Hydrogeological Features and Sustainable Use of Geothermal Resources: Selected Case Studies in Italy

Paolo CERUTTI[1*], Daniela DUCCI[2*], Paolo FABBRI[*], M. Dolores FIDELIBUS[*], Francesco LA VIGNA[*], Stefano LO RUSSO[*], Roberto MAZZA[*], Maurizio POLEMIO[*], Andrea SOTTANI[3*]

(*) Working Group IDROGEOTER, IAH Italian Chapter - www.iahitaly.it, info@iahitaly.it

[1] ECOTER CPA S.r.l., via Selvagreca 14H, 26900 LODI, ITALY, +39.0371.427203, paolo.cerutti@ecotercpa.it

[2] DICEA, Università degli Studi di Napoli, Piazzale Tecchio, 80 - 80125 Napoli, tel. 0817682165-3, daniela@unina.it

[3] SINERGEO S.r.l., contrà del Pozzetto 4, 36100 VICENZA, ITALY, +39.0444.321168, asottani@sinergeo.it

Keywords: hydrogeology, geothermal systems, low-to-high enthalpy, hydrogeochemistry, Italy

ABSTRACT

Within the framework of the activities aimed at studying current and future exploitation and the related sustainability of geothermal resources, the Working Group IDROGEOTER was set-up within the IAH Italian Chapter. The first activity of IDROGEOTER's workplan is the analysis of state of the art in current use of low-to high enthalpy geothermal resources in Italy. Detailed studies supporting the possible optimization of the use of geothermal resources, carried out in different areas are described in the paper, with details regarding the Veneto Region (NE Italy). Further studies and inventory of data and applications will be part of the activities of IDROGEOTER, which will also include the preparation of a proposal of guidelines for hydro-geothermal studies.

1. INTRODUCTION

Within the framework of the activities aimed at studying current and future exploitation and the related sustainability of geothermal resources, and considering the key role hydrogeology plays in the study of geothermal systems and design of installations, in October 2012 the Working Group IDROGEOTER was set-up within the IAH (International Association of Hydrogeologists) Italian Chapter.

The first activity of IDROGEOTER's workplan is the analysis of state of the art in current use of low-to high enthalpy geothermal resources in Italy and of the hydrogeo-logical settings resulting from features (e.g.: hydrostratigraphy, hydraulic and hydrodynamic conditions, hydrogeochemistry,…) influencing the availability of the resource and the potential of the systems. Detailed studies supporting the possible optimization of the use of geothermal resources, carried out in different areas and under different hydrogeological conditions in Italy, are described in the paper, with details regarding 3 case studies in the Veneto Region (NE Italy).

2. GENERAL OVERVIEW

In the Piedmont Region (NW Italy) several experimental sites have been investigated in order to assess the potential subsurface effects of open-loop Groundwater Heat Pumps (GW-HPs) plants for the cooling and heating of buildings. A comparison between field measures and numerical modelling results reveals that the most important aquifer parameters affecting the developing of the Thermal Affected Zone (TAZ) around the injection wells are those related to advective heat transfer.

The Lombardy Region (N Italy) is currently the most populated and industrialized region in Italy and therefore the area where the highest number of GWHP plants (open and closed loop) are installed, from which a representative sample will be selected with the objective of identifying the critical hydrogeological factors contributing both to the geothermal potential and to a sustainable use of the resource.

In the Veneto Region (NE Italy), the Euganean Geothermal Field is the most important thermal field in northern Italy (about 250 active wells) and the thermal waters (65-86 °C) are mainly used for spas; recently, a new conceptual model of the Euganean Geothermal System has been proposed and tested in a numerical model; with regard to low-enthalpy, studies on sites potentially suitable for closed-loop and open-loop systems, together with data from automated monitoring of several wells, could be used for advanced analysis of different hydro-geothermal systems.

Research activities in the Lazio Region (Central Italy) focus also on low enthalpy and are specifically aimed at the mapping of the geothermal potential of aquifers, and at pilot studies of sites characterized by gravel aquifers, alluvial Holocene deposits of the Tevere River and alluvial pre-volcanic Pleistocene deposits.

In the Campania Region (S Italy - Mondragone plain), in the framework of the geothermal exploration programme "VIGOR" (Evaluation of Geothermal Potential in Convergence Region), a groundwater balance, verifying the recharge area of thermal springs (temperature 33-54 °C) connected to a large carbonate aquifer, has permitted the identification of the most suitable area in which to drill a geothermal well.

In the Apulia Region (SE Italy) the thermal field trends consequent to groundwater advection and the influence of seawater intrusion have been reconstructed for two karstic coastal aquifers (Murgia and Salento) at various elevation between -5 and -100 m amsl. These reconstructions are intended to provide required base knowledge for correctly implementing low enthalpy HP plants in the saturated zones.

Further studies and inventory of data and applications will be part of the activities of IDROGEOTER, which will also include the preparation of a proposal of guidelines for hydro-geothermal studies.

As regards case studies in the Veneto region, more details are presented below (Figure 1).

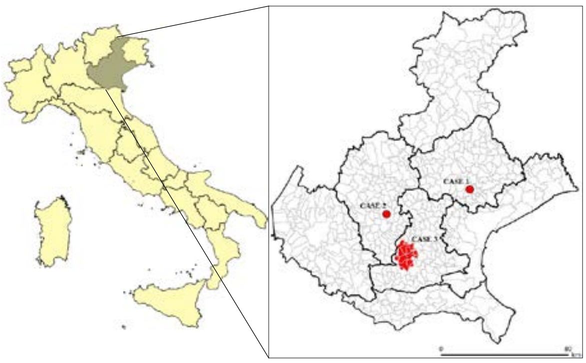

Figure 1: Location of case studies in Veneto region

3. CASE STUDY 1: "APPIANI" AREA, TREVISO

3.1 General project

- Project for the redevelopment of a former industrial area (P.I.R.U.E.A. "Citadel of the Institutions"), designed by the architect Mario Botta;
- Surface area of the site: 68,000 sqm;
- Volume of buildings above ground: 236,000 cubic meters (Figure 2);
- Volume underground (parking): 150,000 cubic meters;
- Public and private users: Municipality of Treviso, Police, Highway Police, Chamber of Commerce, Unindustria, Association of the Province Builders, Confartigianato, Ascopiave, ;
- Public areas: Chapel with seating for 100 – Hall, capacity 500 people, for cultural events – Square;
- New housing units: approximately 100 apartments;
- Total of 10 new buildings, some of them (referred to as C, E, F, G, H corresponding to approximately 120,000 cubic meters) have opted for the technology of an open-loop geothermal heat pump, by means of air conditioning systems using a ground source heat pump with ground water returning into the same aquifer.

Figure 2: Construction of "Citadel of the Institution" where a GWHp system is active from 2010

3.2 Technical data

GW-HP: summer operation detail

- average seasonal warming of well water: $\Delta t = 6$ °C;
- capacity equivalent average summer (122 days): Q = 30 l/s;
- warming peak of well water: $\Delta t = 8$ °C;
- resulting peak flow of groundwater: Q = 95 l/s;

Winter operation

- average seasonal cooling of well water: $\Delta t = 6$ °C;
- capacity equivalent average winter (183 days): Q = 9 l/s;
- cooling peak of well water: $\Delta t = 8$ °C;
- resulting peak flow of groundwater: Q = 36 l/s;

3.3 Details of activities

Pre – works phase

- geotechnical sampling / preliminary piezometers;
- hydrogeological investigation (piezometric monitoring, preliminary hydrogoelogical assessment, conceptual model, etc.);
- temperature monitoring (average T = 13 ° C);
- mathematical model for flow and simulation of heat transfer;
- completion of required documentation.

Installation phase

- drilling of heat exchange wells (Figure 3);

- pumping test and re-emission test;
- sampling of groundwater;
- tests for alternate activating of pairs of wells.

Post activation

- hydrogeological monitoring (Figure 4);
- hydro-geothermal measurements (Figure 5);
- chemical / physical on-site checks;
- laboratory analytical testing.

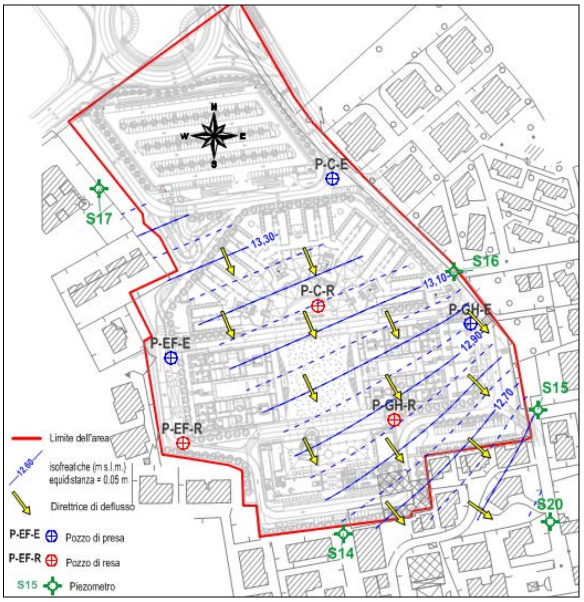

Figure 3: Plan with piezometers and wells

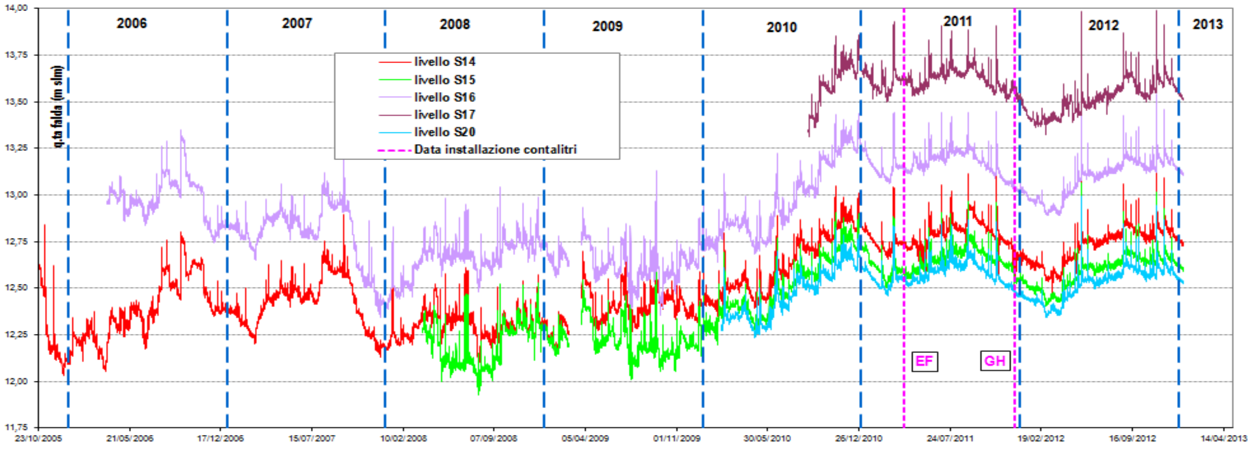

Figure 4: Ground water levels (EF and GH: data of GW-HP activation)

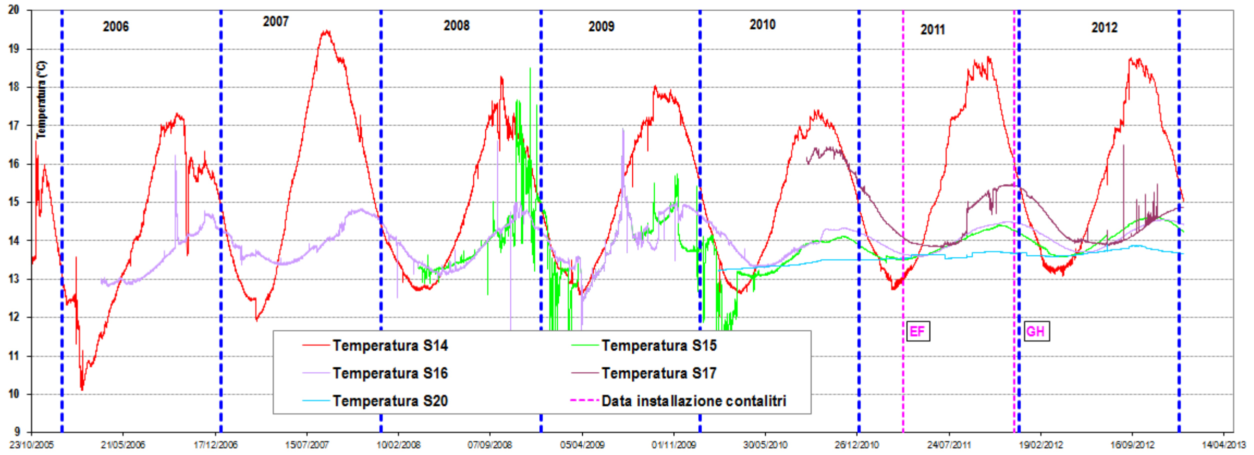

Figure 5: Groundwater temperature trends

3.4 Considerations

To date, no adverse effect on the aquifer is due to the operation of GWHP (no change in either the piezometric levels or the flow directions of the aquifer). Similarly, no correlation (cause - effect) derives from the withdrawals from the heat exchange wells in terms of temperature variations in groundwater at the piezometers.

The chemical-analytical data do not highlight any differentiation between extracted ground water and "waste" water returned to the aquifer, so no qualitative impact on the aquifer is related to the initiative.

All qualitative and quantitative controls are in place in accordance with a Monitoring Plan, that provides for the periodic transmission to the competent authorities of the results obtained.

The geothermal heat pump installation is now in regular operation.

4. CASE STUDY 2: BASILICA PALLADIANA, VICENZA

4.1 General project

The case study comes from the need to optimize the operating costs of the heating/cooling need of the Palladian Basilica, located in the central square of Vicenza.

The use of renewable energy resources was preceded by verification of hydrogeological and environmental sustainability.

The geothermal system is a ground water heat pump (open loop) and consists of 1 extraction well and 1 injection well, completely penetrating the local confined aquifer (Calvino F., 1966).

The scientific value added of the case concerns the local hydro-geological context, as regards the system of confined aquifers (upper aquifer) for which there is a lack of availability of specific information (eg piezometric levels, flows, relationships with other aquifers, chemistry, etc.) and for which the pumping and reinjection pose additional technical problems, including slope/building stability.

4.2 Technical data

GW-HP: Summer operation

- capacity equivalent average summer (120 days): Q = 7.1 l/s;
- average warming of well water: Δt = 6 °C;
- peak warming well water: Δt_summer = 10 °C;
- resulting peak flow of groundwater: Q =17.6 l/s.

Winter operation

- capacity equivalent average winter (150 days): Q= 6.9 l/s;
- average cooling of well water: Δt = 6 °C;
- peak cooling of well water: Δt = 8 °C;
- resulting peak flow of groundwater: Q =13.7 l/s.

4.3 Technical activities

Pre–works phase

- pre-feasibility study of legal requirements:
- carrying out of geotechnical tests to a depth of up to 50 m completion of pilot plant piezometer and thermometric monitoring (Figure 6);
- preliminary parameterization of aquifer intercepted between depths of 30 and 50 m below ground level.

Installation

- drilling of heat exchange wells to a max depth of 50 m from ground level (see aquifers subject to quantitative protection in accordance with All. A of D.G.R. n. 234 of 10 February 2009, article 1);
- pumping test (Figure 7);
- water return tests;
- implementation of mathematical model of flow and heat transport (Figure 11);
- calculation of forecast scenarios;
- definition of monitoring program for medium-term verification (Figure 8, Figure 9, Figure 10).

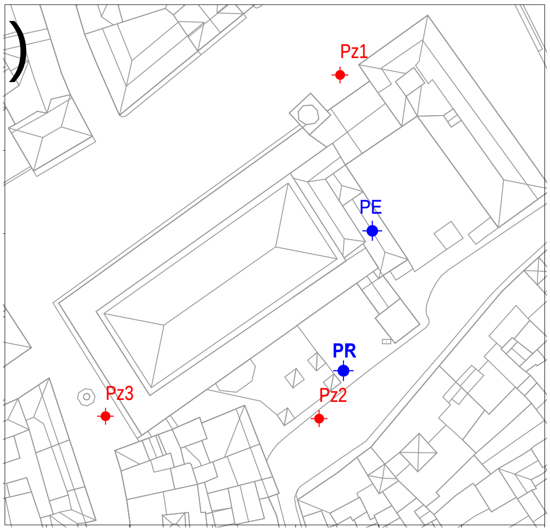

Figure 6: Plan of wells and piezometers

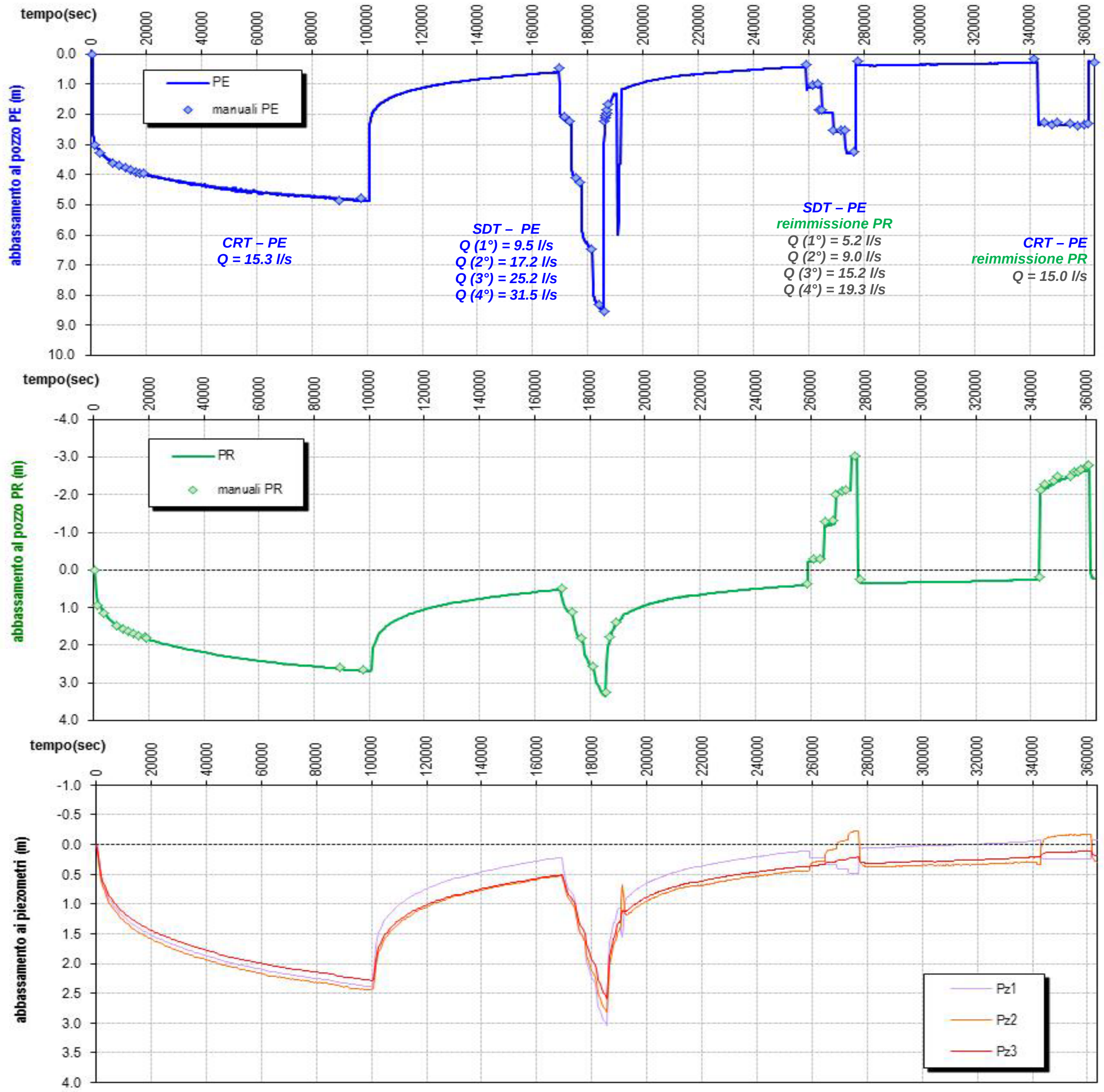

Figure 7: Experimental field tests (pumping test: SDT, CRT, REC)

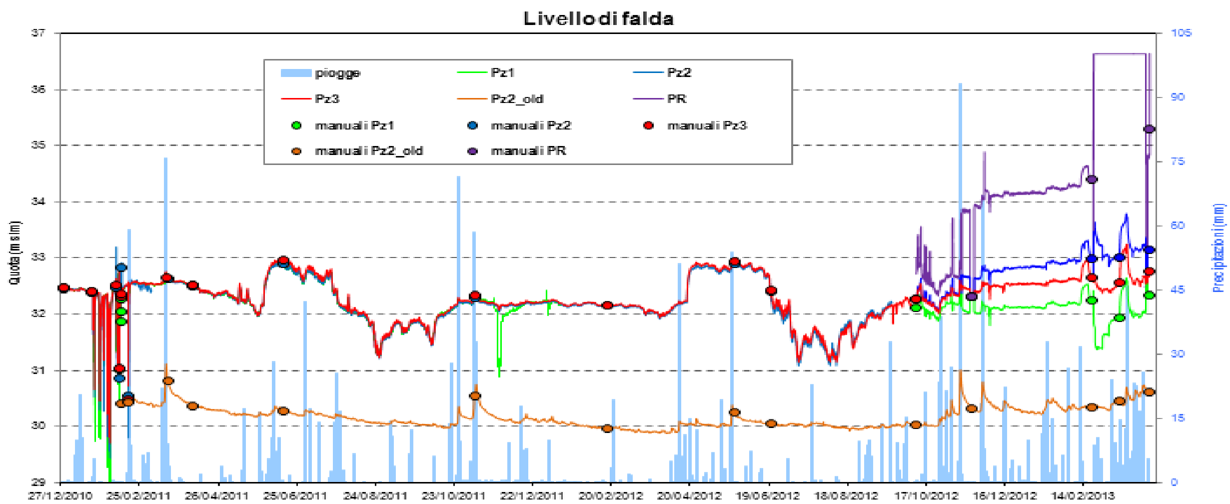

Figure 8: Piezometric level monitoring

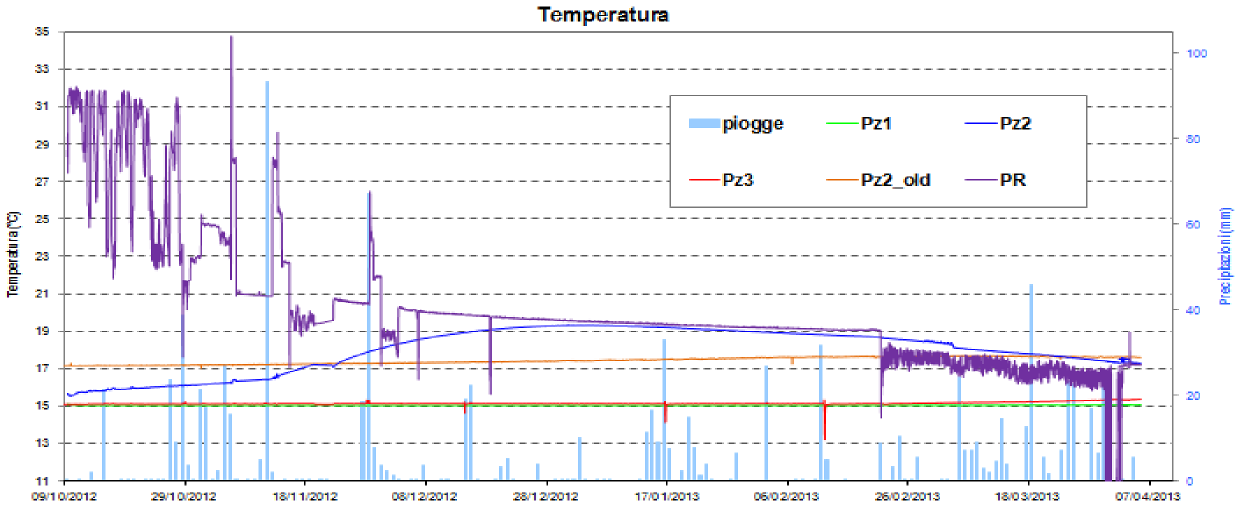

Figure 9: Temperature monitoring (in progress)

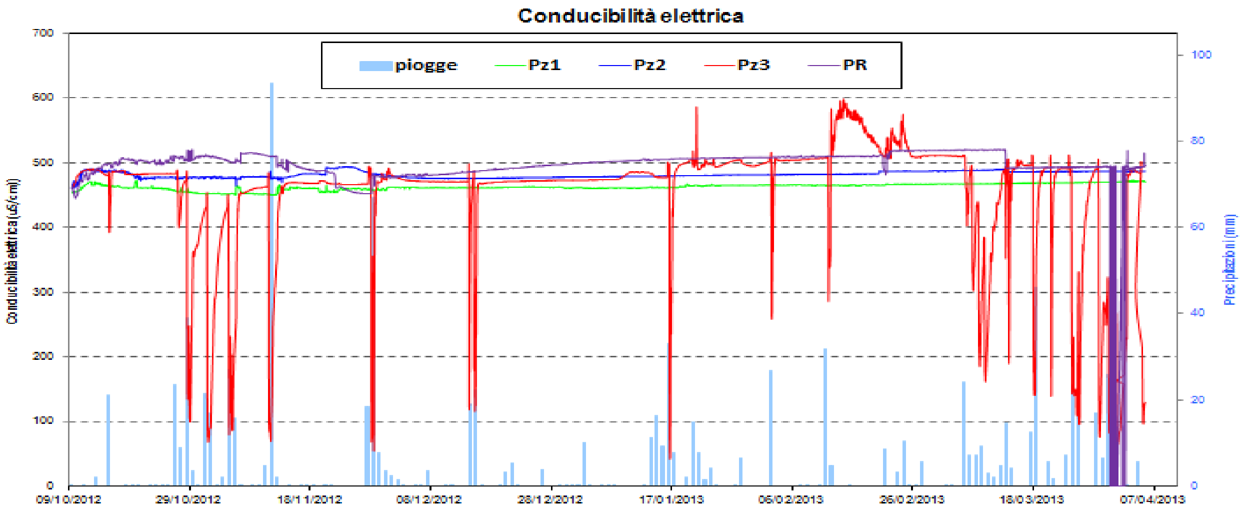

Figure 10: EC Monitoring (in progress)

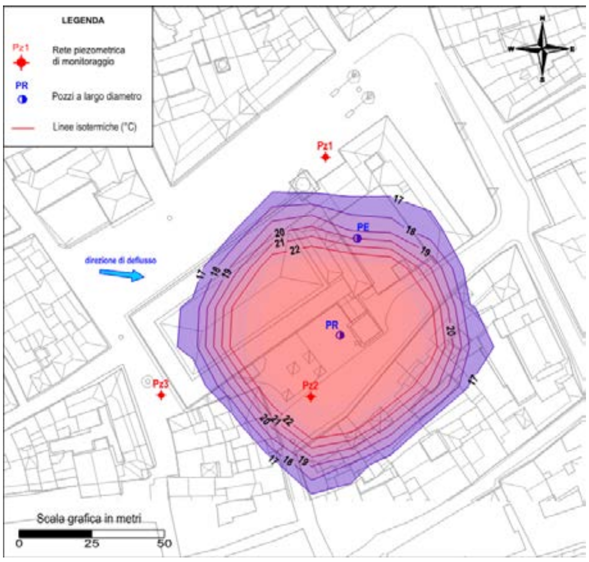

Figure 11: Results of the thermal simulation in transient conditions

4.4 Considerations

The case of the Palladian Basilica reveals interesting results, especially in relation to the thermal effects in a confined-type hydrogeological system, where the outflow velocities of the water are quite low.

All technical activities were carried out in compliance with the regulations imposed by the body responsible for the protection of artistic and architectural heritage; in particular, further study was carried out of geotechnical issues for the structural protection of the Palladian Basilica regarding any differential settlement induced by water withdrawal and return into the aquifer.

The geothermal heat pump is now in regular operation.

5. CASE STUDY 3: CHARACTERISTICS OF THE GEOTHERMAL EUGANEAN BASIN (VENETO REGION, NE ITALY)

The low-temperature (i.e. liquid-dominated) geothermal system in the Euganean area extends over a plain covering about 23 km2 immediately east of the Euganean Hills, which comprises the towns of Abano Terme, Montegrotto Terme, Battaglia Terme and Galzignano Terme (NE Italy). “Terme” is the Italian word for “spa”. About 134 mining claims have been issued in the area (57% in Abano, 31% in Montegrotto and 12% in Battaglia and Galzignano), and more than 400 groundwater wells have been drilled. At present about 250 wells are under exploitation, only 8% of which are flowing artesian wells (Battaglia-Galzignano area). The total volume of hot water extracted in the year 2010 was about 10 millions m3 in Abano, and about 5.0 millions m3 in Montegrotto. Most of the groundwater wells in the Euganean geothermal area are drilled for several hundred meters into rock formations, mainly limestones, but the cased intervals are restricted to the Quaternary cover. The depths of the wells range from about 300 m to more than 1000 m. The temperature of the thermal waters ranges from 60 to 86 °C (Fabbri and Trevisani, 2005), and their total dissolved solids content (TDS) is approximately 6 g/l, with a primary presence of Cl^- and Na^+ (70%) and secondary of SO_4, Ca^{2+}, Mg^{2+}, HCO_3^-, SiO_2.

Piccoli et al. (1973) were the first to hypothesize that the Euganean groundwaters are of meteoric origin, i.e. deriving from precipitation that infiltrates at about 1500m asl (meters above sea level). These authors reached this conclusion on the basis of a detailed geological knowledge of the region, hydrogeological and geophysical studies, and above all, data on $\delta^{18}O$ and saltwater contents. Gherardi et al. (2000) confirmed this hypothesis.

Tritium measurements performed in the early 1970s suggested that groundwater residence time was greater than 25 years (Norton and Panichi, 1978). A study by Sartori et al. (1997) extended the lower limit of the fluid residence time to 60 years. On-going accelerator mass spectrometry (AMS) investigations of ^{14}C content indicate that residence time could be much longer than 60 years, perhaps even several thousands of years (Boaretto et al., 2003).

At present, the groundwater level in the Euganean geothermal area seems to have stabilized, after the aquifer had been overexploited during the 1970s and 1980s. For example, the potentiometric level in the Abano field is now about 3m a.s.l. during periods of low exploitation (winter and summer), and about -3 m a.s.l. during periods of intense groundwater extraction (spring and autumn). The thermal water is mainly used for therapeutic purposes and in popular spa facilities, including more than 170 hotels, at Abano, Montegrotto and Battaglia-Galzignano. In the Battaglia-Galzignano field the hot fluids are also used to heat greenhouses. The Veneto region at present has local legislation prohibiting the private use of the Euganean hot waters for domestic heating purposes.

These groundwater heads correspond to that of the aquifer located in the Biancone limestone at a depth of 300–500 m, whose transmissivity ranges between 13 and 500m2/day; the spatial distribution of the transmissivities was presented by Fabbri (1997).

Recently, deep wells (up to 1000 m depth) have been drilled in the Euganean area, especially in the Abano field, where the water temperatures in the limestone reservoir ranged between 60 and 70 °C. The results were very interesting: not only were temperatures of about 80 °C measured in the deep wells, but the potentiometric levels were also higher than in the 300–500 m deep aquifer. Most of these wells are flowing artesian (i.e. their potentiometric level is about 10–11m a.s.l.). A study of the characteristics of the different aquifers in the area confirmed that the shallow and deep aquifers are hydraulically interconnected (Antonelli et al., 1995). All the wells, many completed in different aquifers and depths, show similar water-level fluctuations over a given year, with two minima (spring and autumn) and two maxima (winter and summer).

REFERENCES

Antonelli, R., Fabbri, P., Iliceto, V., Majorana, C., Previatello, P., Schrefler, B. A., Sedea, R.: The hydrothermal Euganean field: a subsidence modelling approach, *World Geothermal Congress*, (1995), 18–31 May, Florence, 1263–1268.

Boaretto, E., Carmi, I., Fabbri, P., Heinemeier, J., Sartori, S., Sveinbjornsdottir, A.E., Yechieli, Y.: Radiocarbon in thermal and fresh groundwater in Veneto Region, Northern Italy. *XVIII International Radiocarbon conference*, (2003), Wellington NZ.

Calvino, F.: Idrogeologia delle falde artesiane a Nord di Vicenza, *Atti Convegno "Attualità e nuovi orizzonti nel reperimento e nell'uso di acque nelle Venezie"*, Padova (1966).

Dal Prà, A., Bellati R.: Distribuzione dei materiali limoso argillosi nel sottosuolo della Pianura Veneta, *Quad. Ist. Ric. sulle Acque* (1977), v. 34, (4), pp. 87-98, Roma.

Dal Prà', A., Bellati, R., Costacurta R., Sbettega, G.: Distribuzione delle ghiaie nel sottosuolo della Pianura Veneta, *Quad. Ist. Ric. sulle Acque*, (1976) v.28, (12), pp. 337-343, Roma.

Fabbri, P.: Transmissivity in the Euganean Geothermal Basin: a geostatistical analysis, *Ground Water*, (1997), v. 35, no. 5, 881–887.

Fabbri, P. , Trevisani, S.: Spatial distribution of Temperature in the geothermal Euganean field (NE, Italy): a simulated annealing approach, *Geothermics*, (2005), v. 34, 617-631.

Gherardi, F., Panichi, C., Caliro, S., Magro, G., Pennisi, M.: Water and gas geochemistry of the Euganean and Berician thermal district (Italy). *Appl. Geochem*., (2000), 15, 455–474.

Passadore, G., Monego, M., Altissimo, L., Sottani, A., Putti, M., Rinaldo, A.: Alternative conceptual models and the robustness of groundwater management scenarios in the multi-aquifer system of the Central Veneto Basin, Italy, *Hydrogeology Journal* (2012) 20: 1-13, doi 10.1007/s10040-011-0818-y.

Piccoli, G., Dal Prà, A., Sedea, R., Bellati, R., Di Lallo, E., Cataldi, R., Baldi, P., Ferrara, G. C.: Contributo alla conoscenza del sistema idrotermale Euganeo-Berico, *Atti Acc. Naz. Lincei*, (1973), v. XI, 103–131.

Norton, D., Panichi, C.: Determination of the source and circulation paths of thermal fluids: the Abano region, northern Italy, *Geochimica et Cosmochimica Acta*, (1978) v. 42, 1283–1294.

Sartori, S., Boaretto, E., Fabbri, P., Sveinbjornsdottir, A. E., Heinemeier, J.: 14C content of Euganean geothermal waters (Veneto, Italy), *XVI International Radiocarbon conference*, (1979), Groningen NL.