EXPERIMENTAL STUDY OF THE HYDRODYNAMIC INTERFERENCE IN A LOW ENTHALPY GEOTHERMAL AQUIFER OF THE VENETO REGION

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ABSTRACT

A long duration variable rate pumping test was carried out at the low enthalpy geothermal well VICENZA 1 (Veneto Region - Italy), from August, 1990 to August, 1991. The test aimed at defining the long distance/long term hydraulic behaviour of the geothermal carbonate reservoir via the response of some observation wells, located up to 30 km far away the test well, and at determining the extent of the regional interference caused by the exploitation at the mean project pumping rate of 95 m^3/h. The 68°C water, withdrawn during the test, was utilised by the installations of the geothermal district heating project of Vicenza town. The results, mainly the response of the geothermal well Villaverla 1, located 12 km north of the test well, allowed the drawing of different hydrodynamic scenarios fitting the measured drawdown values. The test represents the first application of an experimental approach followed by the regional Authority in order to regulate the exploitation of a geothermal aquifer. The outcome of the work shows that only an experimental approach may supply concrete and reliable indications on the subject.

1. INTRODUCTION

The central-westem part of the Veneto Region is characterised by the existence of significant low enthalpy hydrothermal resources, a part of which, giving rise to hot spring systems, are known since the roman epoch. Another part was ascertained in the last forty years by well and borehole drillings for water and hydrocarbon research. Eventually, recent investigations, carried out for the European Community Commission, pointed out the existence of probable resources within not very deep aquifers which may represent future targets.

Up to 1989 the direct uses of such resources were confined to spa and resort heating of Abano and Euganei Hills area. There, the exploitation of hot springs (up to 70°C) started in the early years of this century. The first shallow wells were drilled in the fifties. At present, more than 200 operating wells, up to 700 m deep, supply 2600-3600 m^3/h of 40 to 90°C water, supporting a tourist organisation of remarkable socio-economical importance, consisting of about 170 spa and hotels. The high mass flow, although ruled by a Veneto Region law which forecasts observation wells for the water level control and imposes a maximum yield of 3 l/min per bed, gave rise to a significant piezometric lowering and seems to cause local subsidence phenomena.

In 1989-1990 the Vicenza geothermal project, consisting of a single well, 2150 m deep, supplying 100 m^3/h of water at 68°C for district heating, was on line. In this frame, the Veneto Region Authority dealt with the subject of the multiple exploitation of local geothermal resources, starting with the study of possible hydrodynamic interference between the Vicenza well and the Euganei-Berici geothermal basin.

As a matter of fact, the new italian law N. 896, December 25, 1986, regarding the discipline of the geothermal resources research and exploitation, forecasts that the exploitation of local resources (below 20 Mwt) is pertaining to the Regions.

In the specific case, the geologic information allowed to exclude a significant interference between the Abano and Vicenza sites, located more than 25 km away, but no quantitative data actually supported that hypothesis.

In order to study the hydraulic behaviour of the aquifer under exploitation and to set a reliable evaluation tool to be utilised also in future utilisation projects of the regional geothermal resources, it was decided to follow an experimental approach, via the execution of a long duration pumping test.

2. HYDROGEOTHERMAL OUTLINE

The study area (Fig. 1) is located in the Veneto plain (northern Italy), between the Adige and Brenta rivers, south of the alpine and pre-alpine belts. The knowledge of the buried sequence of the plain is supplied by some hydrocarbon exploration wells whose location is shown in Fig. 1.

The general conditions are exemplified by the Vicenza 1 and Villaverla 1 well lithologs, as it is shown in Figs. 2 and 3. Below a variable thickness Quaternary cover, where shallow aquifers with significant cold water circulation are found, a pre-Permian to Miocene sequence, similar to the outcropping sequence of the pre-alpine belt, is present. Three main aquifer units were recognised within said lithostratigraphic sequence. These are, from the top:

- Complex of shallow aquifers: in the carbonate permeable intervals of the Oligo-Miocene formations. The base aquiclude is represented by the Eocene Priabona Marl. The hydrogeothermal interest of this unit is negligible

- Main aquifer: in the late Triassic to Paleocene carbonates, including the Scaglia Rossa, Biancone, S.Vigilio Oolite, Noriglio Limestone and Dolomia Principale formations. This sequence, whose thickness is in the order of 1500 m, usually show a good secondary permeability. It is the main geothermal aquifer unit of regional extent, exploited by the Vicenza 1 and Villaverla 1 wells and by all the wells of the Euganei-Berici area. The base aquiclude is formed by volcanics of Ladinian age, from 200 to more than 500 m thick, extending without discontinuity in the Berici-Euganei area, in the Vicenza plain and in the pre-alpine belt

- Complex of deep aquifers: mainly consisting of the carbonate intervals of the Permo-Triassic sequence. The permeable levels are alternated to impervious marl and siltstone layers and to evaporitic strata. The base of the sequence is represented by the crystalline schist of the pre-Permian metamorphic basement. Hydrogeological evidences show that, at least in its upper part, the crystalline schist is characterised by a fair secondary permeability, so that the hydrothermal circulation taking place within the complex of deep aquifers may also extend to the relevant depth of the metamorphic basement.

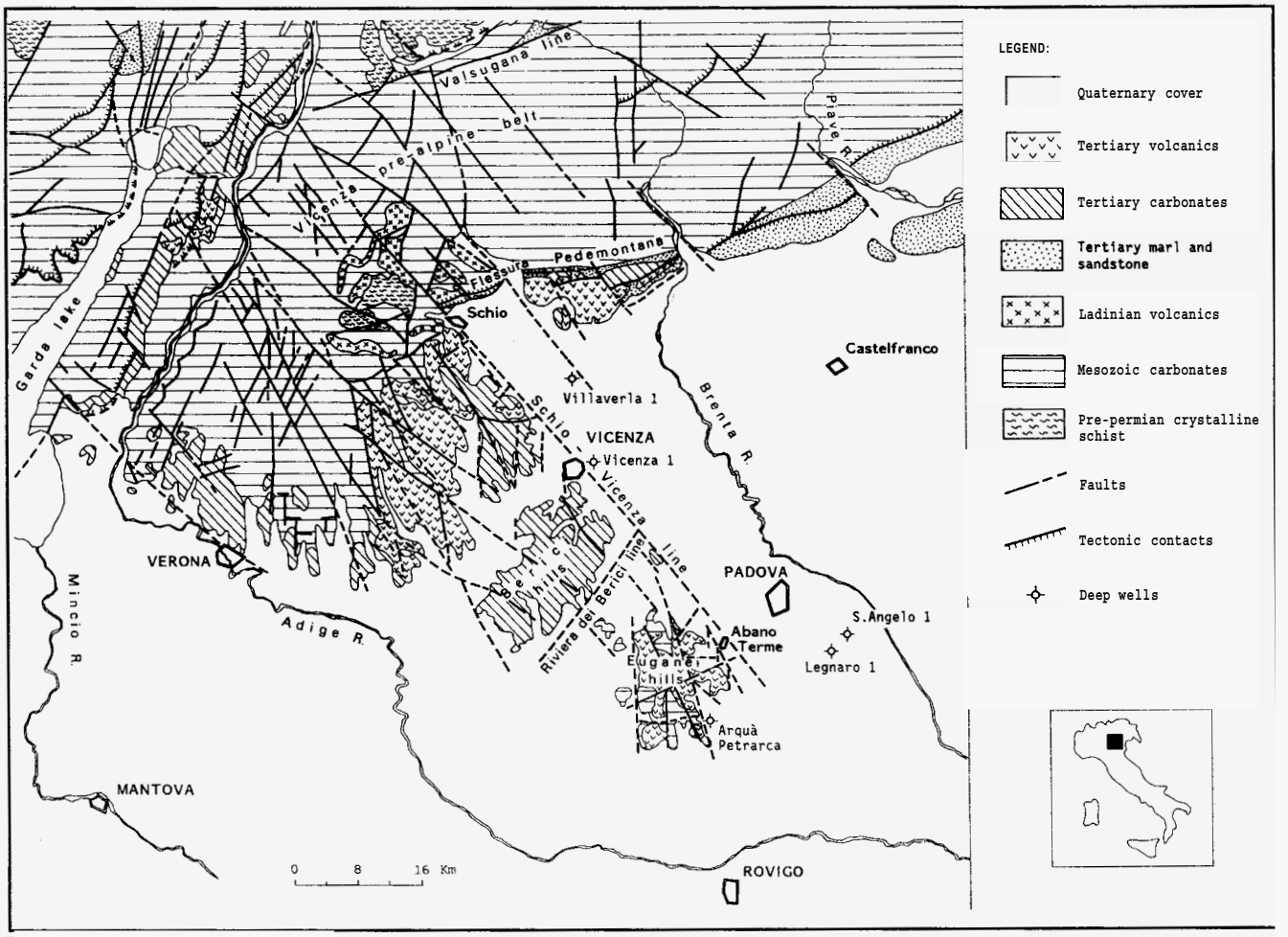


Fig. 1 - Position map of the study area

The aquifer geometry is controlled by the main fault and fold systems. Within the whole area (Fig.1) included between the Flessura Pedemontana to the north, Padova - Legnaro 1 - S.Angelo 1 to the south, the Schio-Vicenza line to west and the Brenta river to the east, the main aquifer can be represented as a 1200-1500 m thick plate, comparatively undisturbed, showing a gentle plunge toward south to south-east with a dip component of few degrees. The aquifer top is found at depth ranging from 1200 to 1600 m b.s.l.. The aquifer outcrops in the Vicenza pre-alpine belt, at elevations from 600 to 2200 m a.s.l., to the north of the Flessura Pedemontana (a sharp fold with ENE-WSW trend associated to minor faults) which originates an upward displacement of several hundred meters. The NW-SE Schio-Vicenza fault causes an upthrow of the western sector variable from 200 to 700 m: the Vicenza-Villaverla and Euganei areas are found on the opposite sides of this fault. Eventually, to the east of the Brenta river, step fault systems give rise to a strong downward displacement of the carbonatic aquifer top.

In this frame, the Vicenza 1 and Villaverla 1 wells are located within the comparatively undisturbed plate, and the Euganei-Berici thermal area is located in a remarkably fractured sector, where crossing systems give rise to a fault block pattern.

Geologic, geochemical, isotopic and geothermal data show the existence of two main types of water, calcium-bicarbonate and alkaline-chloride waters, flowing within two reservoirs which can be differentiated as far as the lithologic nature, the elevation of recharge area and the circulation depth are concerned these are: the main aquifer and the complex of deep aquifers. The two circuits are clearly separated by the thick impervious volcanics of Ladinian age. Mixing between the two water-types may only occur in correspondence of strongly fractured belts, as it seems the case of the Euganei hills area, where upward migration of chloride waters to the main aquifer occur. The main characteristics of the two circuits are the following:

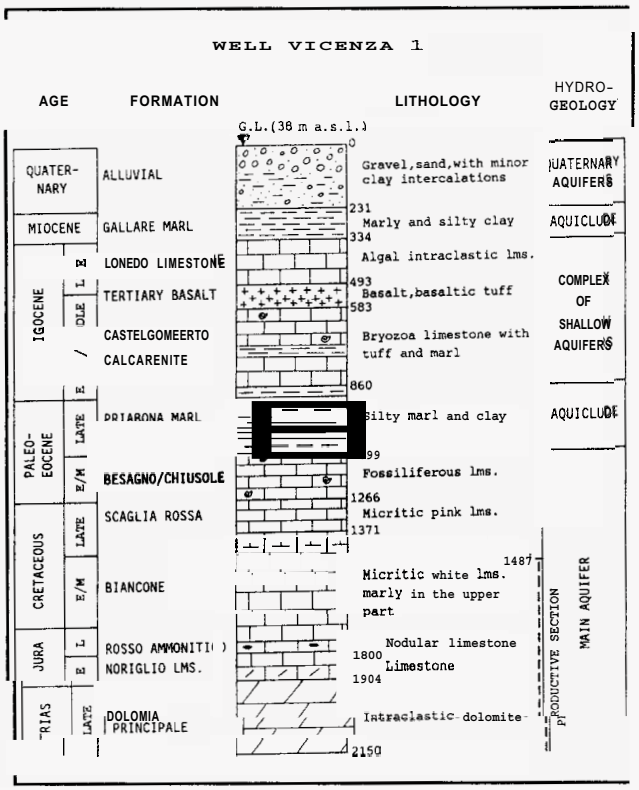


Fig. 2 - Well Vicenza 1 - Geological and hydrogeological sequence

• Main aquifer circuit - values of $\delta^{18}O$ indicate that the recharge area is found at elevation ranging from 1000 to 1500 m a.s.l., i.e. in the pre-alpine belt. Water is of the calcium-bicarbonate type, with very

low salinity (less than 0.5 g/l): this suggests a comparatively short and fast circulation. The thermal waters of the Vicenza plain (Vicenza 1 and Villaverla 1 wells) are of this type: these are found within the main reservoir at depth ranging from 1480 to 2400 m b.g.l. and show well head temperature of 68-70°C. They are of the bicarbonate type with salinity from 250 to **480** mg/l. The recharge area may be located to the north, in the Vicenza pre-alpine belt. The water infiltrated in said area may quickly move downward following the structural attitude of the Flessura Pedemontana.

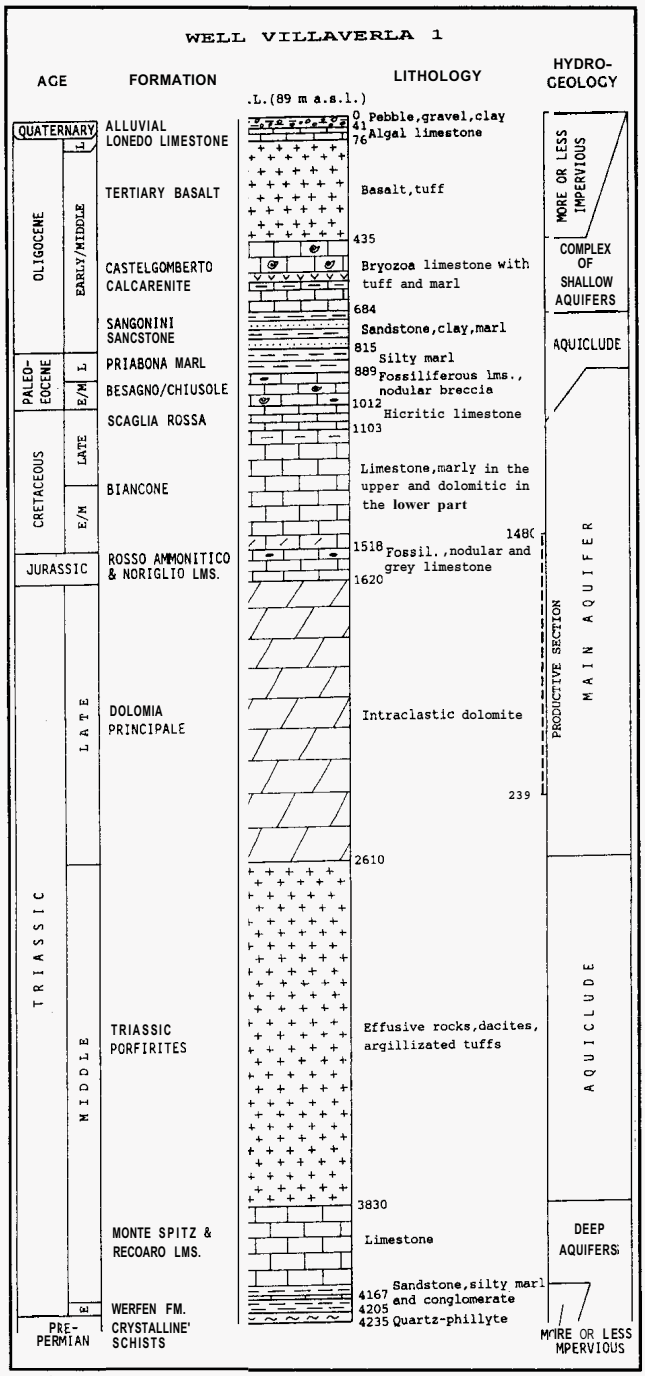


Fig. 3 - Well Villaverla 1 - Geological and hydrogeological sequence

• Deep aauifers circuit - values of $\delta^{18}O$ indicate that the temperature of the infiltration water is about 5°C lower than the main aquifer one. This suggests the alpine origin of the recharge, at elevation of more than 1500 m a.s.l. Water is of the alkaline-chloride type, with salinity from 1 to 6 g/l. This points out a comparatively deep circulation within the carbonatic-evaporitic formations of early Triassic age and, probably, the upper part of the crystalline basement. This seems to be confirmed by geothermomemc determinations which suggest a circulation depth from 5000 to 7000 m, in agreement with the depth range of said formations. In the Euganei area, the main family of thermal water is of this type, but also water of the first type and intermediate salinity waters (where the SO^4 ion becomes the prevailing anion) are found. There is a clear'direct correlation between salinity and temperature.

Given the foregoing, the point is that in the Euganei-Berici area the separation between the two aquifers may be virtually cancelled by the fracture systems intersecting the rock bodies, as it is suggested by the fact that water of the deep circuit is found within the formations of the main aquifer. ***So,*** although it is unlikely, the hydrodynamic interference between the Vicenza and Euganei areas cannot be excluded "a priori".

3. EXPERIMENTAL TEST VICENZA 1

The variable rate pumping test at the geothermal well started in august, 1990 and lasted up to august, 1991. The max. pumping rate (two steps of two months each, between November, 1990 and April, 1991, followed by recovery tests and alternated to periods of minor pumping rate) was about 100 m^3/h and the 68°C water was utilised by the existing installations for space heating of part of Vicenza town. Instruments for continuous monitoring of water level, temperature, elecmcal conductivity and pumping rate were installed at well head. Furthermore, a control system, consisting of a number of observation wells located between Vicenza and Abano sites and exploiting different aquifers at various depths, was selected. The main observation points were:

• Villaverla 1 geothermal well, located about 12 km north of the test well and completed in the same aquifer. A quartz transducer installed at well head supplied water level data from august, 1990 to august, 1991
• one of the main observation wells of the Abano geothermal area, with continuous water level data since 1976.

3.1 Results and interpretation

Atmospheric pressure data of Vicenza station were collected in order to apply corrections due to aquifer barometric effects. The max. drawdown at the test well was about 100 m; the water level of most of the observations wells stood virtually unaltered or resulted to be affected by local conditions.

The Abano well was characterised by a water level fluctuation of about 8 m which resulted to be strictly dependent on the spa hot water demand fluctuations and quite similar to the variations recorded in the previous years. **This** pointed out that the extent of thermal water extraction in the Euganei-Berici area (up to 3600 m^3/h) obliterates the possible short-medium term interference effects due to the 100 m^3/h pumping at the Vicenza 1 well.

The main information was supplied by the Villaverla 1 observation well. After correcting the water level data for barometric effects, a continuous decline trend (from the fist to the last day of the test) was observed. The drawdown rate changed as follows, according to the pumping rate variations of the test well:

• from 0.11 to 0.92 cm/day, during shutdown periods
• from 0.04 to 0.32 cm/day, during periods of pumping at 25 m^3/h
• from 1.00 to 1.03 cm/day, during periods of pumping at 95-100 m^3/h, giving rise to a drawdown of 0.62 m after 60 days.

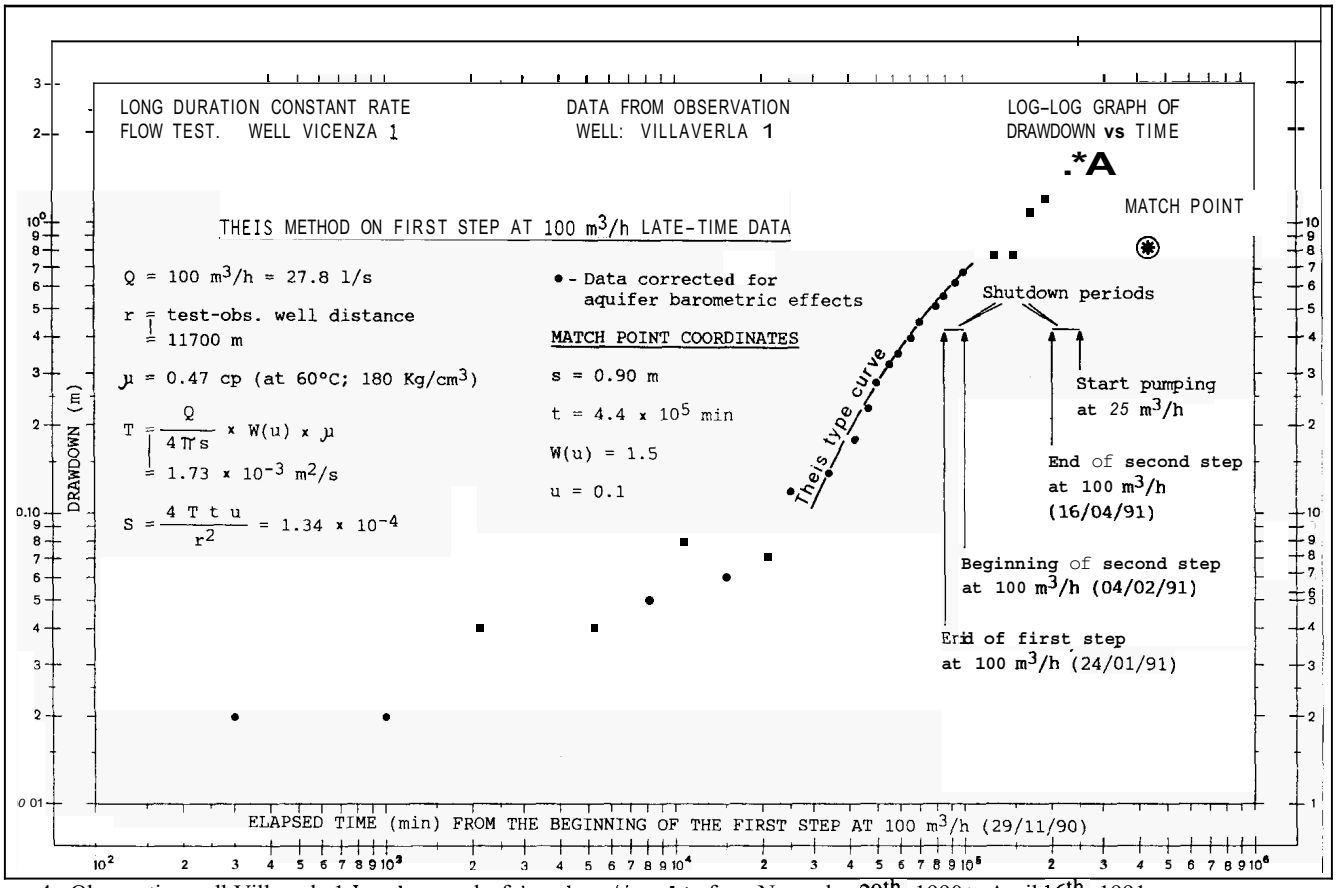
It is possible to observe that the maximum drawdown rate occurred during the periods of maximum extraction rate at the test well, and also that there was no water level recovery at the observation well when the pump was shut down at the test well (Fig. 4). It is to be mentioned that the year of the test was characterised by scarce rainfall, and the lowest rate of decline (0.04 cm/day) was recorded in the period from May to July, 1991, during which both a low pumping rate at Vicenza (25 m^3/h) and snow melting in the area of outcropping of the aquifer contributed to reduce the negative trend. So, the water level decline recorded at Villaverla appears to be due

to either the hydrodynamic interference or to climatic factors which modify the charge conditions of the aquifer.

The interpretation of the test data was firstly carried out under the hypothesis that the Villaverla water level decline was due to the hydrodynamic interference with Vicenza. Well and aquifer parameters were calculated in order to supply input data for hydrodynamic simulations. The Transmissivity values resulted to be comprised between 4.2 x 10^{-4} m^2/s at Vicenza and 2 x 10^{-3} m^2/s at Villaverla site. The permeability is of the *same* order in both sites, as the net thickness is 185 and 900 m, respectively. The Storage coefficient could be evaluated only at Villaverla site: from the aquifer barometric efficiency values from 1 to 2.6 x 10^{-4} were calculated; the pumping test data interpretation supply a wide range, fiom 6.2 x 10^{-5} to 5.5 x 10^{-4}.

The interpretation of the observation well data during the fust period of pumping at 100 m^3/h is shown in Fig. 4.

The Theis method was applied to late-time drawdowns, from 27 to 57 days, and the following values were calculated: T = 1.73 x 10^{-3} m^2/s; S = 1.34 x 10^{-4}.



g. 4 - Observation well Villaverla 1. Log-log graph of drawdown/time data from November 29th, 1990 to April 16th, 1991

Hydrodynamic simulations aiming at supplying provisional space/time interference values were then carried out. To comply with the previously mentioned hypothesis, the following assumptions were made:

- the aquifer is continuous and isotropic in the whole area of study comprised between Vicenza, Villaverla and Abano
- the long term/long distance aquifer hydrodynamic behaviour is that of an equivalent unconsolidated homogeneous confined aquifer, representing both the fracture system and the block flow, and the drawdowns can be predicted by means of the Theis equation
- the drawdown recorded at Villaverla is only due to water extraction at Vicenza.

A two-dimensional ground-water flow model for the calculation of time-variant hydraulic heads and drawdowns was used. The calibration allowed to obtain a couple of T and S values, comprised within the range suggested by the test data interpretation, such to give rise to the minimum mismatch between measured and simulated drawdowns. The difference resulted less than 4% and of the same sign at both Vicenza and Villaverla sites. Anyway, it was shown that small variations of Storage Coefficient within the range of experimental values could greatly affect the long distance interference figures. The S value obtained by calibration, accounting for a drawdown of 0.62 m at Villaverla after 2 months of continuous pumping at Vicenza site at 100 m^3/h, was 1.5 x 10^{-4}; a value of 2.6 x 10^{-4} would supply adrawdown of 0.33 m and a value of 5.4 x 10^{-4} a drawdown of 0.07 m.

The long term hydrodynamic simulations were carried out according to the most critical interference hypothesis, fitted by the storage value of 1.5 x 10^{-4}. The exploitation at Vicenza was simulated by a continuous production rate of 100 m^3/h and the drawdowns were simulated after elapsed time from 2 months up to 30 years. The interference values are hereinafter summarised:

- after 2 months: 0.62 m at Villaverla; 0.01 m at Abano
- after 1 year: 2.50 m at Villaverla; 0.53 m at Abano
- after 5 years: 4.69 m at Villaverla; 2.18 m at Abano
- after 30 years: 7.23 m at Villaverla; 4.58 m at Abano

The theoretical approach was then verified. In fact, if the aquifer is of continuous extent between Vicenza, Villaverla and Abano sites, the water abstraction carried out at Abano must give rise to hydrodynamic interference at Vicenza and Villaverla and the relevant drawdown values can be simulated by application of the same model. The history of the abstractions carried out at Abano geothermal field was reconstructed and simulated via the hydrodynamic model. Low pumping rates from the fifties up to 1970 and a mean pumping rate of 425 l/s from 1970 up to date were considered. As the history of the abstractions is not known in detail, different simulations were carried out and a min-max range of interference drawdown values was obtained. Simulated drawdowns were then compared with measured values. The latter indicate a water level drop of 1.13 m at

Villaverla from 1980 to 1990 and 0.43 m at Vicenza from 1984 to 1991. The simulated values relevant to the same periods are from a min. of 10 to a max of 14 m at Villaverla, and from a min. of 7 to a max. of 9 m at Vicenza. This means that the measured rate of decline is in the order of 6-12 % of the simulated one.

These results show that some of the previously defined critical assumptions are not consistent with the actual hydrogeologic conditions. As already mentioned, a moderate increase of S coefficient may be sufficient to achieve a reasonable compromise between measured and simulated figures.

From a practical standpoint, the evidence brought by this, counter-check allowed to reduce the provisional long term drawdown values. The outcome shows that a continuous pumping of 100 m^3/h at Vicenza may give rise to an interference drawdown of 0.40 - 0.50 m at Abano site after *30* years.

4. CONCLUSIONS

The outcome of the experimental test pointed out the compatibility of the exploitation foreseen by the Vicenza geothermal project with the existing thermal water utilisation.

The interpretation of the test results and the simulations aiming at defining the long term/long distance aquifer behaviour show that, the hydrodynamic interference caused by the Vicenza geothermal well at the mean project pumping rate of 95 m^3/h will be weak at the Abano site. The Vicenza project pumping rate is small and the effects will be overwhelmed by the local pumping, whose extent reach as high as 3600 m^3/h.

As additional geothermal development of the region may have significant effect on the existing installations, further work has to be undertaken in order to assess a reliable model of the Veneto thermal reservoirs. After this first application, it is readily apparent that the experimental tool stands as the more reliable alternative in order to fix a preliminary regulation of the low enthalpy geothermal resources exploitation.

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REFERENCES

Antonelli, R., Barbieri, G., Dal Prà, A., De Zanche, V., Grandesso, P., Mietto, P., Sedea, R. and Zanferrari, A. (1990). *Carta geologica del Veneto.* Regione del Veneto, Servizio Geologico d Italia. Selca, Firenze. 31pp

Leoni, P. (1987). Il teleriscaldamento geotermico della città di Vicenza. *Notiziarw Ordine Ingegneri Verona,* Vol. 3(18), pp. 3-17

Panizza, M., Slejko D., Bartolomei, G., Carton, A., Castaldini, D., Demartin, M., Nicolich, R., Sauro, U., Semenza, E., and Sorbini, L. (1981). Modello sismotettonico dell'area fra il Lago di Garda e il Monte Grappa. *Rend. Soc. Geol. It.,* Vol.4, pp. 587-603.

Piccoli, *G.,* Bellati, R., Binotti, C., Di Lallo, E., Sedea, R., Dal Prà, A., Cataldi, R., Gatto, *G.O.,* Ghezzi, *G.,* Marchetti, M., Bulgarelli, G., Schiesaro, *G.,* Panichi, C., Tongiorgi, E., Baldi, P., Ferrara, *G.C.* Massari, F., Medizza, F., Iliceto, V., Norinelli, A., De Vecchi, G., Gregnanin, A., Piccirillo, E.M. and Sbettega, *G.* (1976). Il sistema idrotermale euganeo-berico e la geologia dei colli euganei. *Mem. Ist. Geol. e Mineral. Un. Padova,* Vol.30, pp. 1-267.

Pieri, M. and Groppi, G. (1981). Subsurface geological structure of the Po Plain, Italy. *C.N.R. - P.F.G.,* RF 414.