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The genesis and the hydrogeological features of the Turin Po Plain *fontanili*, typical lowland springs in Northern Italy

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Abstract - The *fontanili* are typical lowland springs that occur in Northern Italy along the transition zone from the higher to lower plain (the "*fontanili* line") due to changes in both the slope surface and the sediment grain size. These resurgences of phreatic water were investigated in the western sector of the Po Plain in the Province of Turin.

Although the available bibliographic data through 2005 reveal the occurrence of 111 *fontanili* in the study area, only 51 preserved *fontanili* have been identified in field surveys. The principal morphological and geological features of these resurgences were recorded and entered into a database. In addition, the small-scale hydrogeologic framework of these *fontanili* was clarified by means of lithostratigraphic cross-sections.

Taking into account the drastic decrease in the number of these particular springs, 10 *fontanili* were selected for detailed investigation based on their state of preservation and accessibility. A geological map of each emergence was constructed to explain its origin. The main hydrochemical and physical variables and parameters were measured every month for a period of one year. Only three sources provided water throughout the entire year, and their flow rates reach 60-80 litres per second during the summer due to recharge from irrigation channels. All other *fontanili* remained dry during different periods of the year. The hydrochemical data revealed a Ca-Mg bicarbonate composition. The electrical conductivity increased from the north (100-300 μS/cm) to the south (300-600 μS/cm), and nitrate concentrations were below the limits permissible by Italian law (50 mg/l).

This study should be considered as the basis of a proposal to the local government for the protection of a subset of these springs as sites of special geological interest (geo-sites).

Key words: lowland springs (*fontanili*), lithostratigraphy, hydrogeology and water quality, Po River Plain.

INTRODUCTION

The fontanili are typical springs of the plain areas, very common in the Po Plain (Northern Italy; Fig. 1). In detail, the fontanili of the central and eastern Po Plain are relatively well studied, especially in Lombardy (Bertuletti 1992; Bischetti et al. 2012; D'Auria and Zavagno 2005; Gavazza et al. 2003; Guazzo et al. 1977; Laini et al. 2012; Moro 1924; Pisoni and Valle 1992; Vasileiadis et al. 2013), Emilia Romagna (Alessandrini et al. 2013; Bernini and Torselli 1989; Mozzanica et al. 2001; Viaroli et al. 2003) and Veneto Region (Vorlicek et al. 2004; Zini et al. 2012).

The lowland springs in Piedmont Region, and in particular in the Turin Po Plain, are relatively taken into little consideration by authors; indeed most of papers deal with ecological and hydrochemical features of *fontanili* (Baratti 1997; Battegazzore and Morisi 2012; Battegazzore et al. 2005; Milano 1996; Shestani et al. 2007, 2009; Shestani and Morisi 2010) but few studies cover the geological-hydrogeological aspects. A brief reference to these emergences is reported in the hydrogeological reconstructions of the Piedmont area (Bortolami et al. 1978). Only recently a detailed study of these resources is started by the same authors of the present contribution, published in a preliminary way (De Luca et al. 2005; 2009). The present work represents the extension of these previous researches.

The aim of this paper is the characterization of the preserved emergences (51) as number, spatial distribution, morphometric parameters, present use, physical-chemical features, state of preservation and genesis. Moreover 10 fontanili were selected for a detailed investigation, consisting of a geological survey of each emergence constructed to explain its origin as well as monthly discharge measurements and water sampling for a period of one year. This framework is of strategic importance for the preservation and enhancement of these resources.

1 GENERALITIES OF THE *FONTANILI*

1.1 The *fontanili* or typical springs of the Northern Italy Plain

The *fontanili* are typical lowland springs occurring in Northern Italy along the transition zone from the higher to lower plain, where they are a common environmental feature of the region (Moro 1924; Bortolami et al. 1978; De Luca et al. 2005). These springs are located on the "*fontanili* line", which is a largely continuous line than runs for approximately 800 km along the entire Po Plain and Venetian Plain (Fig. 1). The "*fontanili* line" comprises a band that extends in width from a few kilometres to more than 20 km. These springs represent a water supply suitable for agriculture and an alternative to expensive pumping from wells.

These emergences have been used in Northern Italy since ancient times. The first irrigation canals originating from these sources of phreatic water were built in the 11th-12th centuries. The advantage of these sources was critical for medieval humans, who could properly irrigate the fields while also recovering certain wet and previously uninhabited areas. Various names were given to these plain springs (e.g., *risorgive*, *risultive*, *fontanili*, *fontanazzi* and *sortumi*) depending on their regional location. Their remarkably constant flow rate and temperature enabled humans to exploit the springs for agriculture purposes. A characteristic set of flora and fauna have developed around these sources that provide a unique habitat (Minelli et al. 2002).

An accepted classification refers to *risorgive* (springs) as groundwater that naturally rise to ground level due to changes in sediment permeability and topographic slope. On the contrary, the name *fontanili* is used only for the lowland springs modified by human intervention. All of the springs described in this paper have been affected by man-made excavations and are accordingly reported as *fontanili*.

These plain springs give rise to a network of small watercourses that join together and in turn give rise to a significant river. Spring-fed rivers have notably small gradients, e.g., the Stella River in Friuli falls by one metre per kilometre (Minelli et al. 2002). These waterways also have different discharge rates; the largest of these, the Sile River, has an average discharge of approximately 50 m^3/s (Bortolami et al. 1978).

From a stratigraphic perspective, the Po Plain consists of coarse layers (gravel and sand, sometimes cemented, with various degrees of permeability) alternating with fine layers (silt-clay, i.e., mainly impermeable bodies). The "High Plain" is essentially characterised by permeable sediment, and the permeability decreases towards the "Low Plain". A boundary between the High Plain and Low Plain generally occurs along the 50/100-metre contour line (up to 200 m in the westernmost region of the Po Plain). In this context, the subsoil water circulating within the coarse-grained sediments comes to the surface when it meets the fine-grained sediments. This phenomenon promotes the water to rise to ground level and provides the origin of the *fontanili* (Minelli et al. 2002).

1.2 The morphological features of the *fontanili*

The *fontanili* originate in morphologic depressions that are sometimes enlarged by water reaching the ground. These depressions receive water from underground and may form small channels that flow into significant collectors.

The *fontanili* include a spring area known as a “head” and often contain one or more “eyes”, representing the spouts, a channel, in which water flows, and a stretch connecting the head with the channel referred to as the “throat” (Baratti 1997; Minelli et al. 2002) (Fig. 2). The size of the head can vary from 50 cm to several decametres. Its shape is usually round but may differ (Fig. 3).

The widespread *fontanili* found in the area of investigation are a good example of human intervention for water exploitation. In the past, small morphologic depressions in areas where the water table is near the surface were expanded to promote water flow out onto the ground. The bottom of the depression was enlarged to facilitate the collection of water. A metal basin or a wood basket without a bottom was used to keep the eye of the *fontanile* full of water and to provide a constant flow. The lifetime of a wood basket in this system was approximately 10-15 years.

More recently, the *fontanili* have been exploited by fixing a filtering tube (*Calandra* tube, after the name of the maker) placed in the centre of the spout to enhance the flow of water. The *Calandra* tube consists of an iron-slotted pipe screen with a diameter between 10 and 50 cm and a maximum length of 10 to 12 m, and its fixation in the soil is promoted by an elongated cone. Unfortunately, the *fontanili* sites are highly vulnerable to pollution and are often subjected to modification due to the intense water exploitation from wells in the surrounding areas.

2. MATERIALS AND METHODS

Several borehole logs were examined using the stratigraphic criteria reported in the recent geological literature (Barbero et al. 2007). This review allowed for a lithostratigraphic and hydrogeologic reconstruction of the area of investigation, which was realised for the evaluation of the origin of the Turin Po Plain *fontanili*. A detailed geological survey of the Quaternary sediments and morphologic features of the areas around the springs was also performed according to the NACSN allostratigraphic criteria (North American Commission on Stratigraphic Nomenclature 1983).

A piezometric map of the shallow unconfined aquifer was developed using water table levels monitored in the period June-July 2002. The measurement points were prevalently irrigation wells and domestic wells; subordinately the water table was measured in industrial wells and piezometers. The piezometric surface contour map was created also performing:

- topographical control: topographical elevation levels coming from DEM 50 (digital elevation model with 50 m resolution) were used;
- geological and morphological control: the congruence of the water table with geological limits and morphological features was verified;
- surface water control: the relationship between groundwater and surface water network was taken into account.

The piezometric data were interpolated using a GIS with a kriging algorithm.

A search of the *fontanili* located in the examined area was performed using several different information sources. The first investigation was carried out using the maps at a scale of 1:25000 produced by the Military Geographic Institute in the period 1950-1965. The *fontanili* sites were then located on a reference map at a scale of 1:10000 to organise the subsequent field surveys to check their current existence and specific location.

Physical-chemical analyses were performed on the water samples for hydrochemical characterisation. Temperature data (field thermometer), electrical conductivity (conductometer), pH (potentiometer), Ca^{2+}, Mg^{2+}, HCO_3^- (micro-titration apparatus), Na^+, K^+ (atomic emission spectrometer) and Cl^-, SO_4^{2-}, NO_3^- (ion chromatograph) were collected and evaluated.

The seasonal fluctuations in the *fontanili* discharge were monitored by monthly measurements of the instantaneous discharge using the float method. The discharge was calculated based on the average channel velocity and the cross-sectional area (Dingman 2002). The average surface channel velocity was measured by timing of a prescribed distance travelled by small floats (corks). Two sections transverse to the river flow at a distance of approximately three times the channel width were studied.

3. GEOLOGICAL AND HYDROGEOLOGICAL SETTING OF THE TURIN PO PLAIN

The Turin Province (6830 km^2) consists of three distinct sectors: a plain (Turin Po Plain), an alpine area and a hilly area (Fig. 4). The lowlands form the central section and are bordered by mountains and hills to the west and east, respectively.

To get a reliable framework of the stratigraphic succession of the Turin Po Plain area, the regional previous data (Bortolami et al. 1978; Carraro ed. 1996) have been integrated with the recent knowledge regarding the different terms taken into account (Barbero et al. 2007; Festa et al. 2009a, 2009b).

Four superposed geological and hydrogeological complexes, that differ with respect to the grain sizes and permeability of sediments, have been described in the subsoil of the Turin Po Plain:

- the deep pre-Pliocene complex (Eocene-Miocene) consists of highly consolidated sediments, mainly comprising marl, sand and clay, with gravel found only locally. These sediments with a notably low permeability do not contain any significant aquifers;
- the Pliocene marine complex (Lower-Middle Pliocene) has a clayey-silty texture (Argille di Lugagnano) or a fine sandy texture (Sabbie di Asti). The Argille di Lugagnano, with low permeability, represents an aquitard; the Sabbie di Asti, with a variable permeability, constitute locally important aquifers;
- the transitional villafranchian complex (Middle Pliocene-Lower Pleistocene) consists of alternating clayey silt, sand and minute gravel, forming a multilayer aquifer in which the sandy and gravelly permeable layers form important semi-confined aquifers;
- the surficial fluvial complex (Middle-Upper Pleistocene and Holocene) is formed by coarse gravel and sand with minor clayey silt, showing a generally high permeability. This complex represents an important shallow aquifer whose water table is directly connected to the surficial hydrographic network.

The shallow unconfined aquifer feeds the fontanili springs and is mainly supplied by direct rainfall and rivers at the outlet of the valleys in the plain. The groundwater generally flows from northwest to southeast in the northern part of the plain, and from west to east in the southern portion (Fig. 5). In the south-eastern sector of the Turin Po Plain (Poirino Plateaux), the groundwater flow is generally toward west, i.e. towards the Po River, that represents the main watercourse of the study area. In details, the groundwater flows from north and from south toward a minor stream (Banna S.), which is locally the most important draining element.

In the Turin Po Plain, the groundwater is strongly influenced by the draining action of the Po River. In the central part of the plain, also the Chisola S., the Stura di Lanzo R., the Orco S. drain the groundwater. For most of the studied plain, the Dora Riparia R.

shows no relationship with the groundwater, which flows with a substantially undisturbed flow direction at an altitude of 10-15 meters below the riverbed. Proceeding eastward, the difference in elevation between the river and groundwater is progressively reduced. Finally, in Turin, before the confluence with the Po R., the Dora Riparia R. feeds the groundwater table.

In the southern sector of the Turin Po Plain, the hydraulic gradient varies between 3%, e.g. at the edge of the Alps, and 0.1% in the low plain. In the middle sector of the plain, an abrupt decrease in the hydraulic gradient (from 0.6-0.7% to less than 0.3%) was observed; this area, at which fontanili emerge, represent the “fontanili line”. In the area of Turin, south of Stura di Lanzo R., there is a general decrease in the hydraulic gradient moving from the apex of the fan of Dora Riparia R. towards the Po R. Values of the hydraulic gradient are greatest immediately in the high plain, where they reach 1.1%; near to the Po R. the hydraulic gradient is around 0.4 - 0.5%. North of the river Stura di Lanzo R., the hydraulic gradient decreases from the high plain (also superior than 4.4%), towards the Po R., up to minimum values close to 0.5% in the vicinity of the confluence with the Dora Baltea R. Because of the extent of the Turin Po Plain, the texture of its sediments and the large natural recharge, this area is the most important reservoir in the Turin Province.

3.1 The examined *fontanili*

The first step of the study was a research of the fontanili on a regional scale, using all previous data in the geologic literature. A total of 111 fontanili were identified in the Turin Po Plain. These lowland springs are located into two separate areas, in the northern and southern sectors of the Turin Po Plain (Fig. 6). Subsequently a field campaign was performed during June and July of 2007, with the aim of identifying the actual presence of these lowland springs, which has allowed us to find only 51 fontanili. The *fontanili* that had disappeared are mainly located in present-day agricultural areas where mechanised farming and artificial irrigation prevail, and these springs are no longer maintained (ISPRA 2010) (Fig. 7). To a minor extent, they are also located in current woodlands that are not suitable for modern farming systems and are abandoned and no longer maintained. The disappearances of the *fontanili* are driven by the increase in urban and industrial areas as well as fluvial migration. Other more general causes for this disappearance may be the lowering of the piezometric surface due to prolonged periods of drought as well as anthropogenic factors, e.g an increase in the number of water wells.

The 51 *fontanili* identified during the field survey were catalogued using descriptive forms containing general data (e.g., the municipality, code, UTM coordinates, topographic map number, size and other features of the spring). A statistical analysis was performed to define the morphometric parameters of the *fontanili* (Tab. 1). The *fontanili* were successively classified into three groups according to their sizes (Fig. 8):

- *fontanili* of small size (61% of the analysed cases): 1-4 m wide and 0.1-1 m deep at the head;
- *fontanili* of medium size (27% of the analysed cases): 4-15 m wide and 1-2 m deep at the head (Fig. 9);
- *fontanili* of large size (12% of the analysed cases): similar to small lakes, 30-150 m wide and 50-180 m long and with depths greater than 2 m at the head (Fig. 10).

The morphometric features of the emergences were compared (Fig. 11), and a linear correlation was found only between the water depth and the head length. Among the 51 fontanili, 10 lowland springs were chosen (Fig. 12), based on their accessibility and representativeness, to conduct a detailed geological survey; moreover these *fontanili* were also subjected to a monthly monitoring campaign over a one-year period (from June 2007 to June 2008) in which discharge measurements were recorded and water samples were collected for chemical analyses (Tab. 2).

3.2 The stratigraphic reconstruction of the Turin Po plain

To evaluate the local geological context that supports the origin of the examined fontanili, numerous stratigraphic logs were examined using the criteria reported in the recent geological literature (Barbero et al. 2007). In the examined area, the pre-Pliocene and Pliocene marine sediments form the basal sedimentary bodies. However they have not been observed in the used stratigraphic logs because typically covered by subsequent thick complexes. Locally, at the edge of the Turin Hill immediately to the East of the E-E' reported section, these sediments lie a few meters deep, covered by a recent thin body. The presence of these sediments in the immediate subsoil influences, as best seen later, the hydrogeological model. These sediments are characterized by a mainly silty and fine sandy texture linked to deep-sea and littoral environments, respectively.

The villafranchian succession (Middle and Lower Pleistocene) forms the prevalent body revealed by the logs. This complex is located at different depths in the southern and northern areas of the Turin Po Plain. This complex consists of deltaic and fluvial sediments formed by alternating silty-clayey and fine gravelly-sandy levels. Finally, the upper sedimentary body is variably thick and was formed by fluvial sediments (Middle Pleistocene-Holocene), showing a coarse gravelly-sandy texture with subordinate silty-clayey levels.

The lithostratigraphic reconstruction focused on the northern and the southern sectors of the Turin Po Plain, where the fontanili were located, using six geological cross-sections whose traces are shown in Figure 12. The lithostratigraphic features of these sample areas reflect the general context of the entire western Po Plain. In the <u>southern sector of the Turin Po Plain</u>, the cross-sections involve the Pellice River low plain (Upper Pleistocene-Holocene) with a constant and shallow slope (approximately 2‰).

In the A-A' cross-section (W-E trend; Fig. 13, top), alternating fine gravelly and silty levels lie at the bottom of the profile (observed thickness of 60-40 m) and are attributed to the deltaic and fluvial villafranchian sequence correlated to the area-type succession (located 25 km westward) of the Middle Pliocene and Lower Pleistocene ages. A coarse gravelly and sandy fluvial cover (60 m thick) overlies the villafranchian sequence, and its age has been dated to the Middle Pleistocene to Holocene periods. Gravel prevails in the western sector (upstream), whereas the eastern sector (downstream) is predominantly diffuse sand. The origin of the *fontanili* is therefore most prevalently connected to the change in permeability between the gravel and sand that form the proximal and the distal sectors of the plain, respectively.

The features of the B-B' cross-section (W-E trend; Fig. 13, bottom) are similar to those of the previous described in A-A'. Villafranchian fine sediments occur at the bottom, (observed thickness of 60-80 m), above which fluvial coarse gravelly sediments form a relatively homogeneous thick cover (60-70 m). The emergences are located where the water table intersects the topographic surface. Therefore, the origin of the *fontanili* is mainly linked to morphological causes.

In the C-C' cross-section (N-S trend; Fig. 14, top), the alternating gravelly and silty layers from the deltaic and fluvial villafranchian succession are also recognised at the bottom of the section (observed thickness of 50-90 m). Above this layer, a coarse gravelly fluvial body occurs (30-50 m thick) and is locally cut by shallow incisions and partially filled by sand that promotes the emergence of groundwater. The *fontanili* origin is, again, mainly associated with the morphology.

In the D-D' cross-section (N-S trend; Fig. 14, bottom), fluvial coarse gravelly sediments mainly occur (40-50 m thick) above the basal fine villafranchian succession reached by the boreholes (observed thickness of 30-50 m), and these layers are overlain by sandy deposits only in the northern side.

In the northern sector of the Turin Po Plain, the cross-sections shows the terraced Stura di Lanzo River fan and the Orco River fan (Middle-Upper Pleistocene). Both fans belong to the high plain with slopes greater than those in the southern sector (9-13‰) and local scarps. The E-E' cross-section (W-E trend; Fig. 15, top) shows the Stura di Lanzo River fan. The fine villafranchian succession sediments at the bottom are particularly thick (observed thickness of 200 m). To the west (San Maurizio Canavese sector), the sediments mainly consist of sandy levels, whereas in the eastward direction (Volpiano sector), these sediments are silty-clayey with thin sandy and gravelly layers. Overlying these deposits, the coarse gravelly fluvial sediments are relatively thin (20-25 m). These sediments show a significant dip towards the southeast, creating the *fontanili* origin conditions located at the base of the fluvial scarp (approximately 40 m high).

The F-F' cross-section (N-S trend; Fig. 15, bottom) shows the Orco River fan. To the north, the observed fine villafranchian succession is particularly thick (observed thickness of 50-150 m), and the coarse gravelly fluvial body overlies this structure (40-60 m thick). Towards the south, logs have been developed only in the superficial fluvial body (20-40 m thick). The *fontanili* are also of a morphological origin due to the presence of the fluvial scarp (approximately 40 m high) between the upper (Middle Pleistocene) and lower (Upper Pleistocene) terrace.

4. HYDROGEOLOGICAL AND HYDROCHEMICAL FEATURES OF THE FONTANILI

To better define the geological context of *fontanili*, certain significant parameters were described (Tab. 2). The altitude is prevalently comprised between 250 e 270 m. Only some *fontanili* of the northern sector occur at minor quote. They are hosted into fluvial, prevalently sand, gravel and gravelly-sandy deposits, referred to Upper Pleistocene-Holocene. Frequently these sources occur under fluvial erosional scarps (ID 1, 3, 4,6, 7, 10), 1-3 m high. Only in a case (ID 9) the erosional scarp is very high (40 m).

The main geometrical and hydrogeological features of the fontanili were also recorded (Tab. 3). The head shape is rounded, u-shaped or irregular. The depth of the water in the head is generally of a few meters. Also the channel width is relatively low. The flow direction is obviously towards E-SE, according to the slope of the plain.

4.1 Monthly flow rates

The 10 selected *fontanili* (Fig. 12, Tab. 2) were monitored on a monthly basis for a period of one year from June 2007 to June 2008. The *fontanili* can be divided into three groups according to their discharges (Fig 16). In the first group (*fontanili* 1, 3, 5 and 6), water is only present during June and July, and the discharge is relatively low (less than 4 l/s). *Fontanile* 3 is dry from February to April; when water is present, the discharge is low, ranging from 1 to 10 l/s. These *fontanili* are located in the southern sector of the Turin Po Plain. The second group (*fontanili* 8, 9 and 10) show high discharge levels with maximum rates varying from 50 to 80 l/s. These springs emerge in the northern sector of the Turin Po Plain. The third group (*fontanili* 2, 4 and 7) shows water discharge values that are intermediate between the previous groups. These *fontanili* are located in both the northern and southern sectors of the Turin Po Plain.

Generally, the maximum discharges occur in the summer period from June to September due to the spring rains and irrigation activities that induce water infiltration from the soil to the groundwater. The minimum values were observed in the winter, i.e., from January to March. Many *fontanili*, especially those located in the southern sector of the Turin Po Plain, show an absence of water discharge in autumn and winter due to a lack of rain and irrigation. These factors cause the groundwater level to fall, leading to an absence of water in the springs on the plain. In the northern sector of the Turin Po plain, the *fontanili* remained active throughout the year.

4.2 Temperatures

The temperatures of both the air and the *fontanili* water were measured during the monthly surveys. The water temperature remains nearly constant throughout the year (approximately 15°C), generally ranging within 10°C. The consistency of these values is attributed both to the high specific heat and the subterranean origin of the water, which is sheltered from external climatic variations. The highest water temperature values occur in the summer, reaching 17°C, and subsequently decrease in winter to approximately 8°C. The correlation of the water and air temperatures were performed at some *fontanili* 7, 9 and 10, where water is warmer than the air, in the winter, and is therefore particularly suitable for agricultural use (Fig. 17).

4.3 Hydrochemistry

The chemical composition of groundwater is driven by many factors, including the features of the precipitation, the lithology of the watersheds and aquifers, the geological processes within the aquifer along with influence of effluents from agricultural, industrial and domestic activities (Chebotarev, 1955; Hem 1959; Back and Hanshaw, 1965; Gibbs, 1970; Drever, 1988).

Each *fontanile* was sampled for physical-chemical analyses of the water, including measurements of the electrical conductivity, pH and principal ions (Ca^{++}, Mg^{++}, Na^{+}, K^{+}, Cl^{-}, HCO_3^{-}, $SO_4^{=}$ and NO_3^{-}). The electrical conductivity increases from north to south. In samples taken at Leinì (7 and 8), San Benigno Canavese (9) and Lusigliè (10), the values ranged between 100 and 300 µS/cm. These low values are indicative of a low concentration of dissolved salts due to the lithologic composition of the recharge area, the Ultrabasic Massif of Lanzo, which primarily consists of poorly soluble rocks such as peridotite and serpentinite. In the southern sector, the conductivity is significantly higher, ranging between 300 and 600 µS/cm.

In this case, the recharge area is represented by the Dora-Maira Massif and is characterised by rocks richer in calcium and relatively more soluble, such as gneiss and micaschists. The only exception was the sample taken from *fontanile* 6, at Cavour, which showed lower values of conductivity similar to those found in the northern sector.

The pH values were relatively consistent for all samples. The highest pH values occur in the southern sector of the plain, ranging between 7 and 7.8 in Vigone (2, 3, 4 and 5), whereas in the northern sector, the values vary between 6.2 and 6.9 in Leinì (7 and 8), San Benigno Canavese (9) and Lusigliè (10).

The groundwater from the sampled *fontanili* varied from very soft to medium hard. The total hardness increased from the north to the south, ranging from values of 5-13 °f at Leinì (7 and 8), San Benigno Canavese (9) and Lusigliè (10) to values of 22-28 °f at Cercenasco (1) and Vigone (2, 3, 4 and 5). The only exception was the sample from the area of Cavour (6), which presented values lower than at the other *fontanili* located in the southern sector of the plain. Calcium was most abundant in the *fontanili* of the southern sector, and the magnesium concentrations were higher in the waters of the northern sector due to the dissolution of ultrabasic rocks (peridotite). The sodium concentrations ranged between 2.5 and 8 mg/l. On average, the highest values were measured for the *fontanile* 7 “Sorgente Fassino” at Leinì, and the lowest value corresponded to the *fontanile* 9 “Il Fontanone” at San Benigno Canavese. The potassium concentrations were relatively low in all analysed samples, with values between 1 and 5 mg/l. An exception was the *fontanile* 6 “Cascina Mondina” at Cavour, which presented relatively high values of between 5 and 13 mg/l. The chloride concentrations ranged from 4 to 14 mg/l, with higher values for the *fontanili* of the southern sector (8-14 mg/l) and lower values for those of the northern section (4-8 mg/l).

In the northern sector, the analysed waters had bicarbonate concentrations between 40 and 130 mg/l, with the minimum value observed for the *fontanile* 10 “Lusigliè” and the maximum for the 9 “Il Fontanone”. Relatively higher concentrations were detected for the waters of the *fontanili* of the southern sector, such *fontanile* 2 “Biarone” at Vigone, with values generally between 100 and 320 mg/l.

Sulphate levels were fairly consistent throughout the studied area, with concentrations ranging from 3 to 24 mg/l. All of the sulphate values were well below the permissible limits of 250 mg/l for drinking water as for Italian law (Repubblica Italiana 2001).

The nitrate concentrations were uniform throughout the study area, generally ranging between 10 and 30 mg/l, with a maximum of approximately 40 mg/l for fontanile 1 “Mutunè” at Cercenasco. Nitrate levels remained below the threshold of 50 mg/l imposed by italian law (Repubblica Italiana 2001). In this area, synthetic nitrogenous fertilizers and organic manure are used for agricultural purposes and it results in a diffuse pollution by nitrate compounds in groundwater (Lasagna 2006; Lasagna and De Luca 2008; Lasagna et al. 2013). An isotopic study on groundwater in the Poirino Plateaux, in the south-eastern sector of the Turin Po Plain, was performed using nitrogen and oxygen isotopes to explain the origin of nitrate contamination and to identify and quantify the denitrification phenomenon. As result, nitrate in groundwater was interpreted as the associated input of synthetic fertilisers and manure or septic tank effluents. Furthermore, a significant denitrification phenomenon was assessed, with a percentage of denitrified nitrate up to 45%, compared to the initial concentration (Lasagna et al. 2006; Debernardi et al. 2008). Nitrates and chlorides show a quite direct relationship (on average, the level of nitrates is approximately twice that of the chlorides in mg per litre) (Fig. 18) indicative of a probable agricultural origin also for the chlorides in the waters of the sampled *fontanili*.

The Piper diagram for the samples from June 2007 (Fig. 19) indicates a calcium and magnesium-bicarbonate composition for the *fontanili* waters.

Unlike the Piper diagram, the Schoeller diagram permits the comparison of different waters by maintaining the absolute values of individual ions in meq/l; the shape of the broken lines represents the hydrochemical composition of a sample (Fig. 20). From the graph obtained by the samples of June 2007, two facies can be distinguished. They reflect a difference in chemical composition between the waters of the northern sector (with higher concentrations of magnesium, probably derived from ultrabasic rocks of the

Ultramaphic Lanzo Massif) and those of the southern sector (with higher levels of calcium and carbonates due to the dissolution of rocks rich in these ions).

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5. DISCUSSION AND CONCLUSIONS

This research focused on springs known as *fontanili* that occur in the northwestern Po Plain. An analysis of their spatial distribution in the Turin Po Plain, their features, the state of preservation and the genesis is reported. The study highlighted the causes of their emergences and identified a decline in their number. In general, the origin of the Turin Po Plain *fontanili* is the result of different, often concomitant, causes:

• topography: the decrease of the topographical surface and the rise of the groundwater table cause the water to come to the surface;

• hydrogeology: the hydrogeological setting, i.e. certain *fontanili* emerge when groundwater flowing in coarse deposits meets fine-grained materials (silts and clays);

• geology: the presence of an underground barrier related to the impermeable marine succession;

• human activities: the water table may be locally intercepted by excavations of considerable depth.

In details, the analysis of the geological, hydrogeological and litostratigraphical context of reported *fontanili* indicated a different setting between the southern and northern sectors, and consequently a different prevalent reason of their emergence. The southern *fontanili* group is set in a distal plain formed by sandy and gravelly fluvial sediments (Upper Pleistocene-Holocene). In this area, the emergences, which are located at the boundary between the gravel and sand, essentially occur due to a change in the permeability of the sediments and are only locally attributed to the morphological features (Fig. 21).

The northern *fontanili* group is located in the proximal plain where terraced fans occur and consists of fluvial coarse gravelly sediments (Middle-Upper Pleistocene). These emergences, located at the base of the main scarps, are mainly due to the abrupt change in slope of the surface. Furthermore in this sector of the plain, near the deep extension of the Turin Hill, the presence of marine fine sediments in the subsoil probably favours the rise of the water (Fig. 22).

The graph obtained for the samples of June 2007 indicates two main compositions and reflects a difference in the chemical compositions between the waters of the northern sector (with higher concentrations of magnesium, most likely derived from the rocks of the Ultramaphic Lanzo Massif) and those of the southern sector (with higher levels of calcium and carbonates due

Moreover, the study showed that the *fontanili* present a steady decline in number and a progressive deterioration in their environmental quality over the last several decades.

Although the *fontanili* are drastically decreased in number, and in many cases, have lost their previous function, they remain a naturalistic, landscape and cultural site typical of many zones of the Po Plain. Their recovery and valuation must be a priority for present and successive generations to ensure the continuity of such a rare and particular phenomenon typical of the Po Plain.

We owe much of the development and economic growth of the agricultural populations to the existence of *fontanili*. In the past, the population had better knowledge of how to use the specific properties of the *fontanili* and reached a remarkable balance between the ability to take advantage of these springs and to protect their naturalistic and environmental features.

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FIGURES

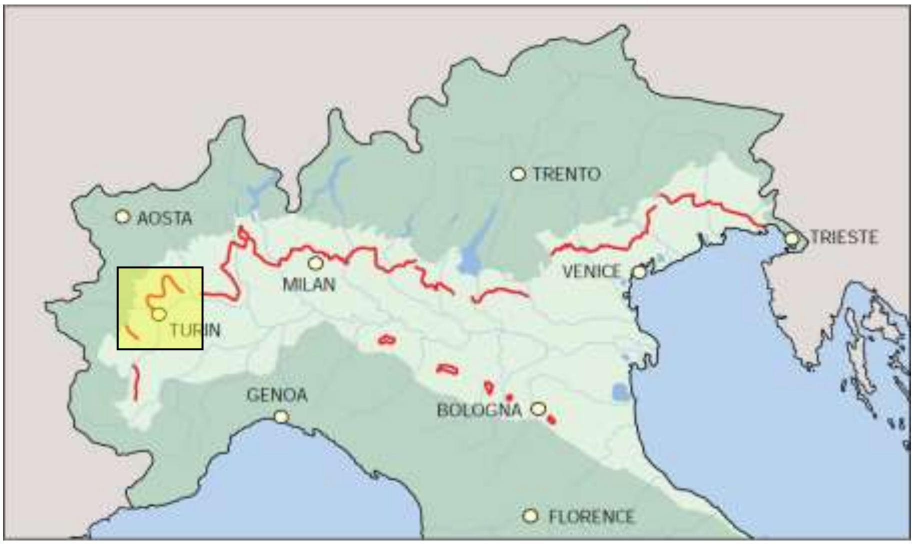

Figure 1 - The *fontanili* line along the Po Plain and Venetian Plain (pale green colour). The square highlights the studied Turin Po Plain (modified from Minelli et al. 2002).

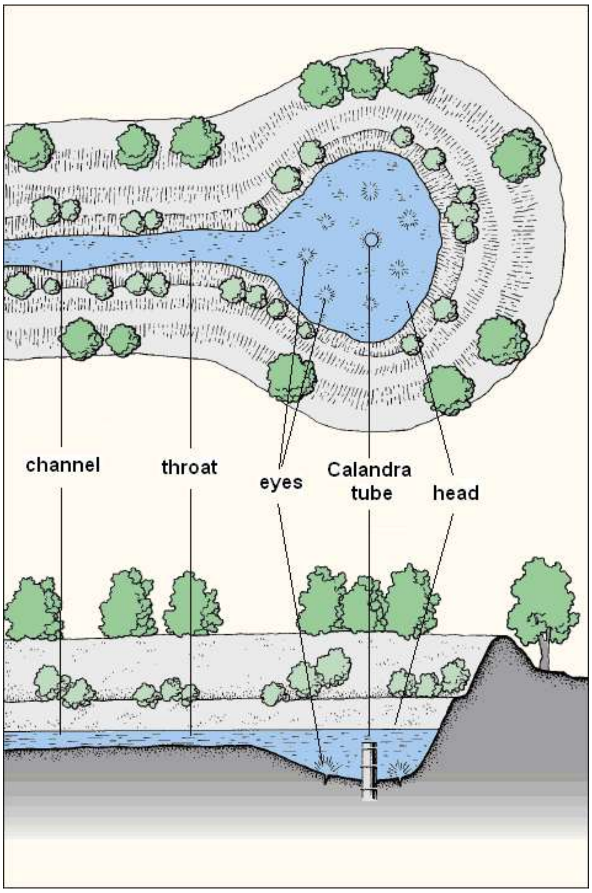

Figure 2 - A *fontanile* in plain view and in cross-section (modified from Minelli et al. 2002).

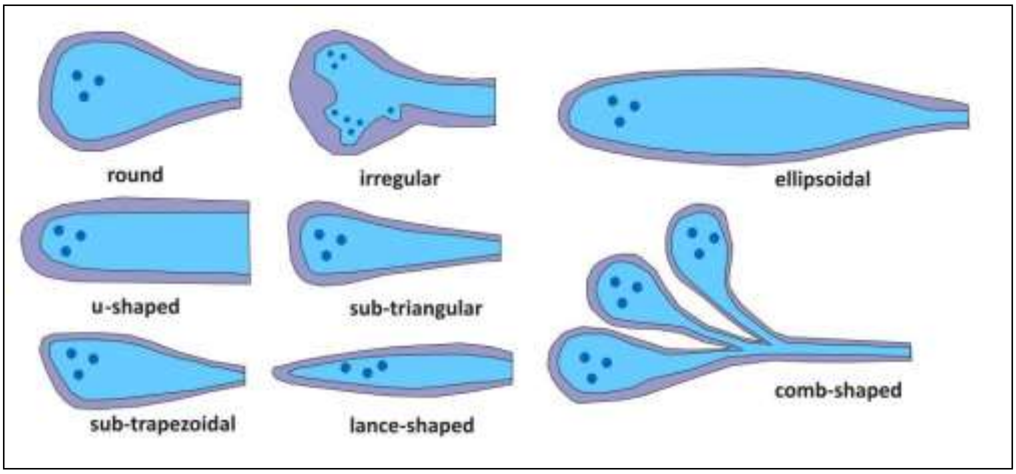

Figure 3 - Different shapes of *fontanile* heads (modified from Moro 1924).

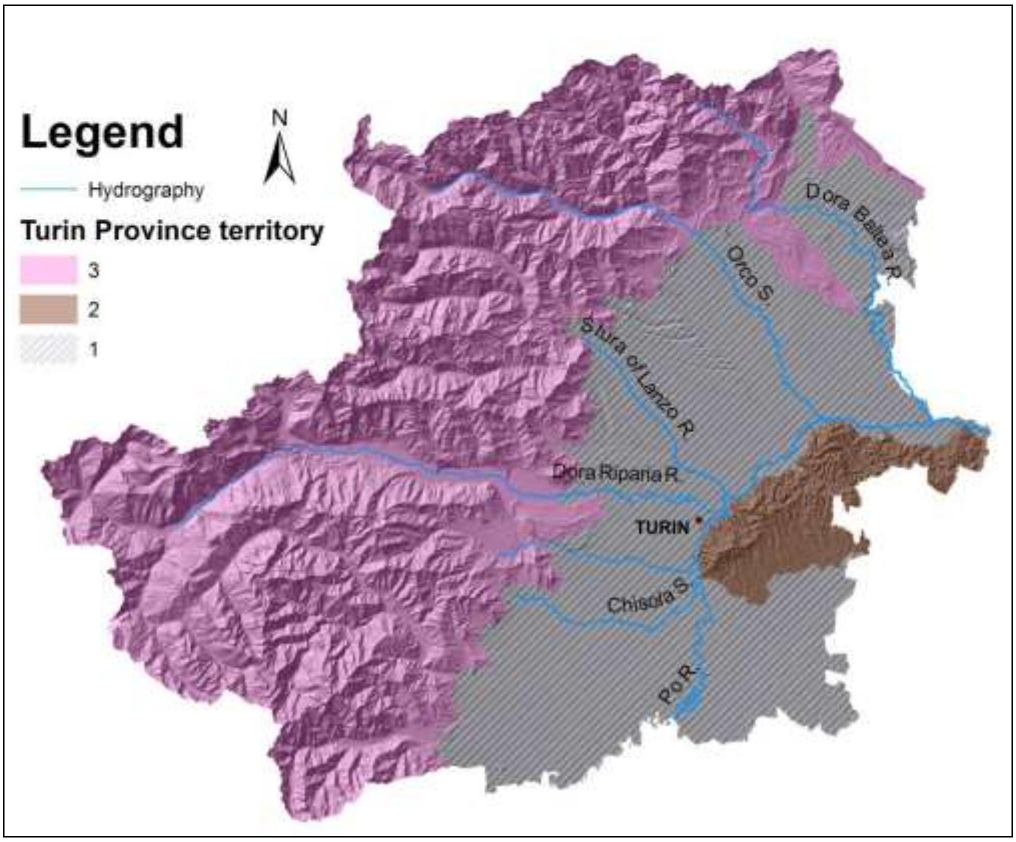

Figure 4 - The Turin Province territory. The Turin Po Plain (1), consisting of fluvial sediments, is interposed between the Turin Hill (2) and the Alps (3), which are formed by sedimentary and metamorphic rocks, respectively.

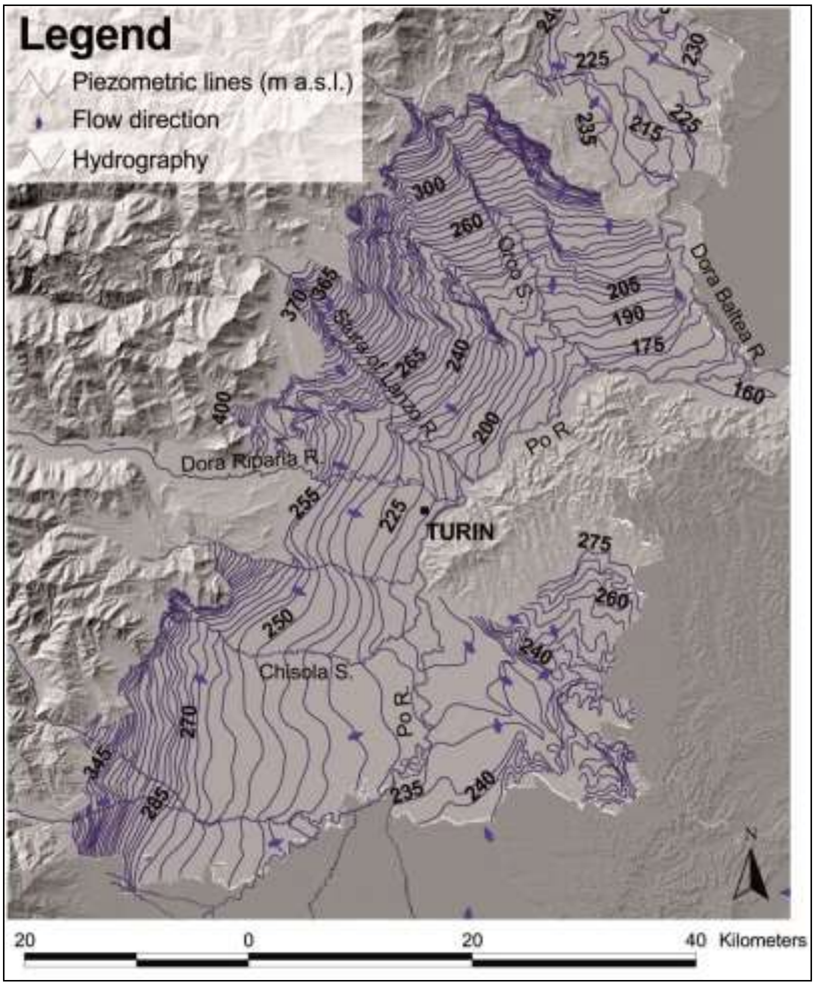

Figure 5 - Piezometric surface of the Turin Po Plain shallow aquifer (June-July 2002).

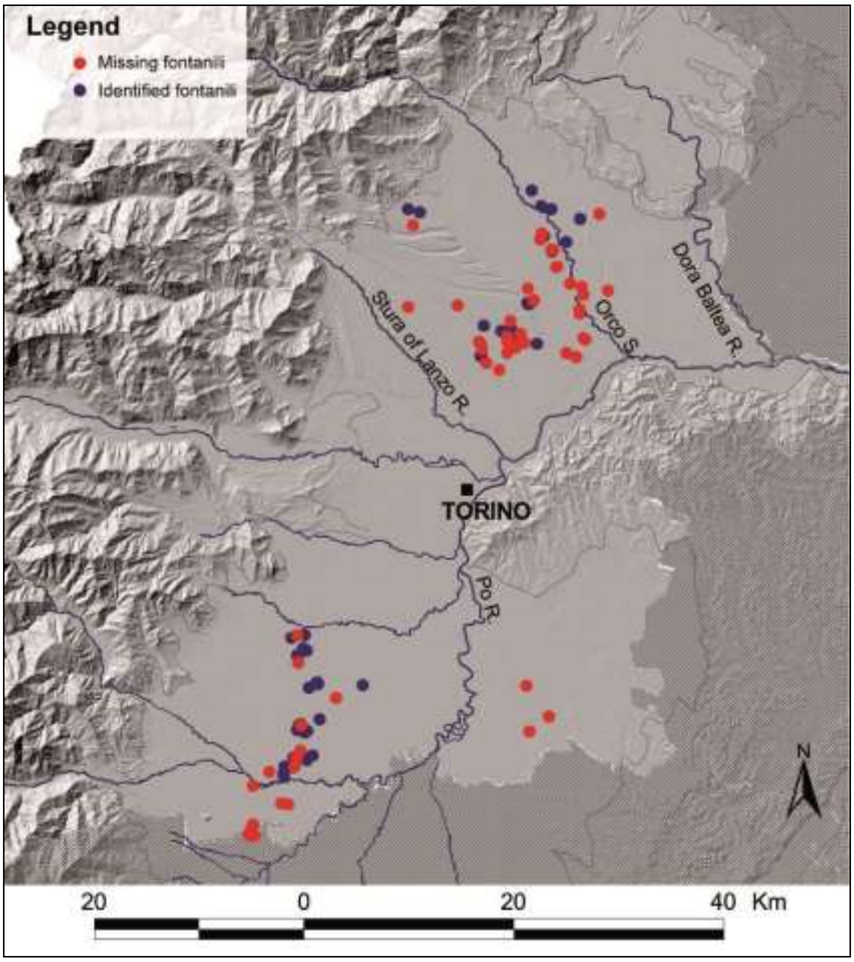

Figure 6 - Location of the *fontanili* within the Turin Po Plain as reported in the previous geological maps (missing *fontanili*) and as noted by the survey (identified *fontanili*, Summer 2007).

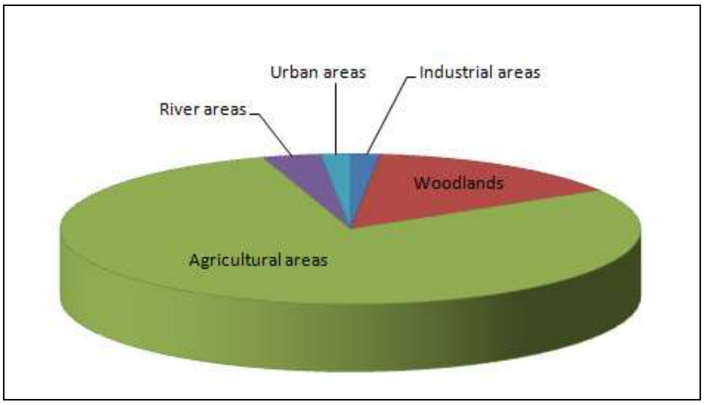

Figure 7 - Locations of the missing *fontanili*, prevalently in current agricultural areas.

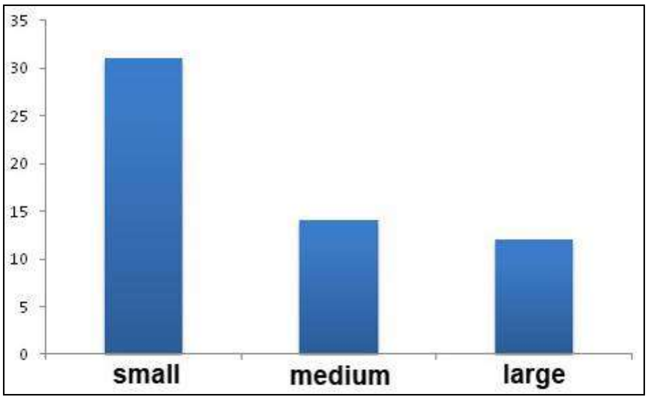

Figure 8 - Classification of the 51 identified *fontanili* according to their width (m).

Figure 9 – Example of the channel (a) and the head (b) of a medium size *fontanile* (“*Il Fontanone*”).

Figure 10 - Example of the head (turned into a small lake and used for fishing, a) and the channel (b) of a large size *fontanile* (*"Lusigliè"*).

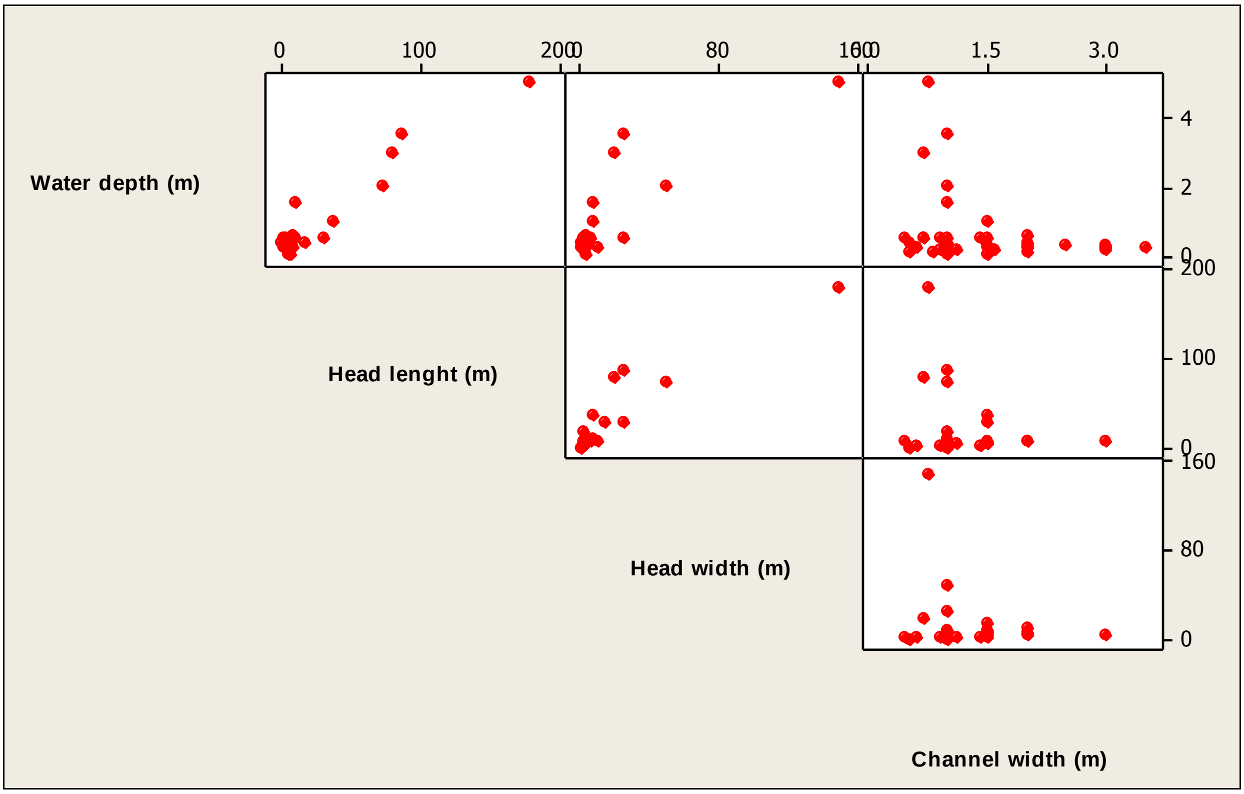

Figure 11 - Relationships between the morphometric parameters of the *fontanili*.

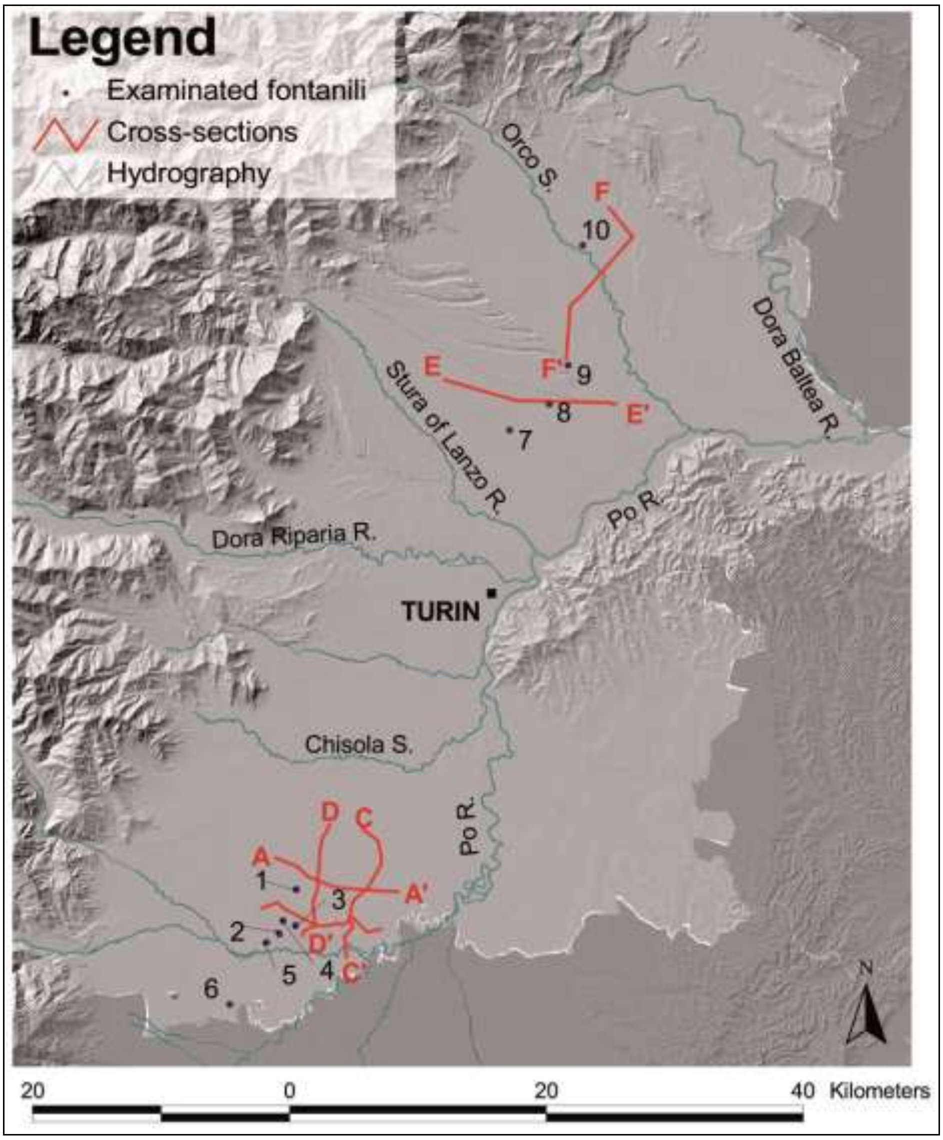

Figure 12 - Location of the 10 examined *fontanili* in the Turin Po Plain and traces of the geological cross-sections of Figs. 13, 14 and 15.

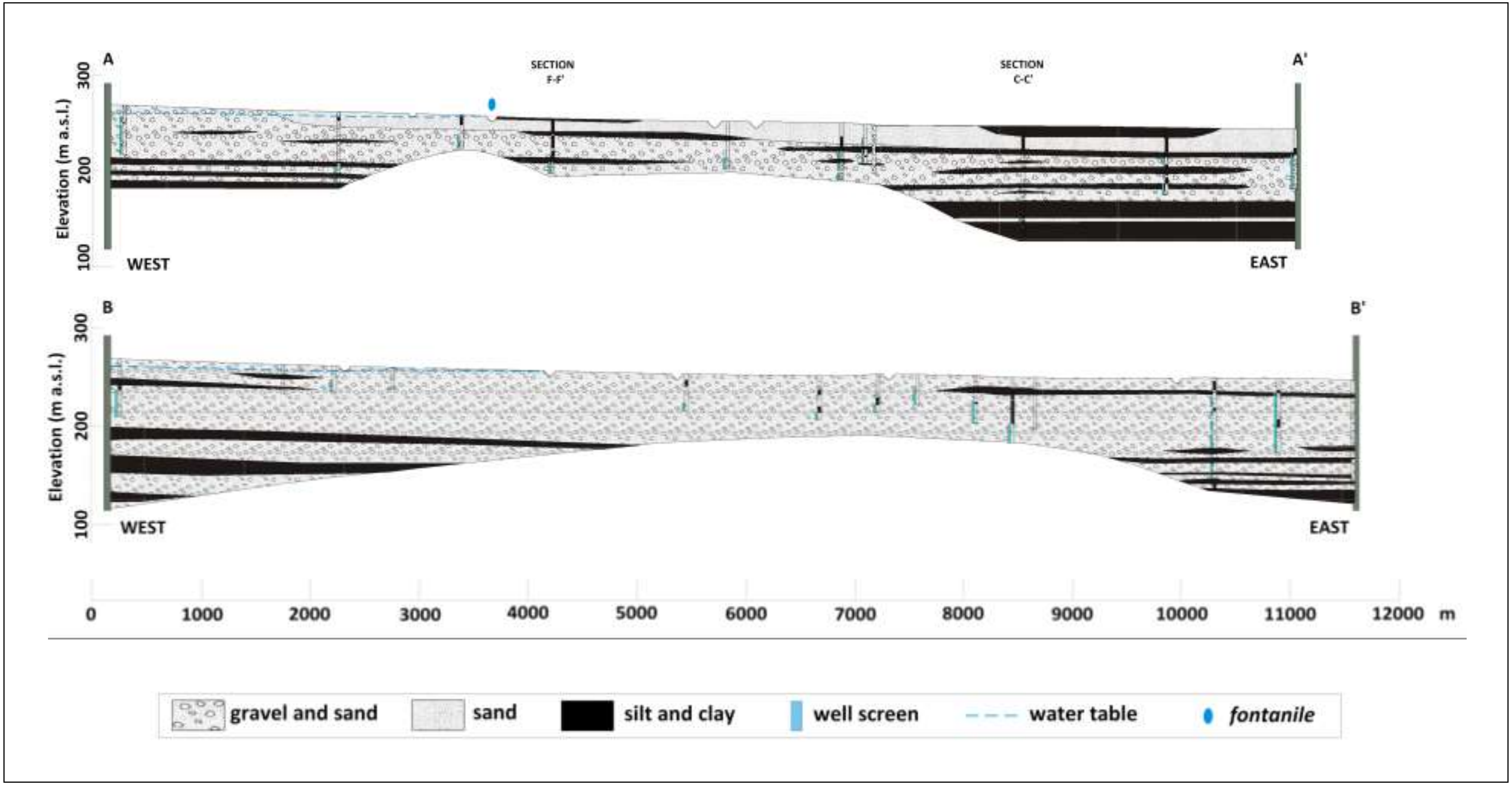

Figure 13 – A-A’ (at the top) and B-B’ (at the bottom) cross-sections.

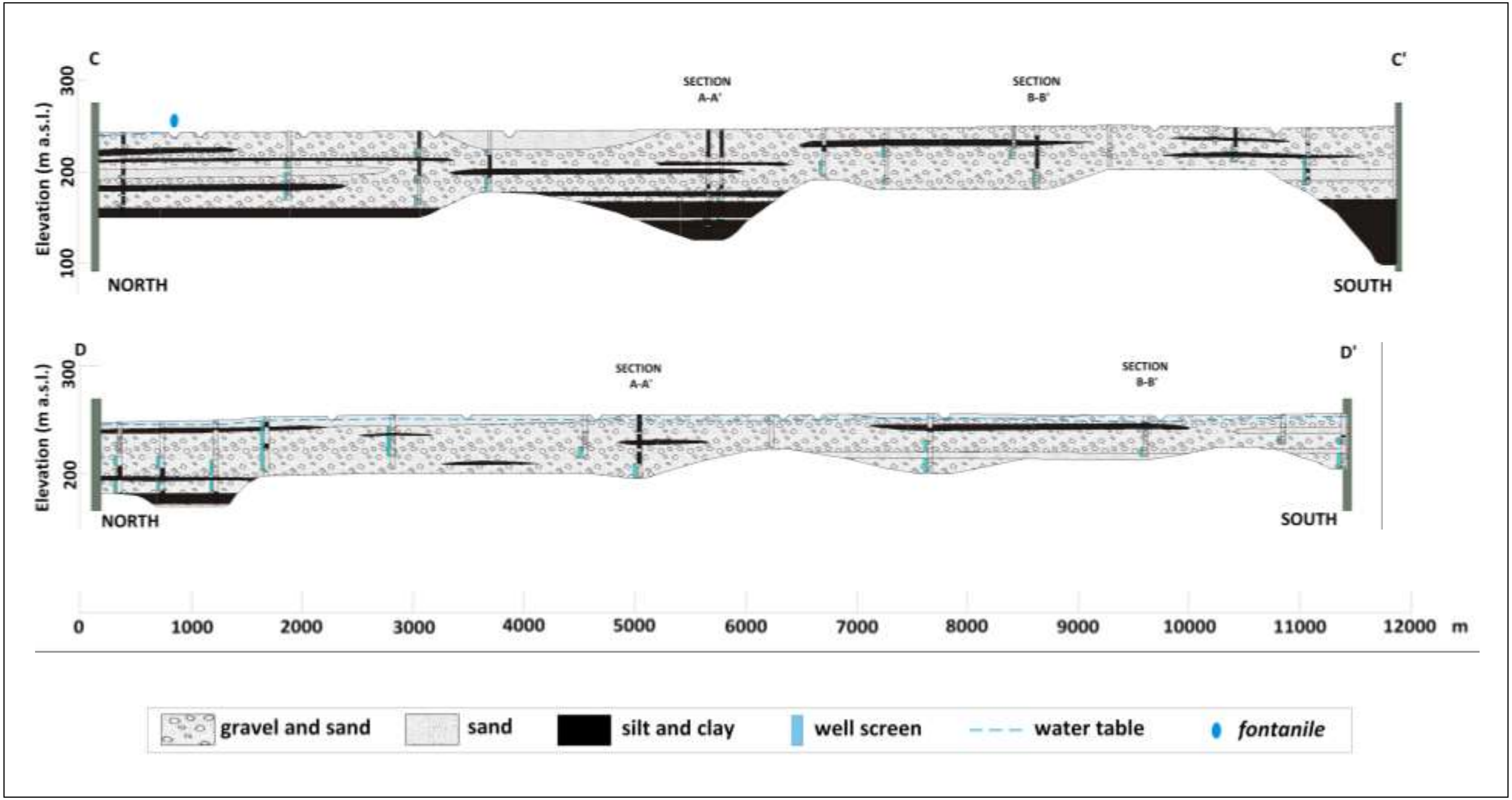

Figure 14 – C-C' (at the top) and D-D' (at the bottom) cross-sections.

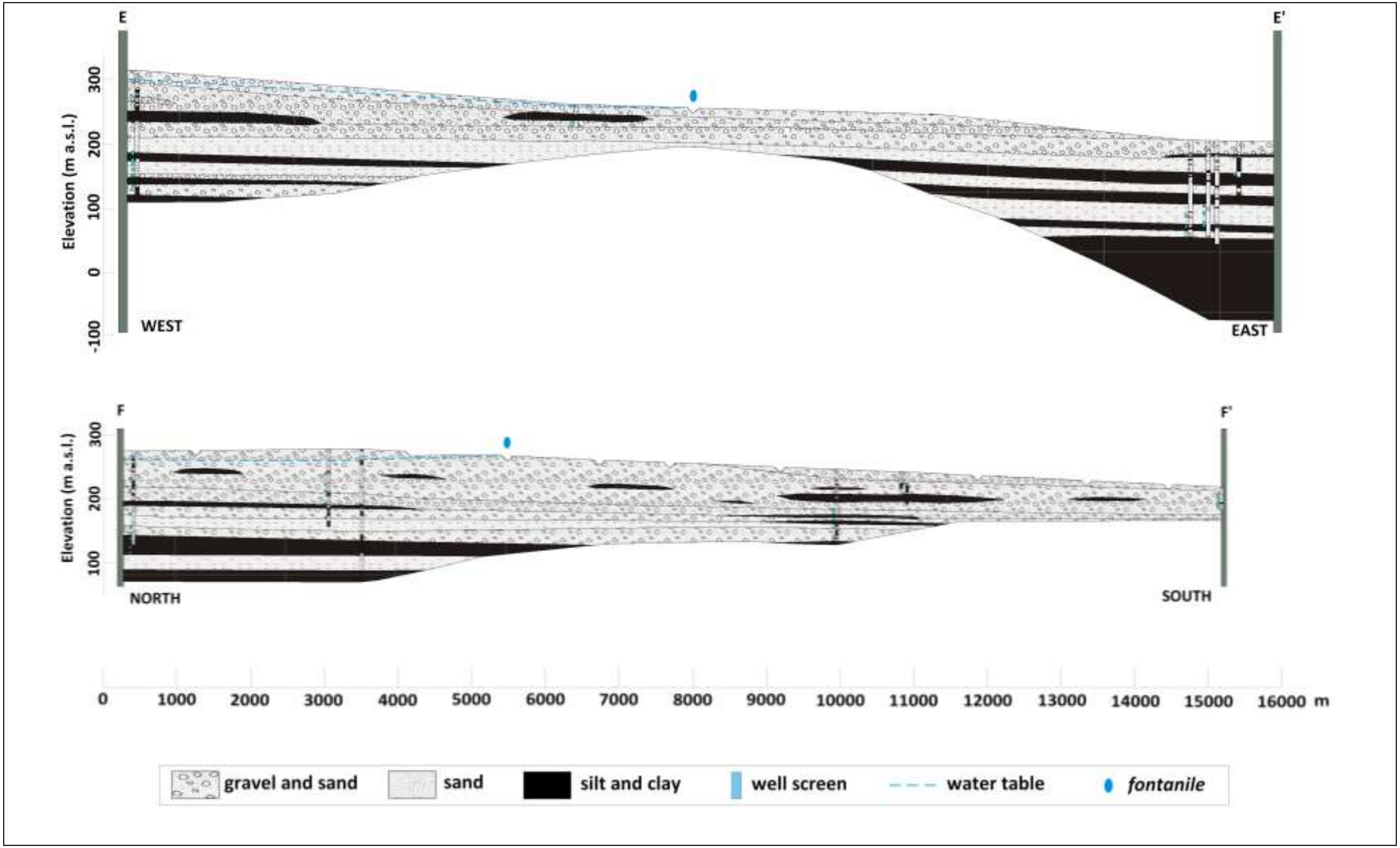

Figure 15 – E-E' (at the top) and F-F' (at the bottom) cross-sections.

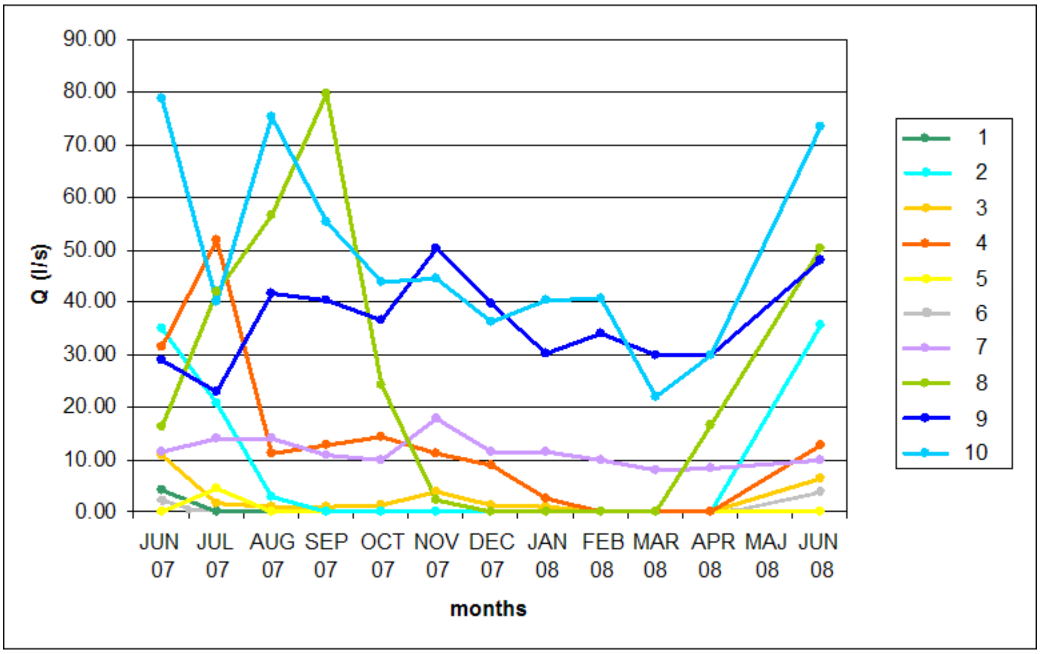

Figure 16 - Discharge of the 10 selected *fontanili* monitored on a monthly basis from June 2007 to June 2008

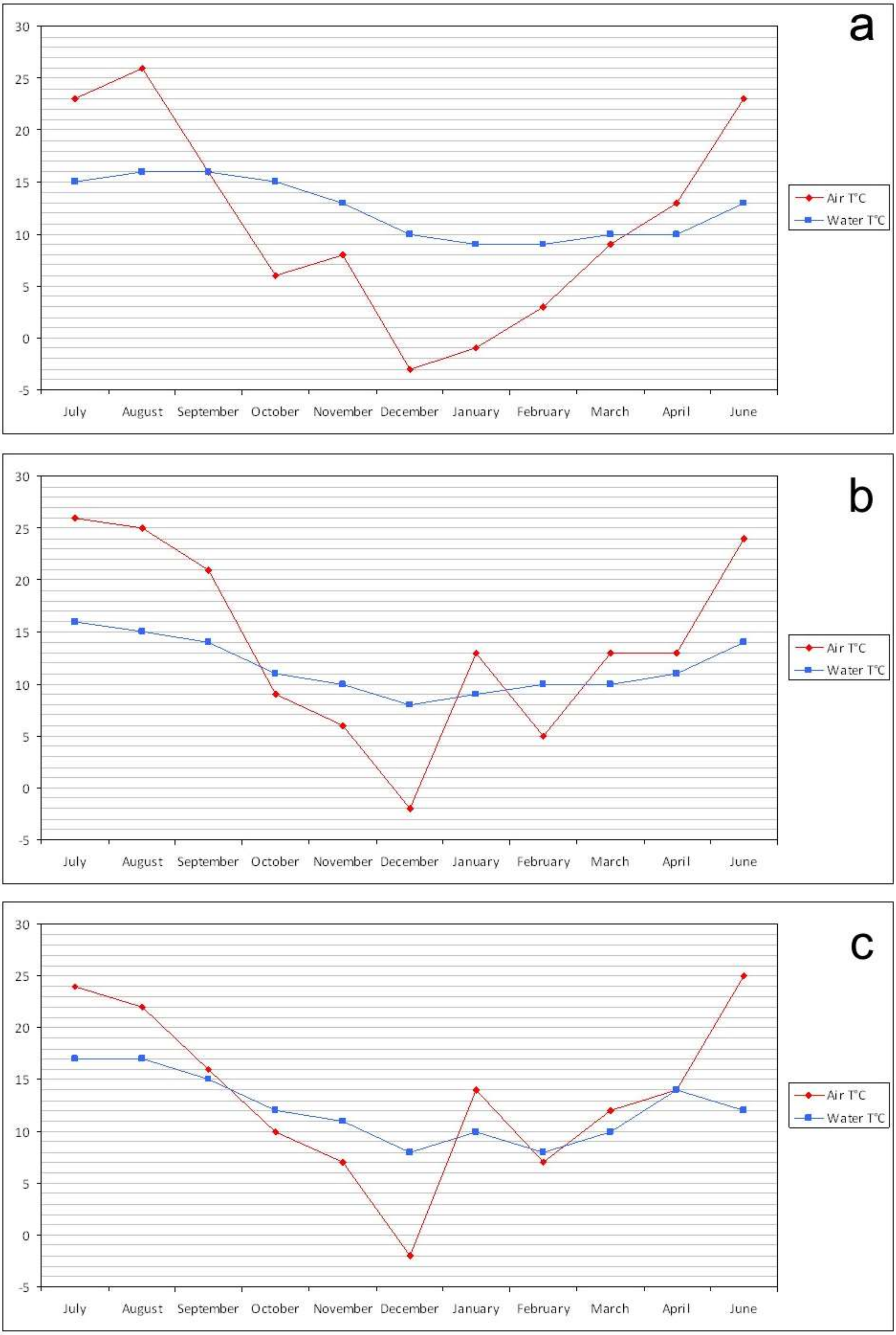

Figure 17 - Air and water temperatures at the *fontanili* 7 *Sorgente Fassino* (a), 9 *Il Fontanone* (b) and 10 *Lusigliè* (c).

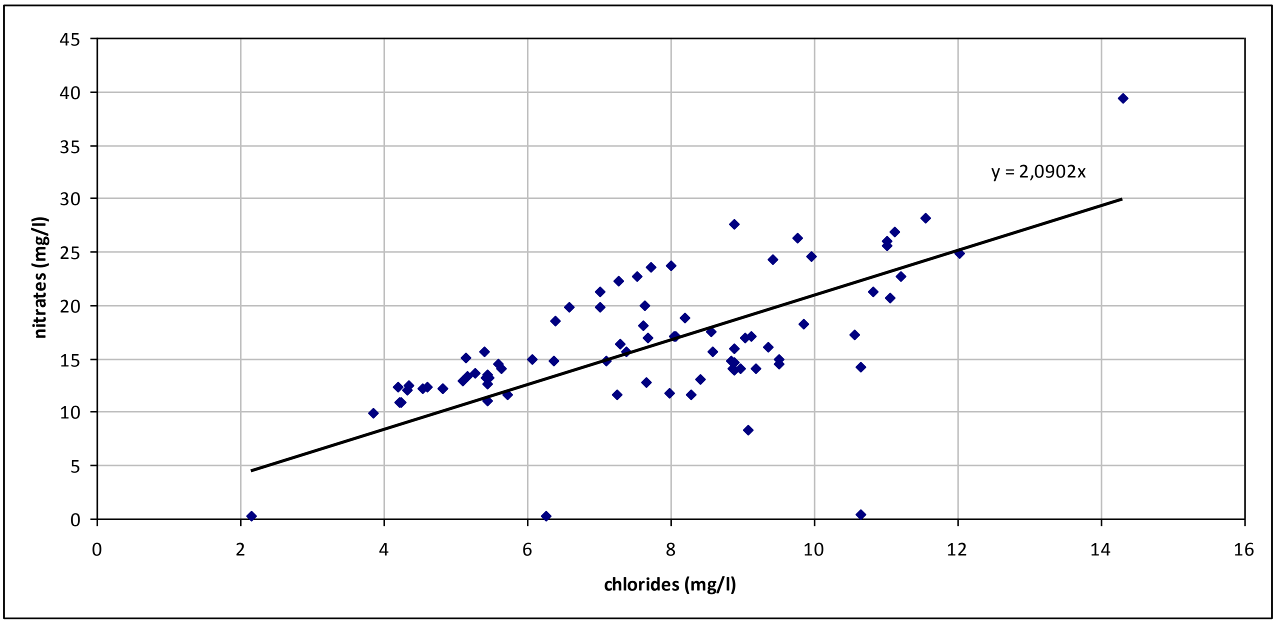

Fig. 18 - Relationship between the concentrations of nitrates and chlorides in the water of the sampled *fontanili*.

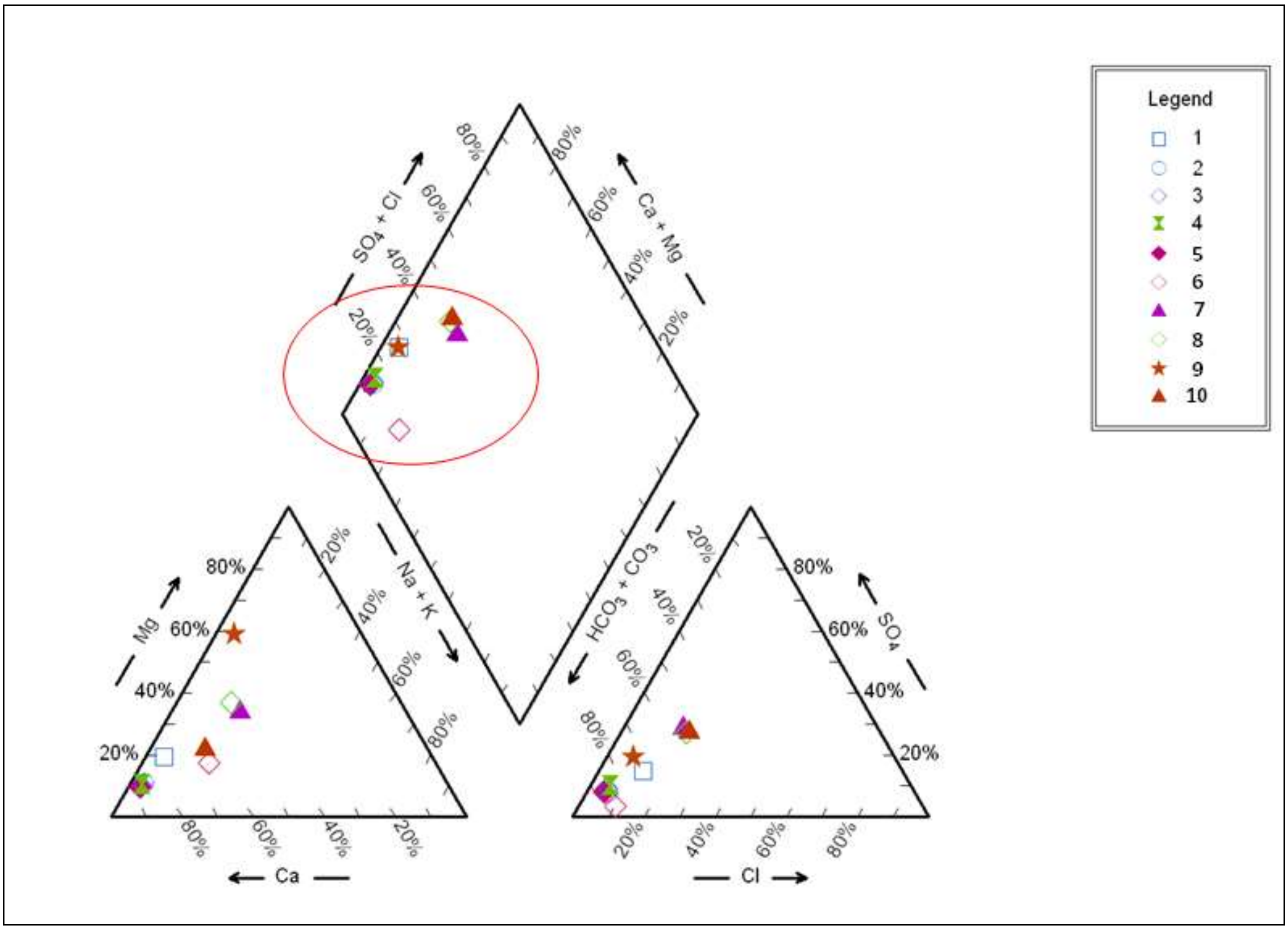

Fig. 19 - Piper diagram for the water of the sampled *fontanili*.

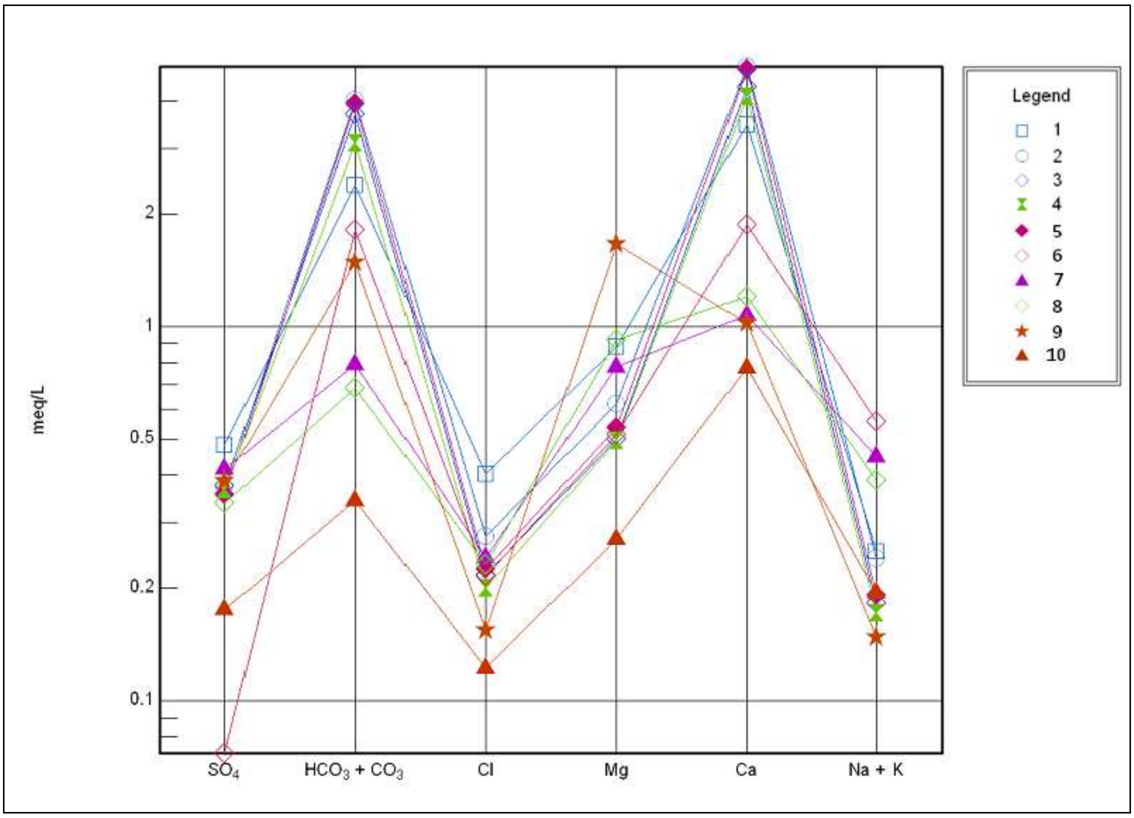

Figure 20 - Schoeller diagram for the water of the sampled *fontanili*.

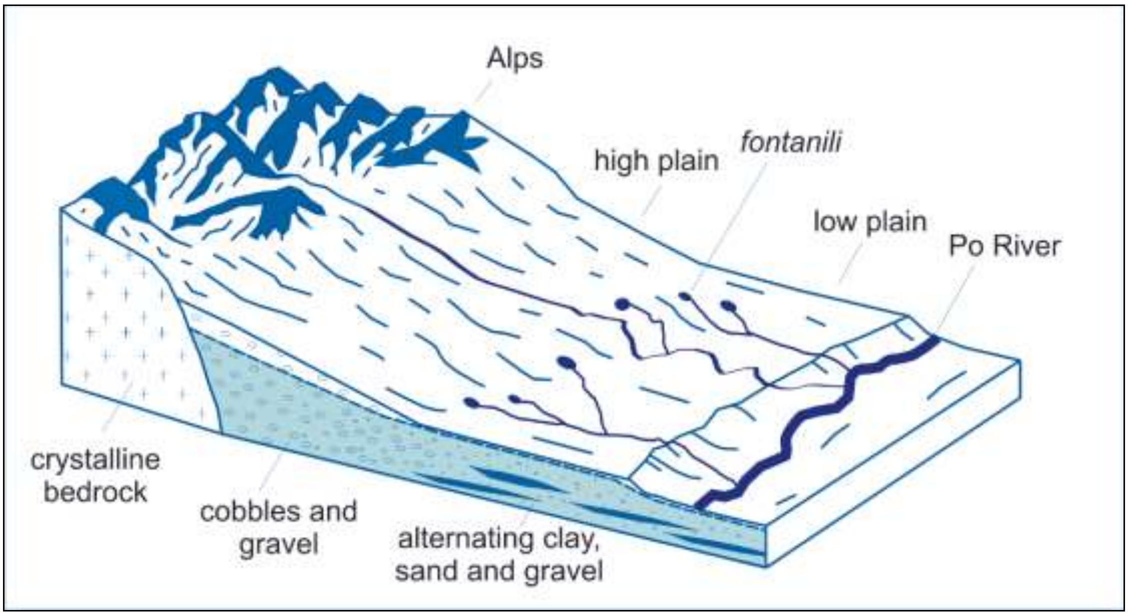

Figure 21 - In the southern sector of the Turin Po Plain groundwater rises due to a change of the sediment permeability.

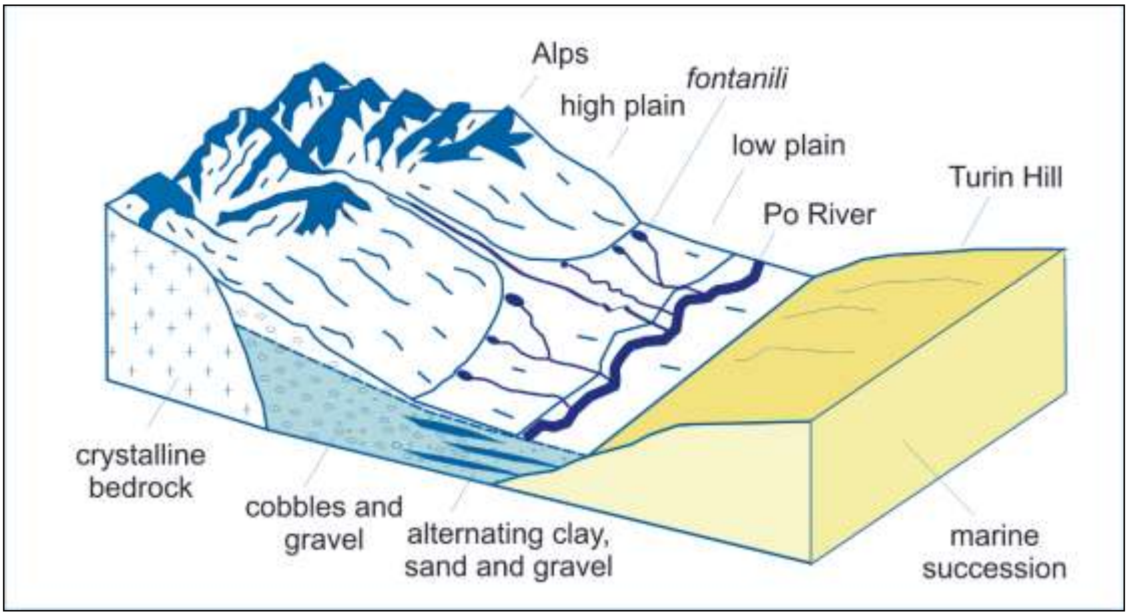

Figure 22 - In the northern sector of the Turin Po Plain, *fontanili* are mainly due to the abrupt change in slope of the topographical surface and to the presence of the impermeable marine succession in the subsoil.

TABLES

Table 1 - Morphometric parameters of the 51 identified *fontanili*.

Values (m)	Water depth	Head length	Head width	Channel width
Minimum	0.05	0.70	0.60	0.40
Average	0.62	24.17	13.69	1.41
Maximum	5.00	180.00	150.00	3.50

Table 2 - Geographical, geological and geo-morphological features of the ten examined *fontanili*.

ID	Name	UTM X	UTM Y	Municipality	Sector of Turin Po Plain	Altitude (m a.s.l.)	Texture of deposits	Genesis of deposits	Age of deposits	Height of the scarp (m)
1	Mutunè	381061	4968257	Cercenasco	southern	257	sand	fluvial	Holocene	1-2
2	Biarone	379744	4964796	Vigone	southern	260	gravel with a sand cover	fluvial	Holocene	-
3	Ulè	380984	4965449	Vigone	southern	253	silty sand	fluvial	Holocene	1-3
4	S. Maria	380028	4965816	Vigone	southern	260	gravelly sand	fluvial	Holocene	1-2
5	Le Vasche	378747	4964149	Vigone	southern	264	gravel with a gravelly sand cover	fluvial	Holocene	-
6	Cascina Mondina	375890	4959312	Cavour	southern	268	gravelly sand	fluvial	Holocene	2-3
7	Fassino	397655	5003971	Leinì	northern	256	sandy gravel	fluvial	Upper Pleistocene	2-3

8	Cascina Cesali	400755	5005997	Leinì	northern	238	gravelly sand	fluvial	Upper Pleistocene	-
9	Il Fontanone	402226	5009011	S. Benigno Canavese	northern	216	gravel	fluvial	Upper Pleistocene	40
10	Lusigliè	403359	5018364	Lusigliè	northern	256	gravel	fluvial	Holocene	1-2

Table 3 - Morphological, morphometric and main hydrogeological features of the ten examined *fontanili*.

ID	**Head shape**	**Head width (m)**	**Head length (m)**	**Water depth (m)**	**Channel width (m)**	**Groundwater flow direction**	**Hydraulic gradient**
1	round	3	5	1.5	1.5	E-SE	0.0023
2	irregular	2.1	4	2.5	1.5	E-SE	0.0031
3	multi-head / irregular	1-2.5	10-17	0.5	1	E-SE	0.0029
4	u-shaped	/	/	2	1	E	0.0037
5	round	4.5	7	5	3	E-SE	0.0031
6	multi-head / u-shaped	/	/	2	2.7	SE	0.0030
7	u-shaped	/	/	0.7	1.1	SE	0.0067
8	u-shaped	/	/	5	1.5	E-SE	0.0080
9	ellipsoidal	10	85	1	2	E	0.0055
10	round	25	87	1	1	S	0.0140