Geothermal Heating and Cooling in the FVG Region: the Grado District Heating and the Pontebba Ice Rink Plants

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ABSTRACT

We present two running applications of direct use of low temperature geothermal resources for heating and cooling of public buildings, recently realized in the Friuli Venezia Giulia (FVG) Region - Northeastern Italy - with public fundings.

The *Grado Geothermal Pilot Project* was an ambitious challenge, initiated in 2002 and completed in early 2015, aimed to demonstrate the feasibility and sustainability of a geothermal doublet on the Grado Island (GO), in the northern Adriatic coastal area, by: i) characterizing the geothermal carbonate reservoir of the Grado area, ii) estimating its heat potential, iii) drilling a geothermal doublet, with one production and one re - injection well. The project had a total cost of 5 million € and included two phases. The 1st phase, completed in 2008, confirmed the existence of a low temperature geothermal reservoir within the buried carbonate platform, assessed its geothermal potential and verified the feasibility of the district heating plant in Grado. Seismic and gravity surveys were completed to locate the first exploratory well. Grado - 1 borehole was drilled down to 1110 m, into a terrigenous cover and a Paleogene - Mesozoic carbonate basement high. The 2nd phase (2012 - 2015) included further geophysical prospecting to extend reservoir investigations and to locate the second borehole. Grado - 2 was drilled in 2014, at about one km distance to the East of Grado - 1, down to 1200 m. By December 2014, two km of district heating distribution network was deployed and the first two public buildings were connected.

We focus here mainly on the geophysical and well data and on the pumping tests that were acquired before, during and after the drilling of the two wells. The data set allowed the characterization of the reservoir and the assessment of its geothermal potential. Some of the main results are: the identification of major fault systems and production areas, the comprehension of the hydraulic circulation systems, the assessment of the geochemical facies of waters and of their sustainable utilization. The Grado reservoir is a confined fractured aquifer hosting anoxic fossil seawaters with temperatures up to 49 °C in Grado - 2 (7 °C higher than Grado - 1), pressure of 250 kPa at wellhead and spontaneous artesian outflow of about 100 t/h. Pumping test results indicate a sustainable water production up to 140 t/h. The circulating system is a complex network of permeable vugs and highly trasmissive karst-fractured discontinuities, interested by several fault systems driven by Alpine and Dinaric deformation phases. Interference pumping tests proved the hydraulic connectivity between wells, but, due to the poor system recharge, the hydraulic sustainability of the geothermal doublet must be guaranteed by re - injection. The initial functioning of the district heating plant, envisaging a geothermal heating of several connected public buildings during cold seasons (up to about 3 $MW_{(th)}$ heating load), will allow a significant economical saving of the order of 80 000–100 000 €/yr. Nevertheless, the geothermal reserve affords to foster other relevant uses besides the district heating. Several future perspectives of development are suggested for Grado geothermal potential; 3D thermo - fluid dynamic numerical modelling will optimize the system production and manage the sustainability of the geothermal plant.

The existing cooling system of the *ice rink of Pontebba* town (UD), located close to the Austrian border, was totally renovated in late summer 2012: a open loop heat pump system using groundwater thermal energy was realized and functions both for the ice production and maintenance, and for the heating and hot water needs of the ice stadium. Two ammonia heat pumps (350 kW each) were installed, supported by two production water wells (32 m deep) and one re - injection water well (30 m deep), drilled into the alluvial deposits of the Fella River. A total production rate of up to 200 t/h could be achieved from the shallow unconfined aquifer, with an average temperature of about 8.5 - 9.0 °C. Numerical modelling of groundwater flow supported the assessment of the production and re - injection rates, as well as the evaluation and the minimization of the impacts on the groundwater resource during the plant management in various hydraulic regimes. Over the first two years of operation, cost reductions of the order of 45% have been achieved.

1. INTRODUCTION

The heat flow map of Italy and surrounding Seas (Figure 1) shows several geothermal provinces, ranging from young and active magmatic provinces (e.g. the Tuscan - Tyrrhenian area), where high enthalpy geothermal resources are usually available at shallow depths, to old and cold sedimentary basins (e.g. the Adriatic and Po valley basins) or mountain belts (e.g. Alpine and Apennine chains), where these resources are far too deep. The FVG Plain belongs to a “cold” foreland area having a surface heat flow ranging between 40 - 60 mW/m^2.

The FVG geologic framework is interested by the eastern and the northern part of the Alpine and the Dinaric active belts (with their foredeep and foreland, respectively), by the eastern part of the Po Valley sedimentary basin and by the northern part of the Adriatic basin.

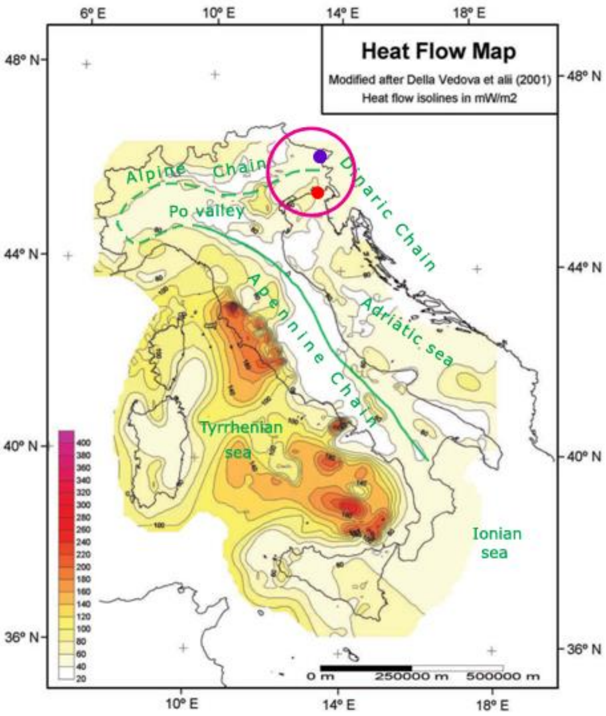


Figure 1. Heat flow map of Italy (modified after Della Vedova et al., 2001). The FVG Region is situated in the pink circle: red and violet dots indicate Grado and Pontebba locations, respectively.

Some weak positive heat flow anomalies are present in correspondence of the buried Mesozoic thrusts, because of the vertical fluid circulation in the carbonate formations. This is particularly noticeable in the FVG southern areas, where low temperature geothermal resources ranging between 40 - 70 °C can be present within 1 - 2 km depth. Local low temperature geothermal systems were detected in correspondence of thrusts system areas, as shown in the Cargnacco - 1 and Cesarolo - 1 boreholes, drilled for oil and gas exploration. Interesting resources are related to local highs in the buried basement and they are well documented by oil exploration and water boreholes in the southern FVG Plain. These highs are approximately present in correspondence of the Cesarolo - Lignano and Grado structural highs (Figure 3). These geothermal resources have an adequate potential to sustain direct use district heating plants.

In the northern FVG mountain areas, the heat flow is quite low (30 - 40 mW/m^2) mainly because of meteoric water circulation; these low temperature resources can foster heating and cooling in closed and open loop system supported by heat pumps.

The abundance of groundwater and recharge in the FVG have, however, a large heat potential since it usually represents a steady source, available at shallow depth and largely renewable. In recent years, the FVG Region launched several calls focused on low temperature geothermal applications (5 calls since 2007) to support heating and cooling of public buildings: they guaranteed substantial EU contributions (up to 300 000 €) to beneficiary public administrations and were designated for geothermal direct uses, including borehole heat exchangers, shallow aquifers and deep geothermal resources (>700m depth).

This paper will present two existing demonstration projects of direct uses of groundwater energy for heating and cooling of public buildings, realized in the FVG Region, thanks to EU contributions and integrational support by national, regional and municipal fund:

- the Grado Geothermal Pilot Project (GGPP), aimed to the realization of a district heating system supported by a geothermal doublet on Grado Island (Gorizia Province),
- the open loop groundwater heat pump system realized for the ice rink stadium in Pontebba (Udine Province).

2. THE GRADO DISTRICT HEATING PROJECT

2.1 Geological Framework

Grado Island is situated in the lagoon part of the FVG Plain (Gorizia province); this plain constitutes the eastern extension of the Po Valley and hosts well developed unconfined and confined aquifers within a complex hydrogeological system evolving in a mainly N - S direction. The Northern (Upper) Friuli Plain is characterized by an alluvial unconfined aquifer made out of highly permeable gravels, extending from the Pre - Alps to the resurgence spring line. The resurgence belt sets a hydrological boundary, between the Northern and Southern Plain, which extends in almost E - W direction and generates spring and river arising, where the water table surface intersects the surface topography. Here - hence, the unconfined aquifer evolves into several multi - layered confined aquifers; this complex hydrogeological system is hosted in a heterogeneous sedimentary wedge, showing a progressive thickness increase in a W direction and towards the Adriatic Sea and locally overtaking a thickness in excess of 500 m; it is made of a wide stratigraphic succession:

- Plio - Quaternary sediments deposited in alluvial - littoral - shallow marine environments at several trasgressive - regressive cycles; this terrigenous cover is mainly made by sandy and silty layers, having a wide range of primary porosity: several artesian aquifers, hosted in higher permeability sediments, are separated by acquicludes and acquitards;
- Oligo - Miocene Alpine Molasses made of prevailing marly intervals with few sandstones, deposited in dominant shallow marine environments, that can host artesian aquifers;
- Paleogene Dinaric foredeep Flysch turbidites made of prevailing marly intervals rich of pelagic deep marine faunas; these sediments generally lack of relevant aquifers.

The Paleogene - to present clastic wedge lays on Mesozoic (principally) limestones, having a combined morphological (“Friuli Platform”, with platform–shelf–talus facies; “Belluno Basin”; “Dinaric Foredeep”) and structural (fractures, faults, thrusts) genesis: its upper surface presents several culminations having mainly dinaric and antidinaric directions (Figure 2 and Figure 3). The whole system is interested by tectonic features still in progress, as part of the complex regional framework due to the coexistence of the foredeep and the foreland of both the Alpine and the Dinaric active chains.

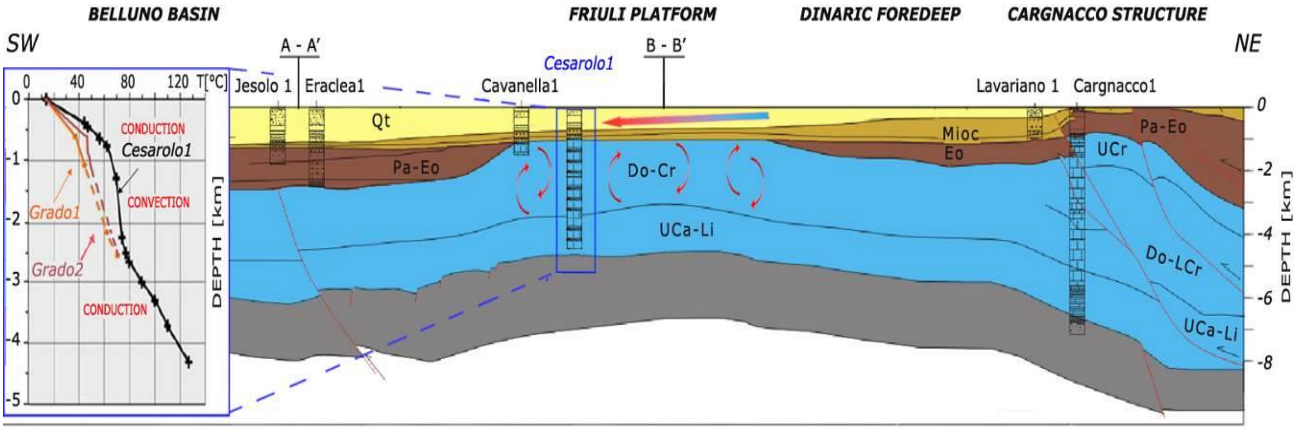


Figure 2. A simplified NE - SW regional geological section of the low Veneto - Friuli Plain: Plio - Quaternary sediments (yellow), Neogene (mustard) and Paleogene marls (brown), Mesozoic limestones (cyan). Positioning of the section is indicated in Figure 3. The box on the left shows the trend of the geotherms measured in Cesarolo - 1, Grado - 1 and Grado - 2 wells.

2.2 Conceptual Geothermal model

The carbonate platform highs host a porous and fractured hydrothermal reservoir that allows convective circulation of geothermal waters in the upper 1 - 2 km, with advective flux and heat upwellings, whereas deeper carbonate intervals are characterized by predominant heat conduction. The upper convective cells generate anomalous temperature gradients in the overlapping soft sediments, hosting hydrothermal fresh aquifers warmed up by heat conduction from below (Figure 2). In this framework, without taking into consideration local faults or limited structures, Neogene and Paleogene marly successions can be considered as a very low – permeability seal, functioning as a hydraulic barrier. The carbonate hydrothermal reservoir and its covering successions were the target of several studies and geophysical campaigns conducted in the Friuli Plain in the last few decades and conducted by the Department of Engineering and Architecture of Trieste University, DEA - UNITS (Della Vedova et al., 1988, 2008; Calore et al., 1995; Nicolich et al., 2004, 2006, 2008).

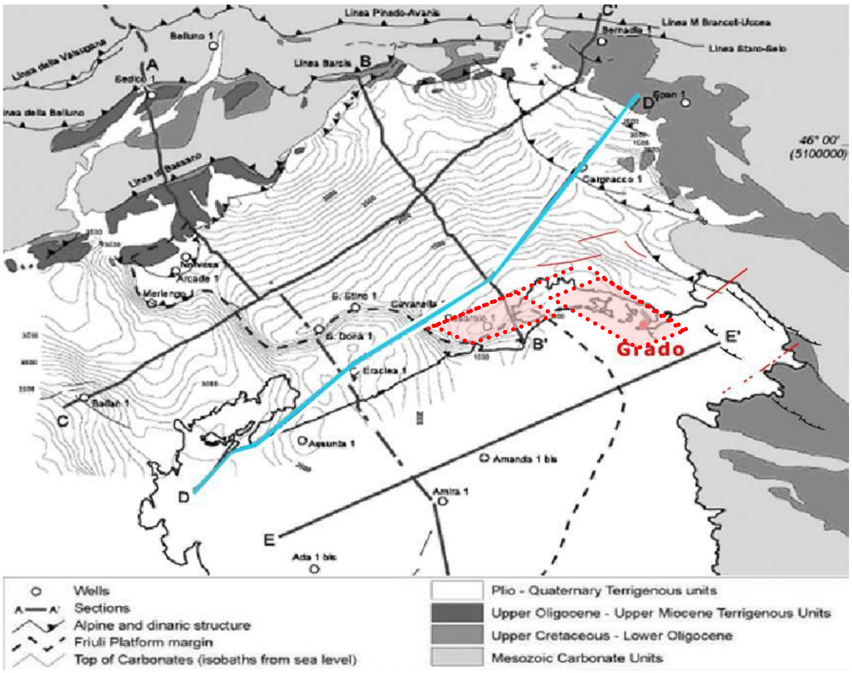


Figure 3. Isobaths map of the carbonate top in the Veneto - Friuli Plain. The dotted line tracks down the western limit of the platform; the positive geothermal anomalies are pink; cyan line indicates the section of Figure 2. The location of Grado Island is indicated.

Geophysical data were integrated with published geological and geochemical data, including oil deep boreholes and water wells. This data set allowed to:

- reconstruct several regional geological sections, across the Plain,
- map the top of carbonate and of alpine molasses,
- draw depositional limits of formations and main tectonic structures.

The isobath map of the Mesozoic carbonates top is characterized by culminations with mainly dinaric NW - SE and antidinaric NE - SW orientations (Figure 3): these structural highs turn out to be located in the Cesarolo - Lignano area and in the Grado Lagoon area.

2.3 The Grado pilot project

The Geological Survey of the FVG Region and the Grado Municipality carried out the two main phases of the *GGPP* with the support of European and national fundings:

- The first phase was aimed to characterize the geothermal carbonate reservoir of the Grado area, to estimate its geothermal potential and to obtain a preliminary geothermal potential assessment of the deep geothermal reservoir by geophysical surveys and by the drilling of the first exploration borehole; it was supported by 2000 - 2006 DOCUP – 2 EU fundings (2.5 million €) and was completed in July 2008;
- The second phase was aimed to the drill the second borehole, to carry out the new potential assessment and the production capacity, and to realize the surface distribution network connecting the two wells; this phase was supported by POR - FESR fundings (2.5 million €), started in 2012 and was completed in December 2014 – January 2015.

Geophysical Surveys and Boreholes drilling

Several geological and geophysical surveys were carried out to characterize the system and to locate the wells: seismic and gravity surveys were completed on land (in the surroundings of Grado Is.) and offshore, both in shallow waters of the Grado and Marano Lagoons, and in offshore areas of the Gulf of Trieste (Nicolich et al., 2006; Busetti et al., 2009). According to the geological context highlighted from the geophysical data, Grado - 1 exploration borehole was drilled (using direct circulation rotary rig) on the sand beach at the westernmost end of Grado city, at about 100 m from the shoreline. The well intercepted the carbonatic reservoir at 618 m and reached a total depth of 1110 m.

The second geophysical campaign was completed in 2012 (Figure 4) in downtown Grado and in its surrounding lagoon (Della Vedova et al., 2013). Several data sets were acquired to extend the investigation and improve the knowledge of the local reservoir, highlighting faulted areas and relative highs, and to reduce the geothermal resource risk for the second well:

- 121 new gravity stations acquired in the surroundings Grado area, integrated with 108 gravity measurements collected every 50 m along the three seismic lines (location in Figure 6c);
- 7.5 km of multichannel seismic reflection profiles acquired with seismic vibrator source and Hydrapulse, along three lines crossing each other and integrating the previously acquired seismic dataset;
- multi - offset vertical seismic profiles (VSP) performed in Grado - 1 with the seismic source located at increasing distances from the well of 45, 266, 449 and 939 m (Poletto et al., 2013).

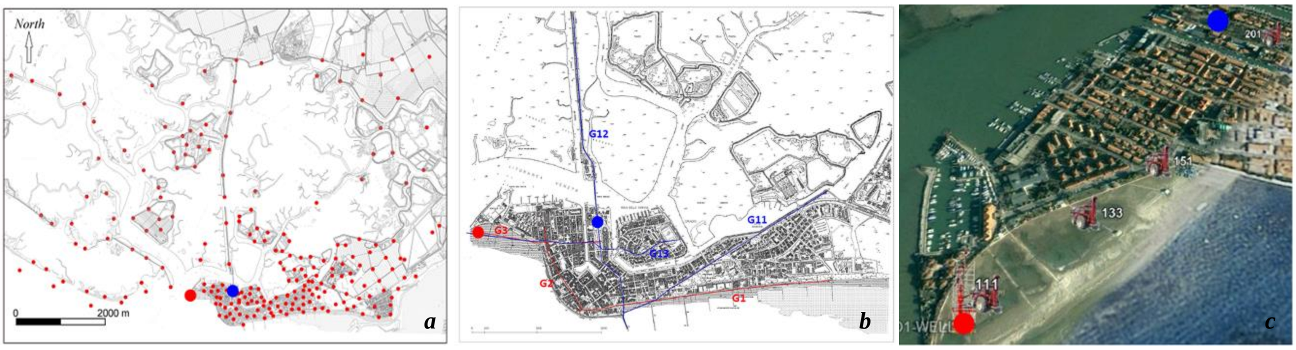


Figure 4. Map of the geophysical survey in the Grado area; Grado - 1 and Grado - 2 boreholes are shown in red and blue full dots, respectively. a) Map of gravity stations including measurements acquired in 1987. b) Location map of the seismic reflection surveys completed during 1st and 2nd phase (respectively red and blue lines). c) Location map of Grado - 1 multi - offset VSP survey.

The results of the geophysical investigations allowed to appropriately locate the 2nd borehole of the geothermal doublet; Grado - 2 borehole was drilled on a local structural high in the center of the city, about one km to the East of Grado - 1. The drilling was accomplished by a reverse circulation rotary rig, down to 272 m, and by a direct circulation rotary rig on derrick, down to the borehole bottom (Figure 5).

The drilling program of both boreholes adopted decreasing bit diameters with depth (24", 17"½, 12" ¼, 8" ½); from almost 680 m deep, the lower interval into the carbonatic reservoir was initially left open hole for logging and downhole measurements. K55 API casings (20", 13"3/8, 9"5/8) were installed and cemented in the upper sections. During the completion of both wells, an accurate monitoring of geology, drilling parameters, mud logging (in terms of temperatures, density, viscosity, conductivity, pH, total dissolved solids) was conducted. Advanced geophysical borehole logs were acquired in open-hole carbonate reservoir, such as: resistivity, acoustic full waveform velocity, neutron, porosity, spectral gamma ray, density, caliper, deviation, circumferential borehole imaging, spinner and fluid temperature logs.

Figure 5. Grado - 2 drilling by direct circulation rotary rig on derrick.

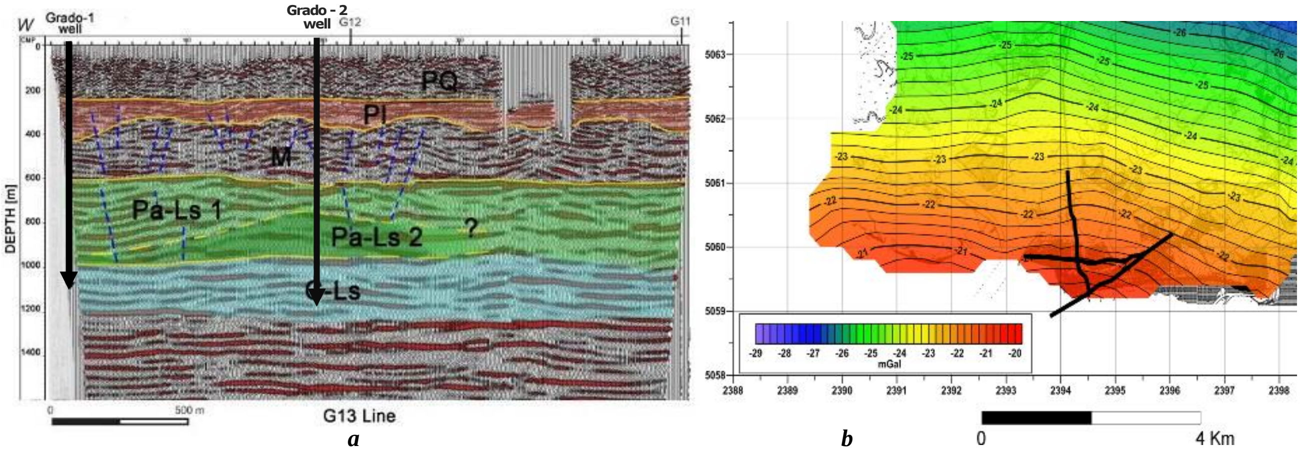
Three cores were acquired in Grado - 1 at the top and the bottom of the intercepted reservoir; moreover, permanent Pt temperature sensors were installed on the outside casing at 300 and 695 m depth in order to monitor temperature recovery after reinjection. Well development included washing - back, airlifting (Figure 8) and packer acidification focused on crucial intervals of the deeper section, in order to reduce the skin effect, improve permeability and remove mud cake and cuttings. A 7” diameter production liner was installed in the reservoir of the production well Grado - 2.

Integration and interpretation of multidisclinary data

All data collected in Grado - 1 well, such as cuttings, cores biostratigraphy, borehole geophysical measurement (Della Vedova et al., 2008; Cimolino, 2010) were integrated into a preliminary numerical thermo-fluidodynamic model and compared with geological features from on land outcrops and offshore data, including oil and water boreholes (drilled in Veneto - Friuli plain and Croatia offshore). Seismic sections were calibrated with Grado - 1 succession and water wells stratigraphies. Previous gravity data (Della Vedova et al., 1988) were integrated with the new measurements to produce the Bouguer anomaly gravity map, which highlights the basement culminations (Figure 6b). This multidisciplinary and integrated analysis, including pumping tests in Grado - 1, provided a first assessment of the geothermal reservoir and resource (artesian outflow of ~ 100 t/h, 41 - 42 °C, 250 KPa, 17‰ salinity), defining:

- stratigraphic - structural constrains, encountering for the first time Paleogene carbonatic series in the Lower Friuli Plain and new evidences of an important regional tectonic feature in the Grado area, such as the presence of a distal Dinaric thrust fault NW - SE oriented (Cimolino et al, 2010);
- average values and vertical changes in lithology, porosity, resistivity and elastic *moduli* of the reservoir rocks.

VSP measurements acquired during the second geophysical survey provided a detailed depth velocity model for P - S waves and the lateral change in elastic properties between Grado - 1 and Grado – 2 (Poletto et al., 2013; Della Vedova et al., 2015), also useful to calibrate the time to depth conversion of surface seismic data [*Integrated Geophysical Characterization of Geothermal Reservoirs*, POLETTO et al. - extended article in this book]. The reservoir was explored eastward of Grado - 1 and its geological features and physical properties were defined by VSP analyse, filling the scale gap between the Grado - 1 borehole data and the multichannel seismic profile (Figure 6a) in Grado city.



a b

Figure 6 .a) Multichannel seismic Line G13, with geologic interpretation after Grado - 2 drilling: PQ (Plio - Quaternary sediments), Pl (Pliocene sediments), M (Molasses: Alpine and Paleogene flysch), Pa-Ls (Paleogene Limestones), C-Ls (Upper Cretaceous Limestones).b) Map of the Bouguer gravity anomalies with the position of the 3 multichannel seismic lines acquired for locate Grado - 2.

The geothermal reservoir assessment was confirmed by Grado - 2 drilling, identifying also major fracture systems hypotisized in seismic interpretation. The wells stratigraphies characterize the geothermal reservoir within the carbonate platform structural highs, covered by about 620 m of terrigenous sediments. This cover is composed by less than 300 m of Plio - Pleistocene sediments, followed by about 250 m of Neogene marly - sandy successions (Alpine Molasses), rich in external neritic faunas, and more than 40 - 50 m of pelagic faunas Paleogene turbidites (Eocene Flysch).

The limestone shelf presents both Rudist rich Upper Cretaceous intervals (from about 1000 m depth) and a thick Paleogene Limestones interval, that was encountered for the first time in the Low Friuli Plain; Paleogene Limestones show classic *Alveolinidae - Nummulitidae – Orbitolites facies*. The transition from Paleogene to Mesozoic limestones includes clear evidences of sub - aerial exposure and karstic phenomena; the K - T boundary turned out to be well marked in both the boreholes at about 1005 - 1010 m depth by high Uranium picks, also recognized in the Northern Adriatic offshore (Cimolino et al., 2010).

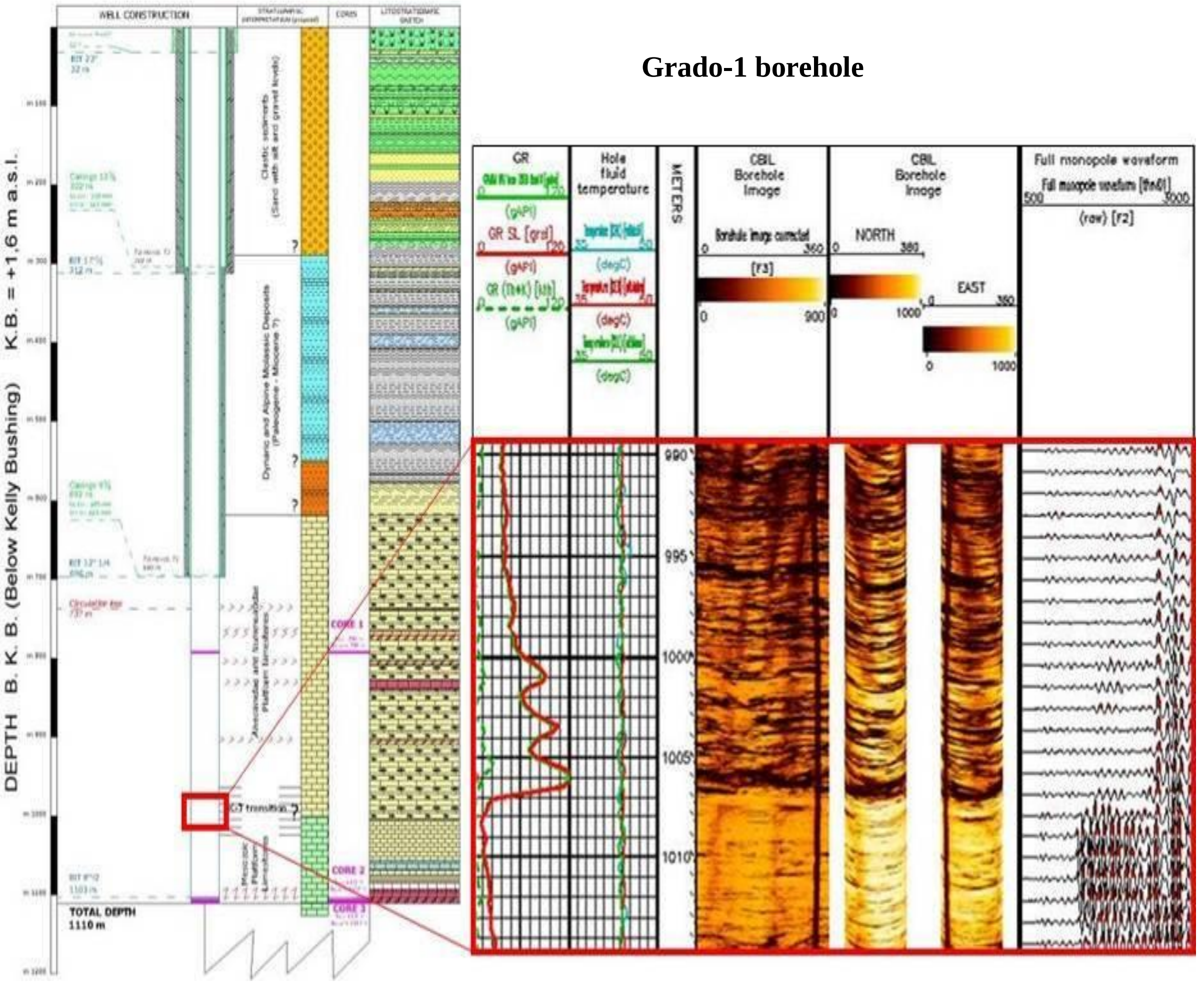


Figure 7. Grado - 1 borehole profile showing cased and open hole intervals, interpreted stratigraphy and an example of geophysical logs, such as: gamma ray, imaging and waveform logs in correspondence of the K - T boundary transition zone.

Geophysical logs and core data provided detailed information on the carbonate reservoir properties: the production area was detected and discontinuity families were identified according to orientation, intensity and origin. The carbonates are characterized by several fracture/faults subsystems having a combined tectonic - karst origin, with individual open karst - fractured discontinuities, widespread paths along permeable vugs and deep seated faults: these subsystems provide vertical geothermal circulation along unknown pathways. The integration of borehole and geochemistry data with the geophysical surveys allowed to roughly image the Grado Lagoon reservoir as a NW - SE oriented high, delimited by Dinaric and anti - Dinaric structures (Figure 6c): the footprint of these structures is somehow observable both in the Bouguer gravity map and in the seismic profiles acquired in the Gulf of Trieste (Busetti et al., 2009, 2010). This local high was interpreted, in accordance with the regional framework, belonging to the outer Dinaric deformation front, indicating active stress regime in the Grado Lagoon area (Cimolino et al., 2010). The stratigraphic sequence and the tectonic framework devised in the Grado area result to be rather different from the Cesarolo - Lignano structures, where the top of the carbonate platform is characterized by Lower Cretaceous formations, covered directly by the Lower Miocene Cavanella Group units (Cesarolo - 1 well; Nicolich et al., 2004) and where a SW - NE orientation dominates the area. On the contrary, the Grado reservoir geological scheme can be directly related to northern Istria geological settings and outcrops, as shown into stratigraphy and logs acquired in northern Dalmatia offshore wells (Placer, 2005, 2007; Tari - Kovačić et al., 1998).

The reservoir volume was then estimated (Table 1), as constituted, on a first approximation, by three interfingered subsystems having variable average effective porosities corresponding to massive, fractured/faulted and intermediate carbonate domains, as suggested by the porosity log data: very low porosity (<1%), low porosity (1 - 3%) and good porosity (8 - 10%). A rough total volume of 0.6 km^3 of moving geothermal waters was estimated for the reservoir of about 75 - 100 km^3. This corresponds to about 6 - 8*10^6 m^3 of moving geothermal waters per one km^3 of reservoir.

Table 1. Estimation of geothermal reservoir volume and effective porosity.

Carbonatic Reservoir		**Effective porosity**
Total surface	50 km^2	85%: n_e < 1%
Average thickness	1.5 - 2 km	10%: n_e 1 - 3%
Total volume	75 - 100 km^3	5%: n_e 8 - 10%
Moving geothermal waters = 0,6 – 0,8 km^3		

Pumping tests and potential assessment

Airlifting and spontaneous water production tests were also realized before pumping tests (Figure 8). Several pumping tests were conducted separately in the two boreholes and a final interference hydraulic test was performed pumping from Grado - 2 and monitoring pressure changes in Grado - 1. Pumping tests were conducted with increasing drawdown steps (by submersible pumps) and a unique pressure recovery step. CTD divers were also positioned in wellheads to measure hydraulic heads (pressures), temperatures and electric conductivities for more than a month (before, during and after tests) to monitor the recovery of the geothermal system towards static conditions.

Figure 8. Combined operation of washback by airlifting, performed in Grado - 2.

One of the project main targets was the characterization of the geothermal fluids and the assessment of the geothermal potential of the Grado reservoir.

The reservoir is a confined fractured aquifer, having a salinity of more than 30‰ and a temperature of 49.5 °C at the bottom of Grado - 2 and of about 42 °C in Grado - 1. Geochemical analyses of the geothermal waters, including Strontium isotope measurements (Petrini R., oral communication), indicate that the fluid is an anoxic seawater having presumably an age of more than 10 million of years. This means that the geothermal waters circulate through a complex network from the older Cretaceous to the younger Paleogene limestones.

A spontaneous artesian outflow of about 100 t/h (laminar flow up to 28 L/s) with a pressure of 240 kPa at wellhead was reached in Grado - 2, after two acidification cycles. With a maximum pumping rate of about 150 t/h (42 L/s), the maximum drawdown in Grado - 2 turned out to be of 23 m from the initial static water level (Figure 9), with fluid temperatures of 48 °C at wellhead. Considering the spontaneous artesian outflow of about 100 t/h and assuming 20 °C as a useful temperature difference, the natural thermal power of Grado - 2 turns out to be 2,3 $MW_{(th)}$. Since a sustainable production was estimated in about 126 t/h (~35 L/s), the available potential thermal power is assessed in about 3 $MW_{(th)}$.

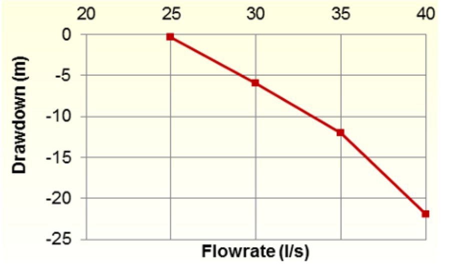


Figure 9. <u>Drawdown vs. flow rate</u> plot from pumping tests in Grado - 2.

In order to verify the properties of the reservoir, pumping steps in Grado - 2 (without rejection) and the hydraulic interconnection between wells were monitored. With a maximum flowrate of 42 L/s in Grado - 2, the hydraulic head in Grado - 1 decreased by about 35 cm, demonstrating that Grado - 1 is within the radius of influence of Grado - 2 (even when the latter is producing spontaneously) and highlighting the existence of a good hydraulic interconnection between wells. Following the pumping stop, there is a quick, but partial (about 20 cm), pressure recovery in Grado - 1, confirming the presence of a good permeability and transmissivity nearby; however, the full recovery of the initial static pressure (pressure build up) needs several days to be reached, yet suggesting the presence of far subsystems with low transmissivity preventing a quick system recharge. The system as a whole is practically a closed reservoir because it has no efficient recharge capacity; the re - injection is then absolutely required to guarantee the hydraulic sustainability of the production well and a long lasting life of the geothermal heating plant.

Numerical thermo - fluid dynamic modelling (*Comsol Multiphysics* software) was carried out as a support tool for the final design of the district heating system (Marcon, 2012) and for the optimization and managing of the DH geothermal plant. The numerical simulations (Figure 10) considered the coupling of the production/re - injection wells and were set up with logging, pumping and interference tests results; they constrain the initial conceptual model, the physical properties and the boundary conditions of the numerical model, including the presence of a high permeability fracture system, which acts as a preferential drain. Modelling is still in progress and will allow to: evaluate geothermal doublet performances, monitor over time reliable scenarios of the production capacity and verify long - term sustainability of the district heating system, as soon as we will gather information during operating and networking seasons to calibrate the simulations.

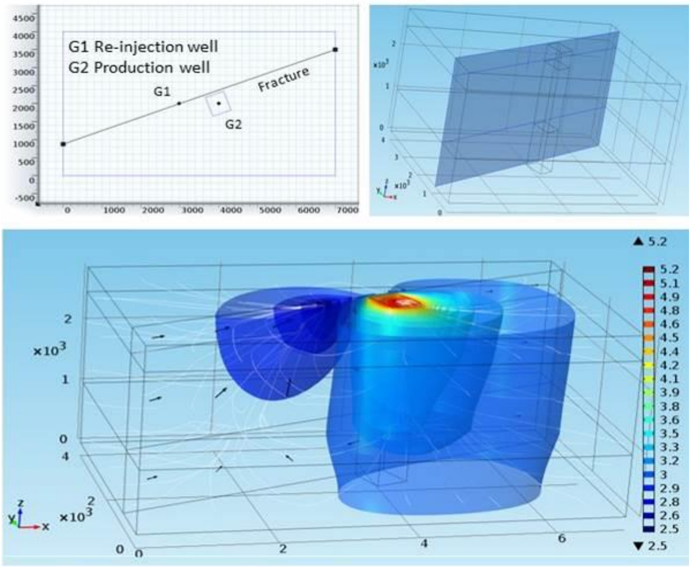


Figure 10. Reservoir modelling framework and pressure field imaging around production and re - injection wells.

2.4 Status and perspectives for the Grado district heating plant

The deployment of the distribution network of the *GGPP* required horizontal directional drillings under the port canal downtown Grado to connect Grado - 1 and Grado - 2 wells (Figure 11); the distribution network is currently about 2 km long and will be further extended. By the end of 2014, four public buildings were connected to the network (2 schools, library). The connection with other four public buildings is foreseen during 2015.

Figure 11. a) Installation of part of the distribution network after the drilling of Grado - 1 borehole. b) Horizontal directional drilling realized under the Grado port canal for the laying of pipeline in 2014.

The heat potential of the Grado Lagoon geothermal system (assessed in about 2.3 – 3.0 MW$_{(th)}$) and the building thermal loads allowed to estimate the district heating capacity factor and related energy savings. The Grado district heating, when completed, is expected to work on average for about 6 month/year, 12 hours/day; with such limitation, the capacity factor will be about 0.2 and the related energy savings should be of the order of 80 000–100 000 € /yr.

However, the geothermal reservoir is able to foster further long - lasting applications (such as: heating of more buildings, greenhouses, fishfarming, balneotherapic uses, resort and touristic activities). On the island, there are 8450 inhabitants, which could increase to twice as much during summer seasons. The technical and economic feasibility of the geothermal pilot district heating system in Grado city could be sustainable, if the capacity factor increases to about 0.4 or more. In this case, the energy savings could double or even more.

The cost of the distribution network represents about 40% of the total investment and should not be included in the cost of the geothermal project, since it represents a primary infrastructure cost.

Several future perspectives of development can be suggested for the GGPP:

- further geophysical exploration should focus on deep structures and deformation zones, giving a contribution for the design of the heating network extensions and for the drilling of a second production well, re - injecting in one single well (Grado - 1);
- enhanced studies of the geothermal reservoir recharge and fluid geochemistry should detect recharge areas, deep circulation circuits and potential mixing phenomena;
- monitoring of the geothermal reservoir parameters and of the district heating plant during one year at least for the management optimization of the overall system and for the assessment of potential impacts during operation;
- calibration of the 3D numerical thermo - and fluidodynamic model to optimize the production and re - injection fluid rates and manage the long - term sustainability of the geothermal plant.

3. THE PONTEBBA ICE RINK PLANT

Pontebba is a small town of about 1500 inhabitants situated in the E - W Fella River valley, in the northeastern mountain area of the Udine province, at a few kilometer distance from the Austrian border; it is placed in the eastern part of the wide Alpine Chain. This area marks the transition from the Carnic Alps to the Julian Alps.

The Pontebba ice rink building, which hosts about 40 000 ice skaters every year and has a parterre area for almost 1800 spectators, was completed in December 2002. The requalification of the ice rink heat pump refrigeration system became quickly a problem: the existing heat pumps were obsolete and unlawful (by 2009) since they used R22 Freon rink and plant was functioning exclusively as a refrigeration system supported by a cooling tower and the parterre areas were lacking of the heating system. Moreover, the old plant was not efficient, since the heat produced by refrigeration was totally rejected in atmosphere by means of the evaporating tower.

A proposal for a new plant with groundwater Ammonia heat pumps having greater energy efficiency was suggested by DEA – UNITS considering heating and cooling and hot water production. The new project included the installation of an open loop groundwater heat pump system, with two coupled 350 kW heat pumps. The total cost amounts to about 600 000 €, whose 300 000 € were funded by PORFESR 2007 - 2013 - Activity 5.1.b “Exploitation of renewable sources (geothermal)". The requalification works were also interested by the benefits provided by the Finance Act 2008 (Legge n°424, 28th December 2007), which allows the recovery of 55% of investment of this type of system, up to a maximum amount of 30 000 €.

The present - day ice rink plant of Pontebba represents, therefore, a working example of efficient direct use of groundwater thermal energy for heating and cooling of public buildings, completed in the RFVG territory.

3.1 Geologic Framework

Pontebba is located in the eastern part of the Alpine Chain, extending mainly in an E - W direction, and it is just close to the junction with the Dinaric Chain, extending mainly in a NW - SE direction. These thrust - fold orogens, produced by passive margins convergence, are characterized by complex wedges of thick and cold sedimentary successions having a thickness up to 10 - 12 kilometers. The mountain area is characterized by a surface heat flow of about 40 - 60 mW/m^2 (Figure 1), mainly because of the major disturbances active within the upper few kilometers (topography, erosion, water circulation, exhumation …).

Focusing on the local geologic settings, Pontebba is located in the Fella River valley (Figure 12). The area is characterized by a carbonate rock basement (nearly outcropping or superficial), which can be wrapped by up to about one hundred of meters of deposits made of alluvials and slope debris: these porous sediments represent the river unconfined aquifer, abundantly fostered by meteoric precipitations from the surrounding catchment basin in Julian Alps. The groundwater temperature ranges from 8 to 9 °C and is excellent to support heat pumps for refrigerating the ice rink.

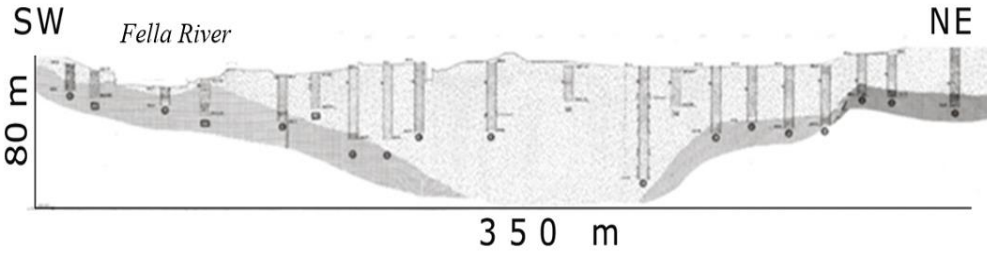


Figure 12. Lithostratigraphic section across the Fella River valley near Pontebba, from existing geotechnical investigations (Comin C., personal communication).

3.2 Water bodies as heat source in open loop systems

Groundwater bodies can be exploited by “open loop systems” to support “groundwater heat pumps (“GHP”), which transfer thermal energy between the aquifer and the buildings by means of production and re - injection wells. In mountain areas, these heating and cooling plants are often feasible using surface water bodies. Open loop systems present several advantages when surface waters and groundwaters are abundant: they need limited investment, have a long lifetime and require a limited maintenance with low operational costs. Moreover, they are now particularly suitable, due to the benefits offered by ammonia heat pumps; they offer the best advantages in terms of efficiency and energy savings (with reduction of operation costs), reliability (no limitation) and minimal environmental impact with practically greenhouse effect insignificant (ozone friendly). Two ammonia heat pump groups (350 kW each), manufactured by Zudek s.r.l. - Muggia TS, were installed.

3.3 The new GHP system: project and realization

The FVG Region and the Pontebba Municipality carried out the requalification of the ice rink heat pump system with the installation of an open loop groundwater heat pump system: ZUDEK - EUREKA® realized the project with the contribution of DEA – UNITS for the resource characterization, wells design and the assessment of the environmental impact. The energy requalification of the old cooling system of the Pontebba ice rink was completed in late summer 2012 supported by the unconfined aquifer of the Fella River (Figure 13).

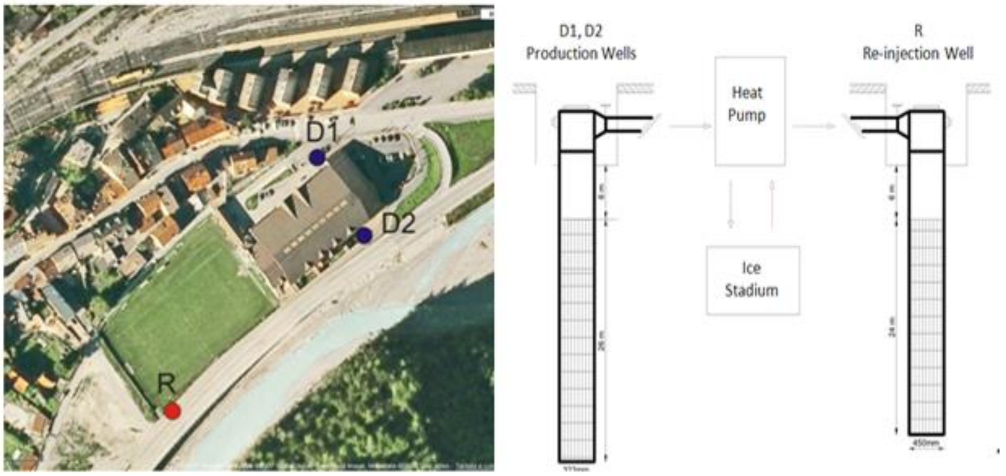


Figure 13. Location of production and re - injection wells outside the ice stadium of Pontebba (UD).

The system was designed to function both for the production and the maintenance of the ice rink, and for heating the rink itself, the locker rooms, the ice stadium seats and for the hot water needs.

The groundwater is produced with submersible pumps from two production wells (D1 and D2), located upstream the Fella River and drilled down to 32 m depth. The re - injection water is returned into the same aquifer through a 30 m deep discharge well (R), located 175 m downstream (Figure 13). Each production well is accompanied by a piezometer drilled at 10 m distance. Step drawdown pumping tests and interference hydraulic tests were completed (Figure 14) in order to assess the transmissivity of the aquifer and to verify the hydraulic response to different production and re - injection rates (up to 90 L/s). Temperatures, conductivities and hydraulic heads were monitored by CTD divers. The characteristic curves of the three wells were elaborated individually considering the drawdown from the initial static water level as a function of the pumping rates. The single sustainable production was estimated in 20, 45 and 60 L/s for, D2, D1 and R wells, respectively. Maximum sustainable total production rates were estimated in 234 t/h for D2 and D1 wells, whereas for R well the maximum re - injection flowrate was estimated in 260 t/h (72 L/s).

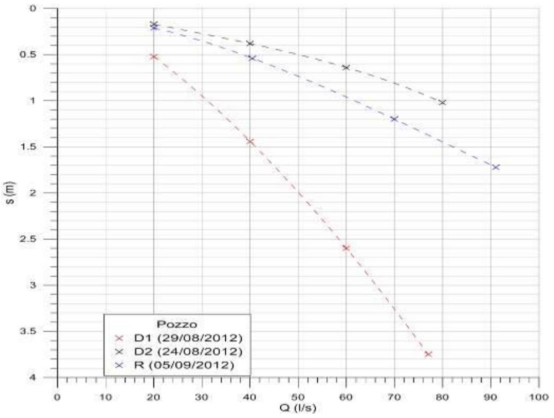


Figure 14. Pumping tests drawdown for production and re - injection wells.

Numerical modelling was also carried out (*Visual Modflow* software, Figure 15) to simulate the aquifer response both in high and in low water recharge conditions, under maximum pumping rates of 72 L/s. Thermo - fluid dynamic modelling (*Fluent* software) was also carried out to evaluate the space and time evolution of the re - injected thermal plumes into the aquifer.

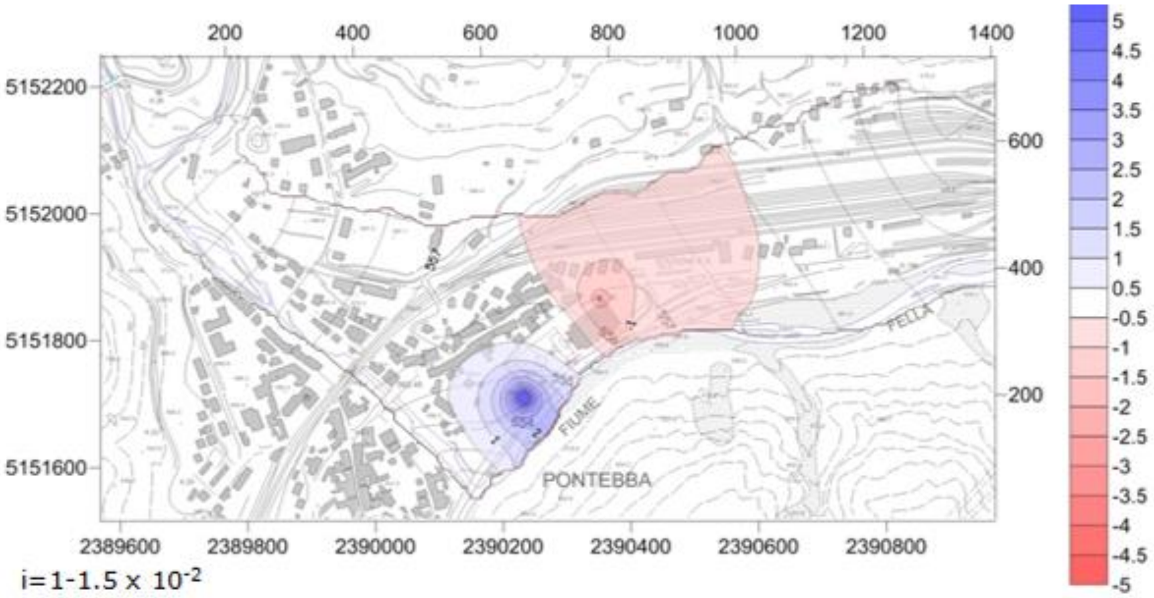


Figure 15. Numerical simulation for the groundwater flow in dry season conditions under maximum pumping and re - injection rates (72 L/s). The production and re - injection cones are shown by hydraulic head isolines.

3.4 Plant performance

The Pontebba groundwater open loop system started functioning in September 2012. A telemetry remote control system, which constantly monitors flow rates, temperature and quality of pumped and re - injected waters, was installed to optimize the management of the whole plants. The two ammonia heat pumps installed can operate under different working schemes, fed by on average temperature of pumped waters of 9 °C:

- the total cooling capacity is 640 kW, with cooling fluid down to - 10 °C for the ice rink,
- the total heating capacity is 720 kW, with warming fluid up to 40 °C for both the lockers room and the ice floor leveling and heating of the parterre area and eventually the rink itself.

Over the first two years of operation, the new system ran for 4400 hours (about 2200 hours/yr from statistics of September 2014); a maximum production rate of up to 200 t/h (50 L/s) was achieved from the unconfined aquifer. The open loop system first economic savings are:

- reduction of the electrical consumption of - 40.5%,
- annual energy savings were calculated in about 33 000 € per year (annual reduction of heating costs 17 000 € per year),
- annual avoided CO_2 emission was estimated in 244 t per year.

Moreover, Pontebba open loop heat pump plant turns out to be certainly reliable and a life cycle of 25 years can be hypothesized.

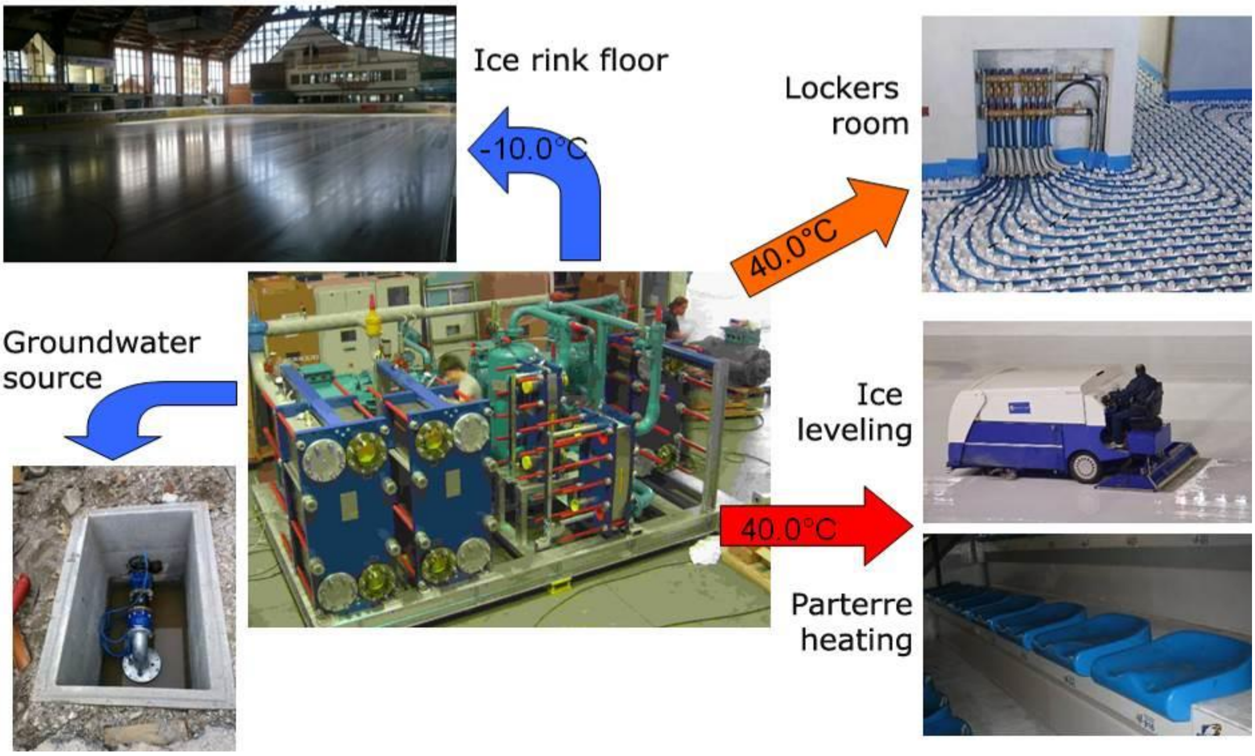


Figure 16. Working scheme for heating and cooling of Pontebba open loop heat pump plant.

4. CONCLUSION

The *Grado Geothermal District Heating Pilot Project* and the *Pontebba ice rink open loop heat pump plant* represent two working example of efficient direct use of geothermal low enthalpy for non - residential heating and cooling of public buildings.

It is pointed out that low enthalpy geothermal resources have a significant heat energy potential at a regional scale, also in geologic cold areas. Since thermo - mineral and geothermal resources are present in similar geologic contexts of the cold Adriatic region, further geothermal doublets and open loop heat pump plants can be realized elsewhere.

The groundwater resources present several advantages; they are largely renewable, often available at shallow depths, easy to integrate with other conventional and locally available RES and, finally, present limited footprint and low CO_2 mission.

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