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The groundwater flow system of Terme Alte (Alto Reno Terme, Bologna, Italy).

Il sistema di circolazione idrica sotterranea delle Terme Alte di Porretta (Alto Reno Terme – Bologna, Italia).

Alessandro Gargini, Alessandro Stefani, Stefano Vannini

Riassunto: : Il giacimento termominerale di Porretta Terme nel Comune di Alto Reno Terme (BO) ha destato interesse per le peculiarità delle sue acque fin dai tempi antichi. Infatti è documentato l'utilizzo delle sorgenti fin dal I-II secolo d.C. e forse anche in epoca Etrusca. La tradizione termale di Porretta si è sviluppata nel corso dei secoli, regolamentata dal 1936 con la concessione di coltivazione del giacimento minerario e dei suoi gas naturali in un territorio dell'estensione di 300 ettari. Le acque termali, bene pubblico, sono infatti regolate da una serie di norme specifiche che governano il loro utilizzo tramite una concessione dove l'Ente Pubblico impegna il concessionario, di solito privato, ad una serie di adempimenti atti a non deteriorarne le caratteristiche quantitative e qualitative (R.D. 29 luglio 1927 n. 1443). Attualmente sono gestite 14 sorgenti termominerali (delle 19 ubicate nel territorio dato in concessione) appartenenti a due gruppi le cui acque si differenziano sia per le diverse caratteristiche composizionali sia per la loro dislocazione topografica. Un primo gruppo di sorgenti (denominate salsobromoiodiche), a più elevata salinità e temperatura, è situato nella parte alta dell'abitato di Porretta lungo il Rio Maggiore affluente sulla sinistra idrografica del fiume Reno. È questa la porzione di giacimento che è stata oggetto degli studi. Un secondo gruppo, sorgenti sulfuree caratterizzate da più bassa temperatura ed a bassa salinità, si trovano a sud est dell'abitato in sinistra Reno. Il patrimonio idrico associato appare di grande valore e merita un'attenzione ed una tutela particolari. Avvalendosi dei risultati delle passate ricerche, la cui bibliografia essenziale è stata curata in calce, si è inteso sviluppare la parametrizzazione idrogeologica dell'acquifero che alimenta le sorgenti termominerali, individuare e comprendere il modello concettuale del sistema di circolazione idrica sotterranea, rilevando anche le interferenze tra le diverse sorgenti presenti nella zona esaminata. Nello studio viene presentata una applicazione ad un acquifero termale di un approccio di parametrizzazione idrodinamica solitamente impiegato per sfruttamento di falde di acque fredde. Notevole è stata anche la raccolta di dati osservazionali sul regime idrologico e sulla composizione chimica delle acque calde rilevati durante i sei mesi di rilievi sul campo che hanno confermato la sostanziale costanza dei valori nel tempo.

Keywords: *Porretta Terme, hydrogeology, thermal water, hydrodynamic parametrization, aquifer.*

Parole chiave: Porretta Terme, idrogeologia , acque termali, parametrizzazione idrodinamica , acquifero.

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Abstract: *The thermal field of Porretta Terme, located in the Alto Reno Terme municipality (Bologna), has always raised interest for its peculiar waters since ancient times. Indeed, the use of the springs dates back to the I-II century A.D. and perhaps even in the Etruscan period. Porretta's thermal tradition has developed over the centuries. First regulation, issued in 1936, allowed to cultivate the mineral deposit and its natural gas in a 740 000 acres wide land. The thermal waters, a public good, are indeed ruled by specific laws which control their use through a grant where the Public Authority makes the licensee, usually a private, follow a series of accomplishments aimed at not damaging the quantitative and qualitative characteristics (R.D. July 29, 1927 n. 1443). Fourteen thermo-mineral springs out of the nineteen located in the given land are currently exploited. They are divided into two groups, which differentiate either for the chemical properties of the waters and their topographic location. The first group of springs, called salt-bromoiodic, with higher salinity and temperature, is located in the upper part of Porretta along the Rio Maggiore, a tributary on the left bank of the Reno River. This is the portion of the deposit that has been studied. The second group of springs, called sulphurous, characterized by lower temperatures and salinity, is located south-east Porretta on the left side of the Reno River. These thermo-mineral water resources appear to be very worthy and need particular care and protection. By using the results of past research, the essential bibliography of which has been edited in the end-notes, the aim was to develop the hydrogeological parameters of the aquifer that feeds the thermo-mineral sources, identify and understand the conceptual model of the groundwater circulation system, also detecting the interference between the different sources in the area examined. This type of research, which is usually applied to aquifers in sedimentary and granular soils, can be considered original. Indeed, an exhaustive hydrodynamic parameterization of a fractured thermal aquifer system such as that of Porretta has never been conducted. The collection of observational data on the hydrological regime and on the chemical composition of hot waters during the six months of field surveys, which confirmed the substantial constancy of the values over time, was also remarkable.*

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Introduction

The Terme Alte's thermal-mineral spring system, in the high valley of the Reno River (Tuscan-Emilian Apennines) has a history of anthropic use more than a thousand years old that has its roots in pre-Roman times. The peculiar arenitic geological hydro-structure at the origin of the water emergence is complex and spatially localized in an engraved riverbed of the Rio Maggiore, a tributary of the Reno River. The several interventions to use the hot-water springs have turned the natural discharge into a sort of field of hot-water wells, where the pumping-caused flow rates are prevalent in comparison with the rest of the undrained water surfacing. This aspect makes the approach of the hydrogeological characterization of the thermal system peculiar, which is essential for the verification of the sustainability of the exploitation. This paper describes the thermal system by highlighting for the first time the hydro-geological features and those of hydrodynamic parameterization of the aquifer.

The discharge of Terme Alte

The Terme Alte spring system is located in the municipality of Alto Reno Terme, near the town of Porretta, 350 meters above sea level and north the Apennine crest. This town is situated along a historic trans-Apennine route, which connected Bologna and Pistoia. Porretta developed in the valley floor where the Rio Maggiore stream flows into the Reno River. The old town centre is located exactly along the stream's bed and unfolds towards the flood plains of the Reno River, hence the name of Porretta, or in ancient words 'porrectus', comes from the Latin 'porrigere' which means an extended development along the waterway. The thermal emergencies are located in the sub-bed of the Rio Maggiore inside a deeply engraved valley (Fig. 1). They are part of a mineral deposit of thermal waters and natural gas given in concession.

As it can be seen from the geological map of the area (Fig. 2), outcropping clayey units prevail (pre-Campanian argillites with intermingled blocks of limestones, AVC); the "Terme Alte" thermal discharge is related to the outcrop of a turbiditic arenaceous pelitic unit represented by the "Arenarie di Suviana" (SUV), of Miocenic Age, commonly known as "Arenarie di Porretta", belonging to the to the Modino-Cervarola tectonic unit. SUV is completely embedded inside the clayey complex but it still maintains the primary structural "Apenninic" alignment (NNW-SSE).

SUV represents the local aquifer from which the thermal system emerges. It comes to light in vertical layers, consisting of alternance of arenitic siliciclastic layers (more than 2 m thick) and pelites (0.1 m thick); arenites are composed by poorly-sorted medium grain cemented sandy fragments. The silt-sandstone ratio is 4 to 1 and is observed to be almost constant.

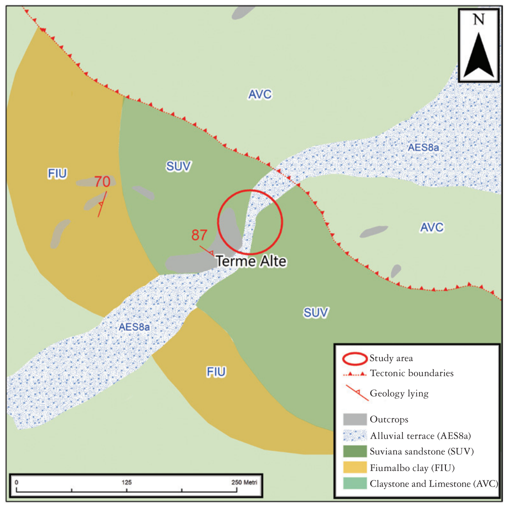

Fig. 2 - Schematic geological map of the research area where the main rock units are found.

Fig. 2 - Carta geologica schematica dell'area di studio in cui si rinvengono le principali unità litologiche.

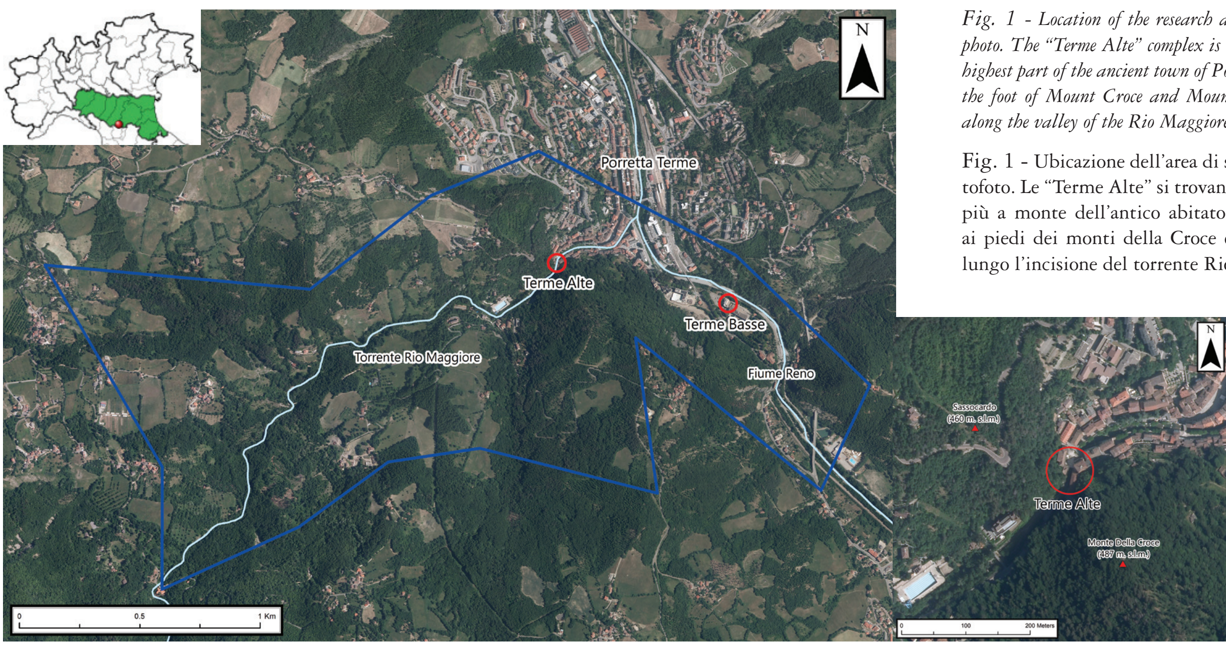

Fig. 1 - Location of the research area on orthophoto. The "Terme Alte" complex is located on the highest part of the ancient town of Porretta and at the foot of Mount Croce and Mount Sassocardo, along the valley of the Rio Maggiore stream.

Fig. 1 - Ubicazione dell'area di studio su ortofoto. Le "Terme Alte" si trovano nella parte più a monte dell'antico abitato di Porretta ai piedi dei monti della Croce e Sassocardo lungo l'incisione del torrente Rio Maggiore.

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The hydrothermal fluids originate from deep fossil waters of crustal provenance, associated with sedimentary marine deposits (Mesozoic Carbonates). The ascent is of artesian type and is facilitated by the geothermal gradient and by the substantial presence of associated methane. As it is highlighted in figure. 3, the classification of the hydro-structure is complex with an artesian emergence from a confined aquifer controlled by a permeability threshold (Civita 1972) represented by the tectonic contact between SUV (aquifer) and AVC (hydraulic barrier). The contact was originally caused by overthrust, but then it was reactivated along the structural weakness line by extensional tectonics as a consequence of the postorogenic Plio-Quaternary tectonic reactivation which affected the Northern Apennines. The springs discharge flows out through the fractures and also the bed joints, along an around 70 meters line where the stream cuts the arenaceous formation. In the exterior layer of the aquifer there is a local mixing of thermal waters with cold water originated by direct recharge and lateral recharge from the Rio Maggiore stream. The verified thickness of SUV in the surfacing area is of at least a hundred meters, whereas the underlying geological structure remains unknown.

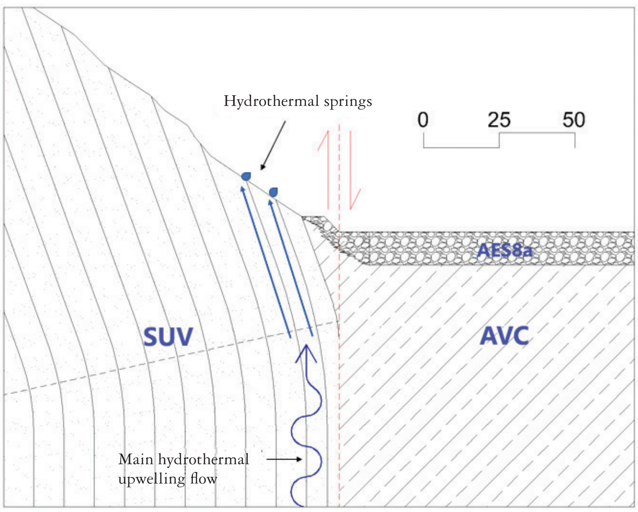


Fig. 3 - Original geologic section with focus on the hydrothermal artesian upwelling inside the "Arenarie di Suviana".

Fig. 3 - Sezione geologica originale con dettaglio della risalita idrotermale nelle Arenarie di Suviana.

The thermal exploitation

The first relevant exploitation of the system took place during the flourishing thermal epoch in the Roman period of the I and II century A.D. Some finds, indeed, date back to this period, such as the mask of a lion head, retrieved in 1888 along the stream bed, and kept as the symbol of Terme Alte (Fig. 4). The presence of real hot springs worth "cultivating and using" is discovered from late Middle Ages and during the Renaissance. From that period are the first denomination and classification of the springs by Giovanni Zecchi (1576), doctor as well as scientist of the Thermal Springs of Porretta, using place names that will then be recovered and definitely adopted by the following and current managers: Leone, Bovi, Marte, Porretta Nova, 3 Bocche, Bagni sotto le Donzelle. However, it is only from the XVIII century that the rich historic documentation tells us about a usage of the hot springs very similar, to some extent, to the current one, with the Bove and Donzelle springs depicted in frescos and paintings of the time.

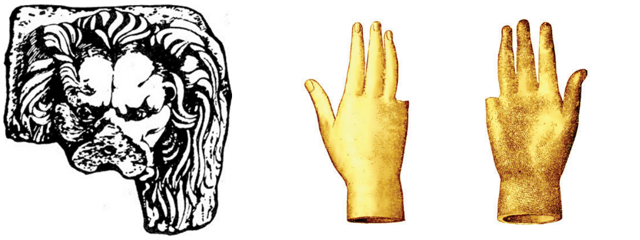


Fig. 4 - Mask from the Leone Spring and votive hand, both from II cen. A.D, found in the riverbed of the Rio Maggiore stream.

Fig. 4 - Mascherone della sorgente Leone e la mano votiva, entrambe del II d.C, ritrovate nell'alveo del torrente Rio Maggiore.

During that century, people used to bathe in the natural hot springs in the riverbed or along the banks of the Maggiore stream. A real thermal exploitation, from an engineering point of view, began in the middle of the XIX century. The thermal baths were founded and, initially, the surfacing in the riverbed was staunched by means of a plateau made of sandstone slabs. In this way, the capacity of the main lateral springs along the banks of the stream was increased. Some of the surfacing hot waters were optimised with the building of spring catchment facilities (Fig. 5).

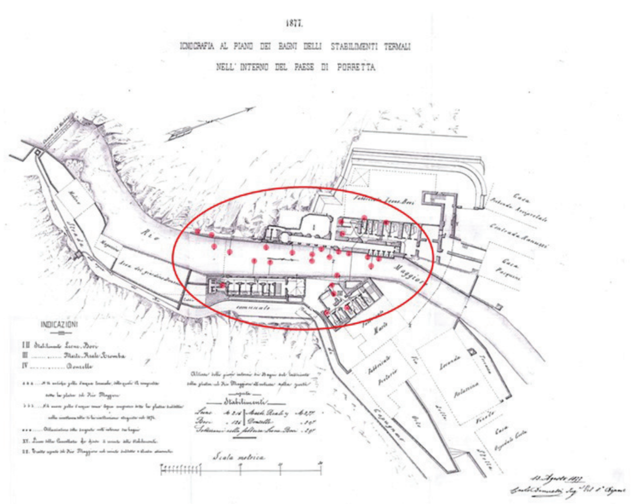
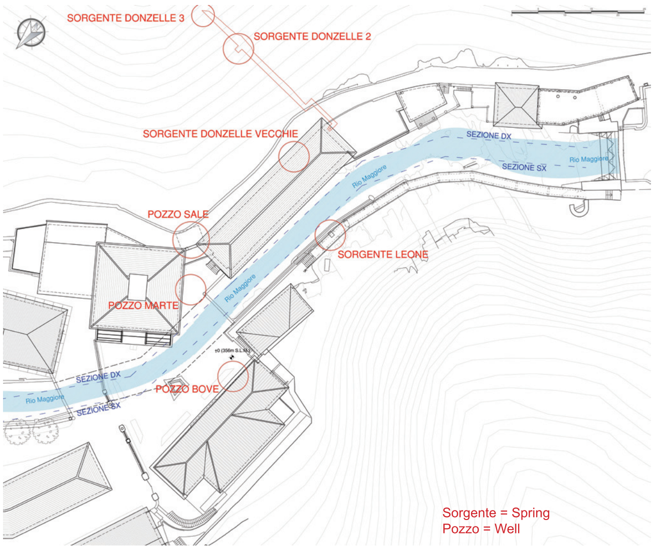


Fig. 5 - Late XIX century map with location of the natural hot springs of Terme Alte.

Fig. 5 - Pianta della fine del '800 con ubicazione delle emergenze naturali delle Terme Alte.

In 1993 the historic complex "Terme Alte" was closed. During the 60s, a draining tunnel, approximately 35 meters long, was dug on the hydrographic right of the Rio Maggiore stream, intercepting some hydrothermal ascents in the aquifer (Fig. 6). Since the late 90s, the exploitation was carried out through pumping wells, with an increase of the overall capacity of the springs that were used, in order to provide higher hygienic protection. Three wells were drilled and they are still operating; their names are 'Sale', 'Bove' and 'Marte'. The extracted water was then channeled to a more modern establishment for thermal use. The establishment is still working today.

Today the "Terme Alte" system consists of three wells (Bove, Sale and Marte), two springs captured with spring catchment facilities located inside the buildings (Leone & Donzelle Vecchie) and two springs captured through draining tunnels (Donzelle 2, Donzelle 3). Their location is shown in figure 6. The wells have variable depth between 50 m (Sale) and 20 m from ground level. In figures 7 and 8 are reported some graphics and photos of the captured emergencies.



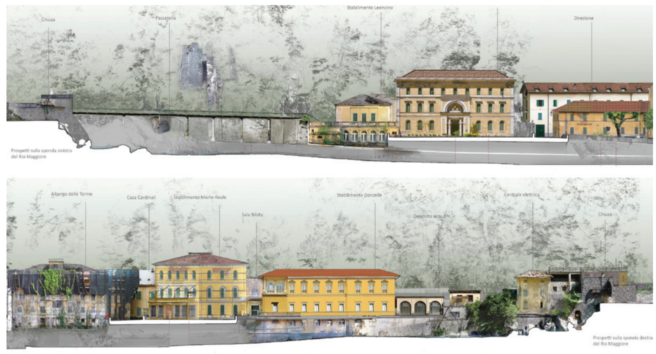


Fig. 6 - Terme Alte's plant with ubication of wells (in Italian pozzo) and spring (in Italian sorgente) and elevations of the ancient establishment of Terme Alte, in hydrographical left and right of Rio Maggiore.

Fig. 6 - Pianta delle Terme Alte con ubicazione dei pozzi e delle sorgenti e prospetti degli antichi stabilimenti delle Terme Alte in sinistra e destra idrografica del torrente Rio Maggiore.

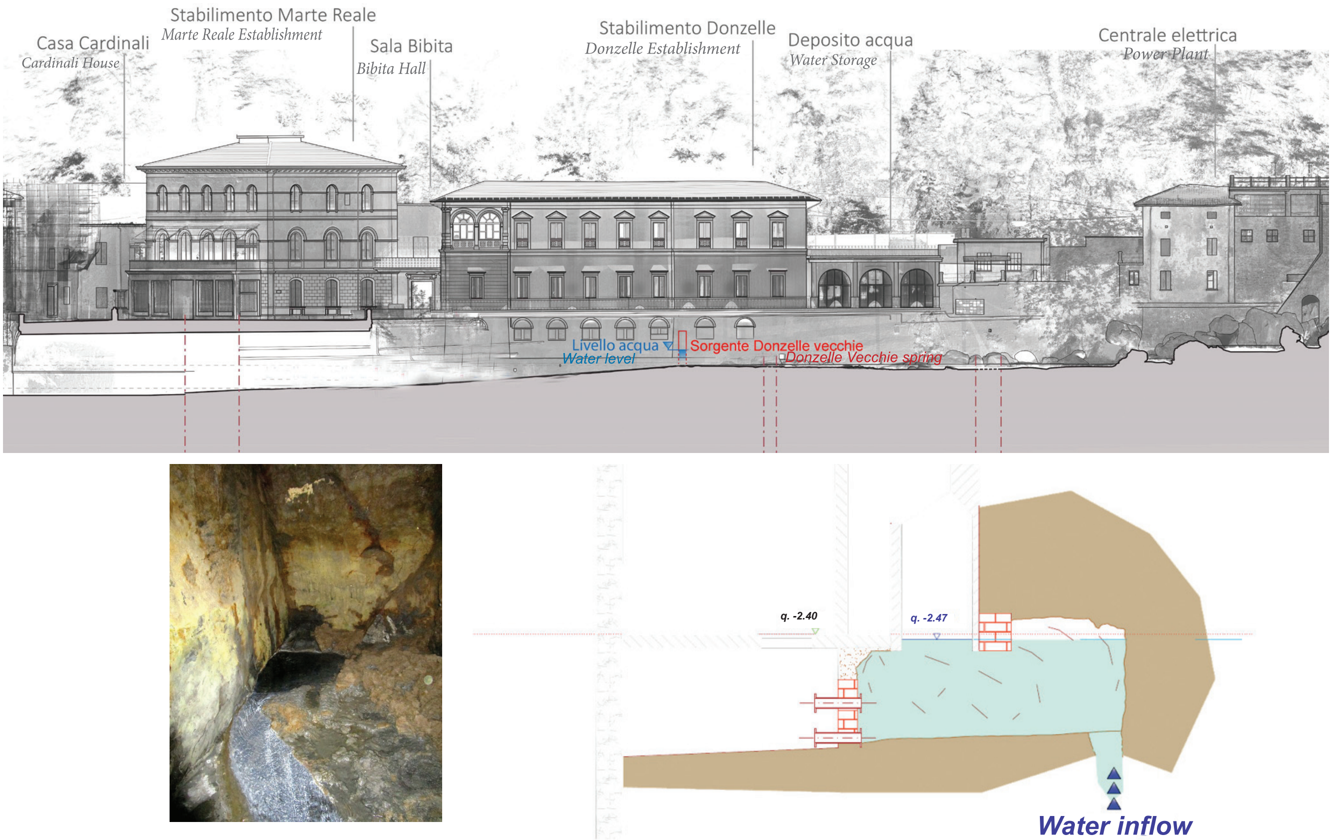


Fig. 7 - Elevations of the hydrographical right of Rio Maggiore with localization of the "Donzelle Vecchie" spring. In the bottom photo the cross section of the spring catchment facility of the spring in contact with "Arenarie di Porretta".

Fig. 7 - Prospetto della destra idrografica del torrente Rio Maggiore con ubicazione della sorgente Donzelle Vecchie. In basso sezione di dettaglio del bottino di presa della sorgente a contatto con le arenarie di Porretta.

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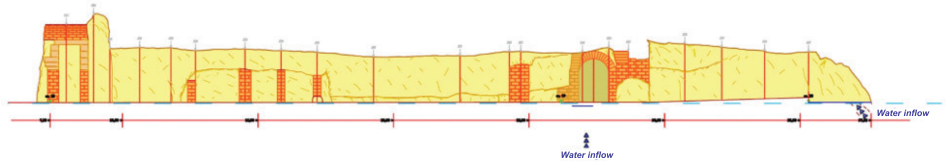

Fig. 8 - Schematic cross-section of the Donzelle tunnel with localization of the springs. In the figure at left there is the "Donzelle 3" spring.

Fig. 8 - Sezione schematica della galleria delle Donzelle con ubicazione delle sorgenti. A sinistra immagine della sorgente Donzelle 3.

Bove and Marte wells, if turned off, show artesian conditions with a continuous water flow. Moreover, always considering quiet conditions, they allow natural emergencies to little previously captured springs in their surroundings (these sources get lost when the pumps are functioning). We can therefore speak of "Systems". Table 1 shows the global features of natural emergencies for every system and source. As highlighted, there is a strong variability of the flow rate in a rather restricted space. The total natural flow rate, according to what measurable, can be estimated in 2.74 l/s, to which must be added the direct and diffuse emergencies which, by the way, tend to restrict until their disappearance with the action of the pumps

Tab. 1 - Natural flow rates of the "Terme Alte" system based on Meinzer classification. (1923).

Tab. 1 - Portate naturali del sistema "Terme Alte" in base alla classificazione di Meinzer (1923).

Natural flow rates of the measurable springs of the "Terme Alte" system		
	Natural flow rate(l/s)	Flow rate class
System Bove	1.08	5
System Marte	1.25	5
Spring Leone	0.06	7
Spring Donzelle Vecchie	0.3	6
Spring Donzelle 2	0.002	8
Spring Donzelle 3	0.05	7
	2.742	

Materials and Methods

Some activities of hydrological and hydro chemical monitoring were performed alongside with the parametrization (pumping tests). These activities took place in six months, started on June and completed on November 2018.

Monitoring: the hydrological (flow rates and piezometric levels) and hydro chemical monitoring of the thermal system is based on activities performed discontinuously as well as continuously. There are 2 possible conditions: natural artesian conditions and artificial conditions. Natural artesian conditions mean that pumps are not operating while and artificial conditions mean that either pumps are working at constant pumping discharge or discontinuous discharge.

All of these operations are finalized to detect reciprocal interferences between wells and springs or between wells (Fig. 9). The discontinuous monitoring has interested all of the water spots while the continuous one is relative to Marte well and Donzelle Vecchie spring with measurement of the piezometric level, the water temperature and specific electrical conductivity with an acquisition rate of 30 minutes in a period between June and November 2018 (OTT CTD multi-parametrical probe). To the monitoring data caught in 2018 is here added a synthesis of the composing features of

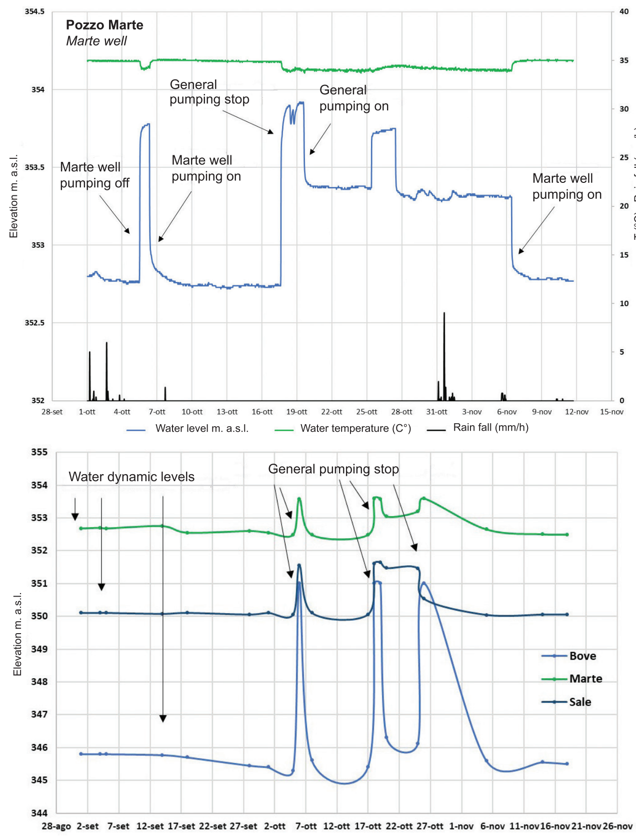

Fig. 9 - Examples of continuous and discontinuous monitoring applied to the Terme Alte thermal system. In the upper diagram: continuous monitoring of the Marte well (data recorded with 30 minutes pace) of the piezometric level, of the temperatures with multi-parametrical probe, correlated to the hourly precipitations recorded from the hydroclimatic station of Porretta Terme (BO). In the bottom diagram: discontinuous monitoring of the hydrodynamic level of Bove, Marte and Sale wells (the peaks represent the thermal ascension with pumping deactivation).

Fig. 9 - Esempi di monitoraggio in continuo ed in discontinuo applicato al sistema termale delle Terme Alte di Porretta. In alto: monitoraggio in continuo del pozzo Marte (dato registrato con passo di 30 minuti) del livello piezometrico e della temperatura con sonda multi-parametrica correlati alle precipitazioni orarie registrate dalla stazione idrometeorologica di Porretta Terme (BO). In basso: monitoraggio in discontinuo del livello idrodinamico dei pozzi Bove, Marte, Sale (i picchi rappresentano la risalita idrotermale con disattivazione del pompaggio).

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the thermal waters, derived from quarterly analysis carried out by USL agency or ARPAE institution (in the latest 10 years) other than from the original analysis developed by the Direction of the Mine (in a period between June and November 2018).

Hydrodynamic parameterization: step tests were performed (Fig. 10), as well as tests with constant discharge on the thermal wells, in order to understand both the hydrodynamic parameters and the efficiency of the system. Another goal was to verify the reciprocal interferences.

The test carried out under constant discharge were interpreted with the equilibrium method (Thiem's equation) as well as with the non-equilibrium method (Cooper-Jacobs' logarithmic approximation of the Theis method). The objective was the parametrization of the rock mass and the study of the sustainability of the thermal water pumping. This method is usually used for cool water systems.

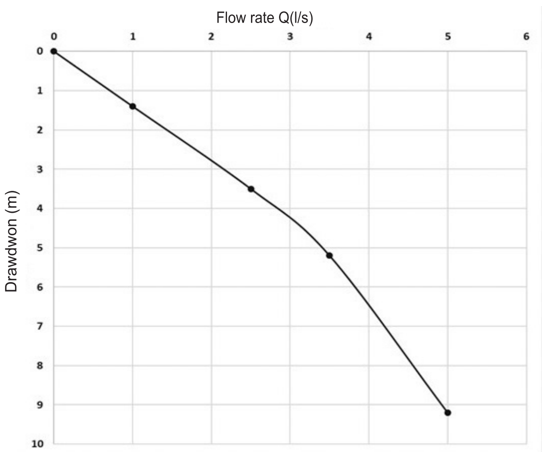

Fig. 10 - Example of the characteristic curve of the Bove well.

Fig. 10 - Esempio di curva caratteristica del pozzo Bove.

Results

Hydro chemistry of the thermal discharge: the composition shows a strong variability, like the already seen hydrological variability. This sensibility is a peculiarity of the thermal system of such a small area. In Table 2 is reported the variability of the values of temperature and electrical conductivity among the various emergencies, which appears to be among the hottest of the Northern Apennines

The basic chemical composition of all the waters belonging to the Terme Alte system is characterized by a alkali-chloride hydro chemical facies with iodine and bromide anion in traces (Fig. 11).

In Table 3 is reported an example of hydro chemical features of one of the thermal wells (Bove well). The chemical composition is constant in time (Fig. 12) for what concerns the main elements as chlorine, sodium and bicarbonate ion (HCO_3^-). Total dissolved solids are always over 4000 mg/l. These data were gathered, as said, from official analysis of ASL and ARPAE (over 40) during the interested decade.

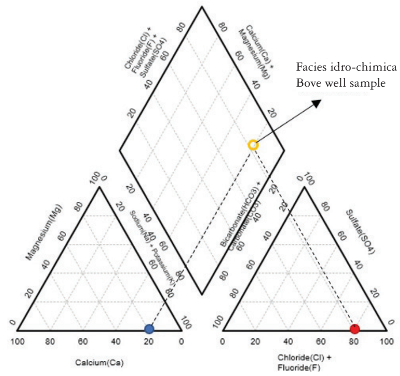

Fig. 11 - Piper's diagram of the water caught inside Bove well (ARPAE data 2018).

Fig. 11 - Diagramma di Piper relativo all'acqua del pozzo Bove (dati ARPAE 2018).

Tab. 3 - Hydro-chemical features of the Bove well (ARPAE data 2018).

Tab. 3 - Caratteristiche idro-chimiche del pozzo Bove (dati ARPAE 2018).

Temperature (C°)	35	Parameter	mg/l	meq/l	%meq/l
Electical conductivity (µs/cm)	8000	Cl^-	2140	68	39
Mineralization (mg/l)	5189	SO_4^{2-}	5	0,1	0,1
pH	7,6	HCO_3^-	1056	17,3	9,9
Dissolved oxygen (mg/l)	2,4	Na^+	1982	86,2	49,5
Presence of methan gas	high	K^+	75,2	1,9	1,1
Hydrogen sulfide H_2S	<1	Mg^{2+}	6,1	0,3	0,2
Bromine Br^-	2,4	Ca^{2+}	15,5	0,4	
Iodine I^-	1,4	NH_4^+	14,7		
		Total anions		85,4	49,1
		Total cations		88,8	50,9

Tab. 2 - Temperature and electrical conductivity at their maximum and minimum of the emergencies examined between June and November 2018.

Tab. 2 - Temperature e conducibilità elettriche minime e massime delle emergenze esaminate nel periodo tra giugno e novembre 2018.

	Temp. min (°C)	Temp.max (°C)	ΔT (°C)	Cond.min (µS/cm)	Cond. max (µS/cm)	delta Cond. (µS/cm)
System Bove*	35,2	36,4	1,2	7900	8100	200
System Marte*	34,4	35,4	1	7200	7600	400
System Sale*	35,9	36,5	0,6	8500	8600	100
Leone Spring	18,2	28	9,8	6900	8200	1300
Donzelle Vecchie Spring	28	30	2	6800	7600	800
Donzelle 2 Spring	21,2	24,3	3,1	6600	7450	850
Donzelle 3 Spring	18	24	6	2800	6000	3200
* constant flow on the thermal wells during the monitoring period (june - july 2018)						

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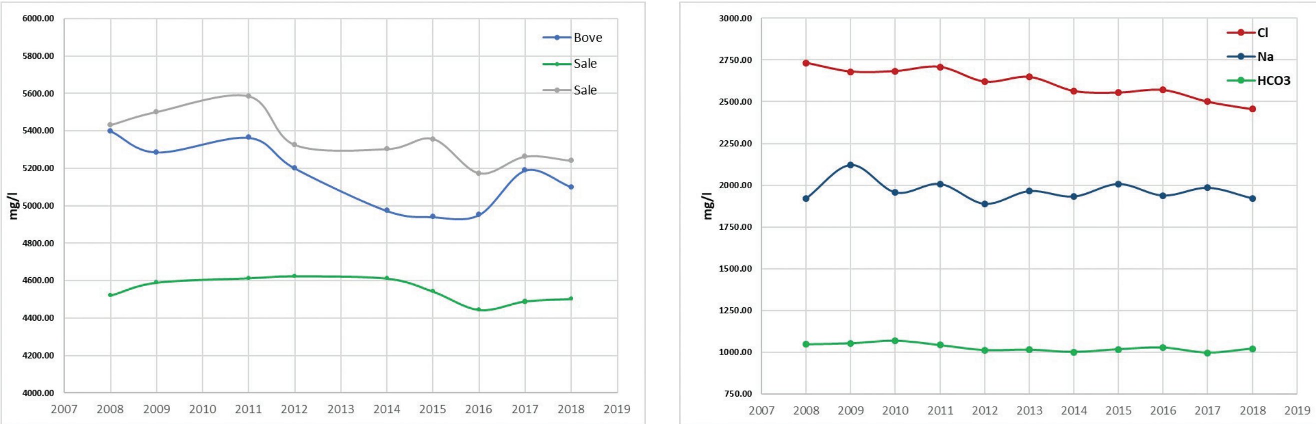

Fig. 12 - Left: Total dissolved solids graph (mg/l) for the three thermal wells; right: graph for the Cl^-, Na^+, HCO_3^- levels for Sale well.

Fig. 12 - A sinistra: andamento del valore di residuo fisso (mg/L) per i 3 pozzi termali; a destra: andamento del valore di Cl^-, Na^+, HCO_3^- (mg/L) per il pozzo Sale.

This kind of composition reflects a common hydrothermal matrix, bound to the original nature of waters. High content in chloride is related to the extreme depth of the Mesozoic carbonate unit reservoir (higher than 1000 m b.g.s according Bonoli 2009). The composition is then influenced by the effects of the rock-water interferences caused by the geological unities crossed along the path to the surface (the abovementioned Mesozoic carbonates, the Modino-Cervarola unity and the Sestola-Vidiciatico unity). Considerable effects on the composition are also due to the mixing with soft and recharge waters coming from water courses. The waters appear rich in methane in gas and aqueous phase as they emerge. It presumably comes from the degradation of the marine biomass.

Compositional differentiation could be born by the different ascension speed related to the different permeability of the crust.

Hydrodynamic parametrization of the rocky mass of the aquifer: in Table 4 are reported hydrodynamic parameters (hydraulic conductivity, transmissivity, storage coefficient) determined on the thermal wells. The hydraulic transmissivity value of the rock mass is in the order of $3x10^{-4}$ m^2/s and appears almost invariable in scale with the emergence zone. Therefore, is demonstrated the presence of hydrodynamic homogeneity of the discharge zone. The value of the hydraulic conductivity (K) depends on the aquifer's thickness. The value of K reported in table 4 was derived from the thickness of the well's filtered tract and also from the thickness of the presumed influenced area relative to the pumping effects (estimated to be 100 m). Is evident how the SUV unity is characterized, at least in the sub superficial portion interested by pumping mechanisms, by a rather high hydraulic conductivity for an arenaceous aquifer, with fracture permeability in the order of 10^{-5} /10^{-6} m/s. The storage coefficient, determined through tests on a station, is inside the range for confined aquifers (10^{-4}).

Pumping system efficiency: in Table 5 are shown the values of the current operational flow rates and of the sustainable flow rates determined through analysis of the flow rate-level lowering ratio.

Tab. 4 - Hydrodynamic parameterization of the thermal aquifer.

Tab. 4 - Parametrizzazione idrodinamica dell'acquifero termale.

	Transmissivity (m^2/s)	Hydraulic conductivity (m/s)		Storage coefficient
	Sale well	Sale well		Marte well - Sale well
The Cooper and Jacob method (Non-equilibrium method)	$3x10^{-4}$	Well filtred thickness (50 m)	$2x10^{-5}$	$3.2x10^{-4}$
		Aquifer thickness (100 m)	$2x10^{-6}$	
Thiem equilibrium method	$1.3x10^{-3}$			

Tab. 5 - Matching between the present flow rates of exercise and the critical ones calculated both with graphic method and with well efficiency method.

Tab. 5 - Confronto tra le portate d'esercizio attuali misurate e quelle critiche calcolate sia con metodo grafico che con metodo dell'efficienza del pozzo.

	Present flow rate (l/s)	Critical flow "graphic method" (l/s)	Critical flow "well efficiency" (l/s)
Bove well	3,5	3,3	2
Marte well	1,5	1,25	1,17
Sale well	1,5	1,3	1,19

There is a connection between all of the springs on the right and on the left of Rio Maggiore and the following map shows it (Fig. 13). The hydrological interference is stronger between the banks of the river, according to the stratification's direction, highlighting the importance of the layer junctions in the discharge process. In figure 14 is shown the interference of the pumping inside Sale well onto Leone spring and the effects of the Bove well's pumping onto Marte well. Considering the sea level, the static and hydrodynamic levels referring to the wells are compared both to the local hydrogeological level (Rio Maggiore) and to the outcropping level of the springs (Tab. 6).

Tab. 6 - Absolute values of the hydrodynamic and static levels of the wells and springs in the Terme Alte matched with the basic level.

Tab. 6 - Quote assolute dei livelli idrodinamici e statici dei pozzi e sorgenti presenti alla Terme Alte in confronto con il livello di base.

	Hydrodynamic level (m. s.l.m.)	Static level (m. s.l.m.)	Natural emergency hydrological height (m. s.l.m.)
Bove well	346,1	351*	
Sale well	350,1	351,8	
Marte well	352,7	353.8*	
Marte 2 spring	353,3	353,5	
Leone spring			355,3
Donzelle Vecchie spring	353,3	353,75	
Donzelle 2 spring			357,5
Donzelle 3 spring			358
Local base level's height (m. s.l.m.)	350,2		
* flowing well (flowing artesian)			

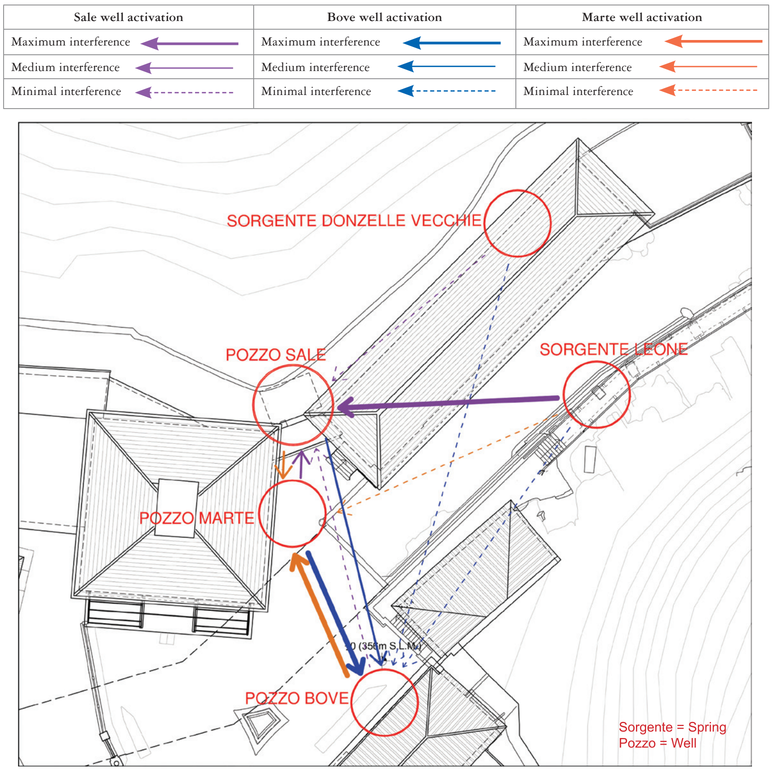

Fig. 13 - Interferences map on the levels of wells and sources at shut-down of alternating pumping.

Fig. 13 - Carta delle interferenze tra i livelli idrodinamici dei pozzi e delle sorgenti durante l'arresto e attivazione dei pompaggi.

It is therefore clear how the static levels (in absence of active pumping) in all of the springs and wells are above (in some cases significatively) the local base level's height. Bove and Marte wells are flowing artesian in quiet conditions. Static hydraulic head of wells is higher in elevation respect to natural springflow level. The artesian nature of the thermal ascent is therefore confirmed. The hydraulic head longitudinal profile, along Rio Maggiore river is shown in figures 14 and 15, respectively on the hydrographic right and left.

Conclusions

All the waters that flow into the Terme Alte system are related to the same hydrothermal matrix originated in depth. Despite this common matrix, every thermo-mineral emergence appears to be characterized by a peculiar hydrogeological activity, noticeable in the natural flow rate, temperature, and hydrochemical features. The emergence is controlled mainly by layer surfaces of arenaceous and by the fracture systems that connect them. The hydraulic transmissivity of "Arenarie di Porretta" formation is hight in correspondence of a fractured aquifer and is sufficiently homogeneous in the spring outcropping scale. The pumping wells discharge is higher than natural undisturbed groundwater discharge. A great vagueness, in the absence of isotopic studies, remains on the genetic mechanisms and the ones involved in the ascension process. We are aware that this work could be useful for further studies to better define the features of the thermal deposit of Porretta, a natural and economic resource on a national scale.

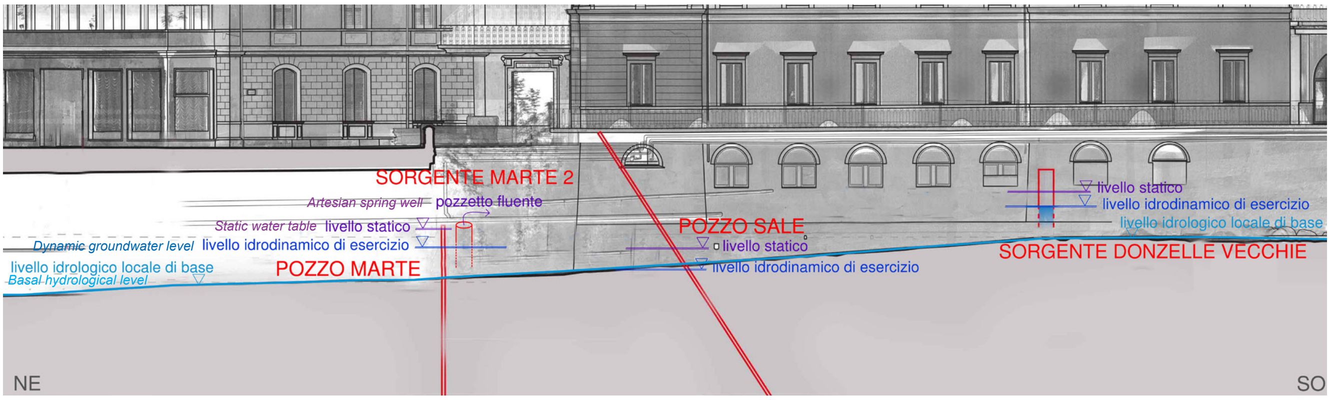

Fig. 14 - Hydrodinamic level of exercise and hydrostatic levels on the right of the Rio Maggiore (height values are calculated on the sea level).

Fig. 14 - Livelli idrodinamici d'esercizio e livelli idrostatici in destra idrografica del torrente Rio Maggiore (le quote sono in m s.l.m.).

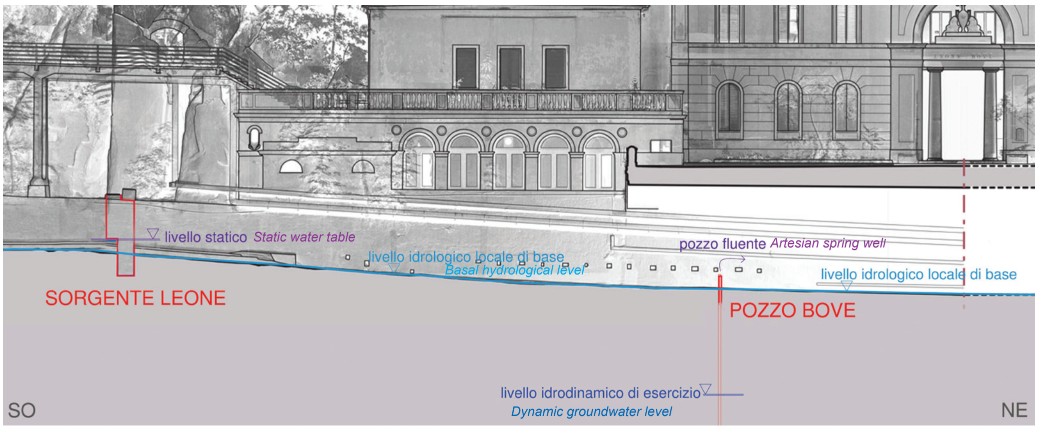

Fig. 15 - Hydrodinamic operational levels and hydrostatic levels on the left of Rio Maggiore (height values are calculated on the sea level).

Fig. 15 - Livelli idrodinamici d'esercizio e livelli idrostatici in sinistra idrografica del torrente Rio Maggiore (le quote sono in m s.l.m.).

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