to the land use: PZC1 is drilled few centimetres far from an
195	asphalted road, while PZE6 is some meters far from an unpaved road and around 10 m far
196	from buildings. Overall, groundwater in PZC1 is overheated by the heat transported from
197	the polluted sector, where exothermic reactions of organic matter degradation likely occur
198	(the site has methane burners), and by the asphalted road that, according to previous
199	studies (i.e. Taylor & Stefan, 2009), can increment the temperatures up to 3 to 4 $^{\circ}$ C.
200	
201	Figure 3
202	Figure 4
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204	CONCLUSIONS
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206	The climatic component has a major influence on the shallow aquifer temperatures in
207	Turin area, creating vertical temperature heterogeneities up to 10 m depth. Seasonal
208	thermal variations are more effectively damped as long as the vadose zone is thicker. Other
209	factors play an important role at regional level, such as recharge conditions and altitude of
210	infiltration waters: the high plain sector has colder waters, compared to the low plain
211	sectors. Anthropogenic heat sources were also recognized: a diffuse temperature increase
212	below the Turin city was indeed detected that ranges between 0.6 and 1.6 °C season-wise.
213	At the same time, warmer outliers linked to local heat sources (polluted sites, industrial
214	districts, geothermal systems) and/or site-specific conditions were also detected. For
215	instance, S to Turin a contaminated site constitutes an interesting case study of pollution-
216	driven groundwater warming. Other outliers need further surveys for better comprehension
217	of the measured temperature values.

218 Concerning the geothermal applications, the groundwater temperatures of shallow aquifer

can be assumed as relatively constant throughout the year if compared with the wider seasonal air oscillation recorded in a medium temperate climate of continental Europe. The thermal features of shallow aquifer, combined with the high productivity and the legal protection of deeper aquifers, contributes to create favourable conditions for the large-scale diffusion of groundwater-coupled heat pumps (GWHPs).

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226

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Fig. 1 – Correlation between groundwater temperatures and temperature difference along
water column of the monitored wells in 2014



Fig. 2 – Temperatures of the shallow aquifer in autumn of 2014. \*The values refer to the
 well bottom temperatures

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## 25/03/2016 Temperature [°C] 12.0 14.0 16.0 18.0 0 5 10 Depth [m b.g.l.] 15 20 25 PZC1 (Site 1) 30 PZE6 (Site 1) 35 PZ3 A (Site 2) 40 PZ34 (Site 3) 45

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349 Fig. 3 – Groundwater temperatures at 3 urban sites in spring of 2016

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