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High pressure artesian wells to tap Torbido Spring, Italy

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ABSTRACT: Torbido Spring is located at the foot of Mount Sirino (Basilicata, Italy). From the bottom upwards the geological formations include: Flinty Limestones with high secondary permeability, forming the spring aquifer; Siliceous Schists consisting of radiolarites and multicoloured jaspers; and Galestrino Flysch, formed of argillites and marls. The Spring is singular in that the artesian waters from the limestones which are at a depth of 80 m here, come to the surface because of the marked fissuring of the Siliceous Schists. The headworks consist of a system of unpumped wells. The groundwaters are intercepted before they leak away in the detrital surface cover and before they lose their hydrostatic head (more than 4 bar above ground level). The maximum discharge which can be abstracted and handled by the wellfield and appurtenant works is around 300 l/s. This permits peak demand to be met without any waste of resources and guarantees the annual hydrologic balance between recharge and discharge. These objectives are attained by continuous monitoring of the significant hydrogeological and hydraulic parameters.

1 INTRODUCTION

Torbido Spring provides an example of the role played by geological phenomena which can result in groundwater flow being preferentially vertical. Such conditions create hydrogeological and technological problems for the rational use and conservation of groundwater resources.

Mount Sirino is a tectonic window. Lagonegro I Unit which forms the mountain is bounded by the Lagonegro II Unit to the north, the Liguride Unit and Carbonate Platform Units to the east, the Liguride Unit to the south and Carbonate Platform Units to the west (Fig. 1).

The mountain itself is characterised by outcrops of a succession belonging to Lagonegro I Unit, originated from the deformation of Lagonegro Basin sediments during the tectonic phases which led to the building of the Apennines during the Tertiary (Scandone 1972).

From the bottom upwards Lagonegro I Unit consists of:

- Flinty Limestone Formation: dolomitic limestones with flint bands and nodules (Upper Triassic);
- Siliceous Schists Formation: multicoloured radiolarian jaspers, siltites and red and green marls (Upper Jurassic-Upper Triassic);
- Galestrino Flysch: argillites, marls and dark-grey siliceous limestones (Lower Cretaceous-Upper Jurassic).

The succession forms a brachyanticline with Flinty Limestones in the core; the southern limb of the structure connects up to the south with a synform fold. The structure is truncated by faults at Il Vallone gorge.

There are axial culminations and depressions on the N-S axis of the structure.

The Spring is located where the Torbido Gorge - cut into the Siliceous Schists - emerges from a deep ravine.

For many years the Torbido Spring was held to be a barrier spring due to an impervious sill. However, field investigations and schematic flow models have revealed a number of incongruent points.

The jaspers possess exceptional mechanical properties, primary permeability being absolutely negligible, while secondary permeability is very variable, depending on the degree of fracturing.

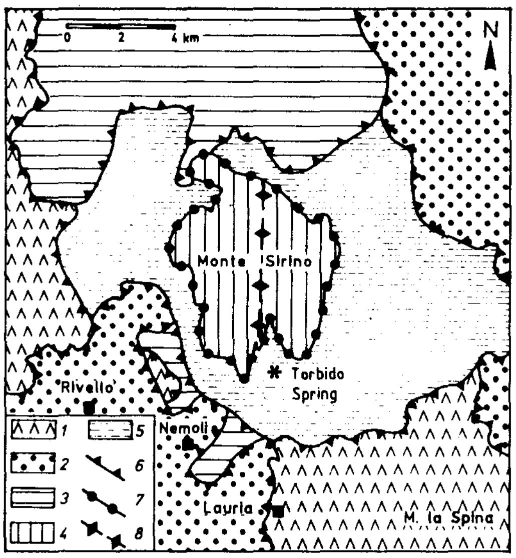

Fig. 1 - Structural schematic. 1) Platform Unit; 2) Liguridi Unit; 3) Lagonegro II Unit; Lagonegro I Unit; 4) Flinty Limestones and Siliceous Schists; 5) Galestrino Flysch; 6) Tectonic contact; 7) Limit of water-bearing formations; 8) Main axis of structure.

Despite the fact that the bottom of the gorge reaches the elevation of the resurgence, it is dry upstream of that point. Downstream, instead, water oozes from the clayey-marls of the Galestrino Flysch in many places, giving rise to permanent widespread surface runoff.

Piezometers drilled upstream of the Spring encountered the Siliceous Schists for the most part, as well as a thin shallow water table. As it was originally thought that these shallow groundwaters fed the Torbido Spring, a system of drainage galleries was built; these provide an average discharge of about 100 l/s.

Despite the construction of these galleries, however, a considerable amount of spring water continued to flow freely, the average discharge being estimated to be around 315 l/s, a figure which could not be justified on the basis of the presumed size of the aquifer and the poor hydrogeological properties of the Siliceous Schists.

The hydrogeological model of the Torbido Spring thus had to be reconsidered and the idea was explored of the existence of a substantial vertical flow from the much more extensive limestone aquifer (with greater transmissivity) to the ground surface.

2 GEOLOGICAL AND STRUCTURAL CHARACTERISTICS OF THE SPRING

Argillites and siliceous marls belonging to the Galestrino Flysch outcrop in this area, while jaspers and radiolarites belonging to the Siliceous Schists Formation occur right in the highly-incised channel of the Torbido.

At between 96 and 116 m below ground level, underlying the jaspers there are grey dolomitic limestones with bands and nodules of black flint.

Locally the formations occur as an asymmetric fold striking roughly NNE-SSW, the western limb having the steepest dip (20 to 30°) (Figs 2 and 3). In the spring area there is an axial culmination on the axis of the fold which induces a decidedly southerly dip.

Here the Siliceous Schists dip below the Galestrino Flysch and come to the surface again about 3 km south near Il Vallone, where the structure is interrupted by normal faults which bring it into contact with the Lagonegro II Unit and with the Liguride Unit.

The jasper beds, which outcrop along the steep slopes upstream of the Spring, are visibly affected by a system of subvertical tension fractures that markedly increase the permeability of the rocks along the hinge of the fold, into which the gorge has cut its bed. This effect reaches a maximum in the Spring area where another system of fractures is superimposed on the first, at the axial culmination.

3 HYDROLOGIC AND CLIMATIC CHARACTERISTICS

Torbido Spring lies at 905 m a.s.l, while the highest point of the catchment basin is 1907 m a.s.l. (Mount Sirino). Rainfall and temperature data are available from a station at about 650 m a.s.l. (LL.PP. 1922-1987). Precipitation is of the maritime type, so it is influenced by the vicinity of the Tyrrhenian Sea and the mountain (Fig. 4). Mean annual rainfall is 1832 mm.

There is generally only one minimum temperature and one maximum temperature during the year. The climate is moderate, the mean annual temperature being 13.4 °C.

According to the Thornthwaite-Mather and Turc methods, evapotranspiration is 590 mm, so an average of 1242 mm of rainfall is available for infiltration and runoff (Thornthwaite, Mather, 1957) (Turc 1954).

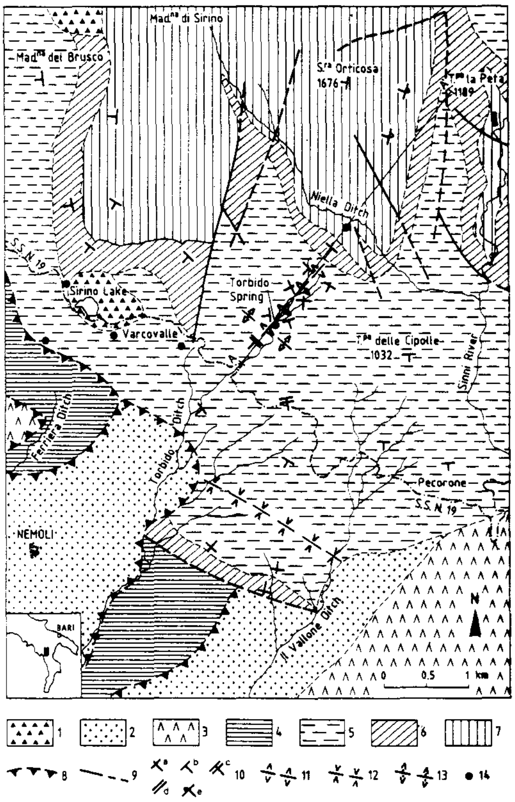

Fig. 2 - Geological map. 1) Detritus; 2) Liguride Unit: argillites and siliceous marls; 3) Platform Unit: limestones and dolomitic limestones, subordinately marly clays; 4) Lagonegro II Unit: clayey marls, siltites and sandstones, subordinately limestones with bands of flint; Lagonegro I Unit; 5) Galestrino Flysch: argillites and siliceous marls; 6) Siliceous Schists Formation with multicoloured jaspers and radiolarites; 7) Flinty Limestone Formation: dolomitic limestone with flint bands and nodules; 8) Overthrust; 9) Fault; 10) Attitude and dip of strata: (a) 0-10°, (b) 11-45°, (c) 46-80°, (d) 80-90°, (e) overturned; 11) axis of secondary antiform structure; 12) axis of secondary synform structure; 13) axial culmination; 14) spring.

The presumed catchment basin of the spring measures 8 km^2, which gives an annual effective rainfall volume of 9.9 Mm^3, equivalent to an average discharge of 315 l/s, which is exactly that of the average from the Spring, determined through a series of measurements.

Since the available rainfall and temperature data were recorded at a station with a lower elevation than the average of the basin, it can

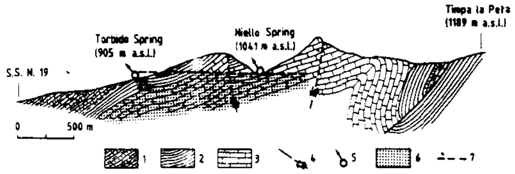

Fig. 3 - Hydrogeological section. 1) Galestrino Flysch; 2) Siliceous Schists Formation; 3) Flinty Limestones Formation; 4) Fault; 5) Spring; 6) Aquifer; 7) Piezometric line.

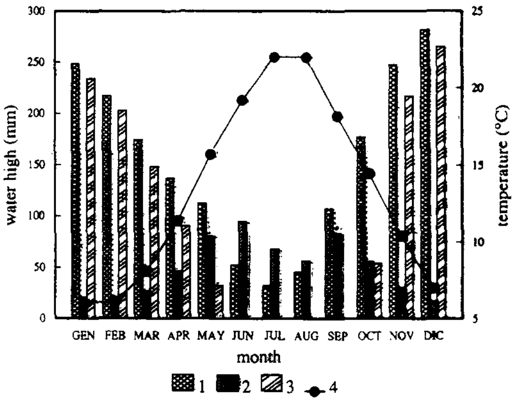

Fig. 4 - Hydrological regime. 1) Mean monthly rainfall; 2) Real evapotranspiration; 3) Surplus water; 4) Mean monthly temperature.

be taken that the effective rainfall is underestimated. Regional-scale studies on temperature and rainfall variability put this underestimate at not more than 25%, which is more or less the portion of runoff in such environments.

4 HYDROGEOLOGICAL CHARACTERISTICS

Mount Sirino contains an aquifer formed mainly of the Flinty Limestones with secondary permeability. The Siliceous Schists and the Galestrino Flysch for an impervious belt around the aquifer, rendering the system closed and independent (D'Ecclesiis, Grassi, Sdao, Tadolini, 1990)

Because of the brittle behaviour and the thickness (about 70 m) of the Siliceous Schists, they are so closely fractured in stress zones

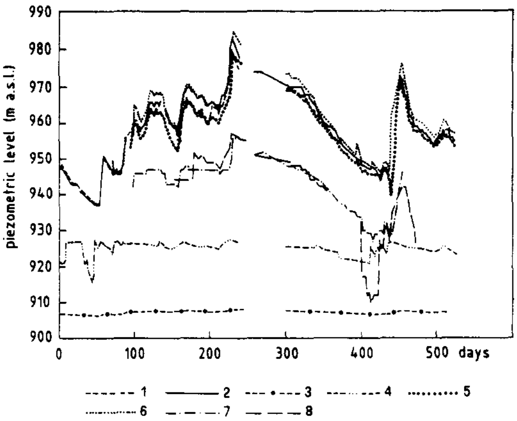

Fig. 5 - Piezometric Hydrograms. Piezometers considered are: 1) S1; 2) S2; 3) S3; 4) S4; 5) S4b; 6) S5; 7) S6; 8) S6b (For locations see Fig. 6).

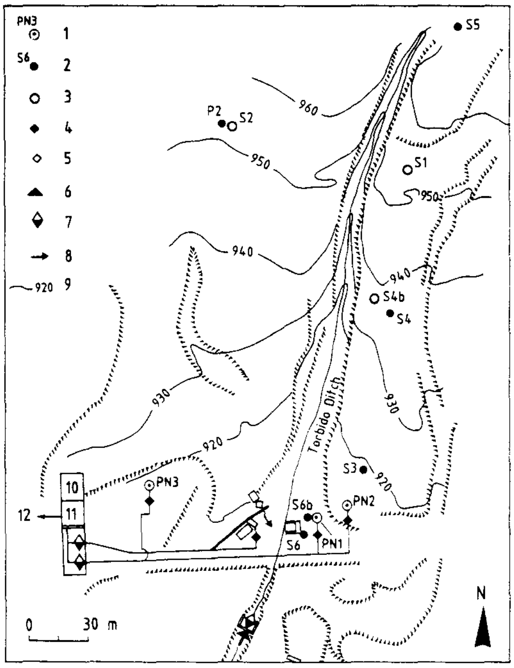

Fig. 6 - Spring area and monitoring works. 1) Production well; 2) piezometer; 3) Piezometer with pressure and temperature measurements; 4) Measurements and safeguards on wells; from upstream to down: pressure measurement, dissipator, discharge and pressure measurements; 5) discharge measurement on pressure line; 6) discharge measurement on gorge; 7) multiparameter measurements: pH, dissolved O_2, conductivity, temperature; 8) secondary users; 9) contour (m a.s.l.); 10) data logging; 11) collection tank; 12) to water supply line.

that they provide an outlet from the underlying water-bearing limestones, which allows the groundwaters to reach the surface.

Torbido Spring is located in an area in which the jaspers are particularly fractured. Here, in fact, in addition to the effects resulting from the tension exerted on the hinge of the fold with a NW-SE axis, along which runs the line of the Torbido gorge, there are those present in the axial culmination of the fold where the spring lies.

The piezometric surveys indicate that it is very likely that the groundwaters seep through the fractured Siliceous Schists, losing a considerable amount of head, and come to the surface at the Spring.

The piezometric surveys lasted about 525 days (Fig. 5). A few days after the beginning of the observations the preexisting well P2 completed in the Siliceous Schists started to be used, the intention being to abstract 45 l/s. However, this discharge rapidly emptied the well, creating a depression of over 10 m in the 80-m deep piezometers S1 and S2, while also resulting in a delayed piezometric drop in S4, which is only 30 m deep (Fig. 6).

As P2 is close to S2 and around 100 m from S1 and S4, this substantial difference in behaviour is bound up with the depth of S4 which does not penetrate through the slightly-fractured or fractured strata that occur at depths of over 50 m (RQD>80%).

The use of P2 was suspended and S4b was completed at a depth of about 100 m close to S4. The levels revealed by that borehole stabilized at 26 m above that of piezometer S4, indicating artesian flow conditions. This result adds weight to the hypotheses postulated by the authors, though some workers are of the idea that two aquifers are involved, one shallow (unconfined) and the other deep (confined).

However, during the drilling of S5, the farthest from the Spring (340 m) no waters were encountered that could be tied in with a presumed shallow aquifer. On the other hand, maximum piezometric levels were recorded which tie in well with those in the piezometers completed in the presumed deep aquifer.

The small piezometric fluctuations of the two shortest piezometers (S3 and S4) would appear to indicate that this temporary aquifer in the Siliceous Schists is fed regularly from below during the year and that it reaches piezometric levels which depend markedly on the boundary conditions, namely the geomorphology of the Spring area, being influenced to only a secondary extent by the hydrostatic heads found in the true carbonate aquifer.

The start-up, after four hundred days, of the first hydrological well designed - PN1 - , influenced the 80-m deep piezometers S6 and S6B.

5 DESIGN AND CONSTRUCTION OF PRODUCTION WELLS

From pumping tests it was estimated that the permeability of the limestones close to the Spring is around 10^{-5} m/s and that the radius of influence varies between 10 and 20 m. The usual formulae were adopted to study various solutions for a wellfield containing from 3 to 6 wells at four different spacings and completed at three different depths in the limestones.

When seeking the optimum solution it was always assumed that at least 20 of the available 40 to 50 m of hydrostatic head at the wellhead would not be used. This assumption was adopted to ensure that the aquifer would not be tapped too energetically and to guarantee that it would be invulnerable for an extensive area around the Spring.

It was finally decided to drill three wells (Fig. 7) using a cable-tool rig and reverse circulation. To prevent the leakage of rising waters under high lateral pressure during boring and to ensure there was no lateral diffusion through the highly-fractured mass, drilling was interrupted several times to permit the squeeze cementing of stretches of hole affected by intense fracturing.

The wells reached the water-bearing formation at different depths, due to their diverse position vis-a-vis the hinge zone of the fold. Near the roof of the aquifer, every increase in drilling rate due to the increase in fracturing, was accompanied by an increase in the discharge tapped. The maximum discharge of 150 l/s was provided by the well which penetrates farthest into the aquifer. The hydrostatic head of the three wells varies between 4 and 5 bar.

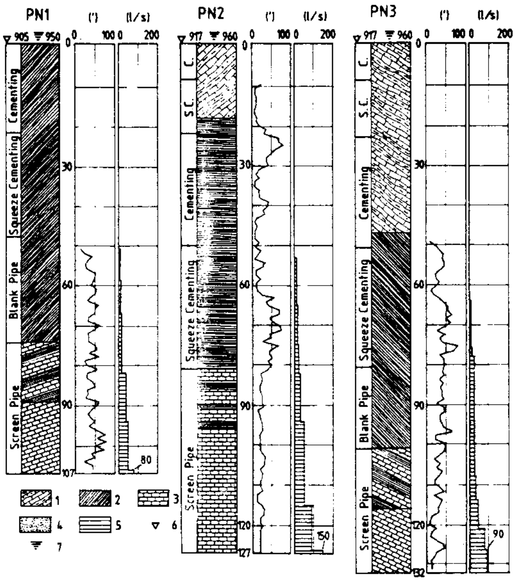

Fig. 7 - Characteristics of hydrological wells. 1) argillites, siliceous marls and blackish siltites; 2) multicoloured jaspers and radiolarites; 3) dolomitic limestones with flint nodules; 4) time required to drill one metre; 5) cumulative discharge tapped; 6) wellhead elevation (m. asl); 7) piezometric elevation with well closed (m a.s.l.).

6 MONITORING AND MANAGEMENT OF THE ABSTRACTION

A hydrogeological and hydraulic monitoring programme (Fig. 6) has been implemented to ascertain the effects of tapping the Torbido Spring via artesian wells. This information is required for a variety of reasons, namely, to conserve this precious resource, minimise the risk of pollution and optimise management of the installation so as to satisfy demand without the need for balancing reservoirs and without any waste, while at the same time not overexploiting the groundwaters.

The programme provides for a series of observation points represented by production wells, piezometers, and hydraulic structures for branching and control, complete with sensors for monitoring parameters of interest, all connected to a data logging and storage system.

The piezometric heads vary over the year, sometimes rising above ground level. On three piezometers it is planned to install two pairs of water temperature and pressure sensors.

The vertical position of these sensors is established on the basis of stratigraphic knowledge and comparison with the gamma-logs and the RQD, so as to cover the most significant water-flow levels.

The purpose of these measuring stations is to ascertain variation in the vertical flow components during natural conditions and during well operation. It is planned to install electric piezometers as well as Pt-type temperature sensors.

To safeguard the groundwater resources some of the water-flow energy in the production wells is absorbed by fixed dissipators consisting of gravel filters immediately downstream of the wellhead. These devices also filter out fragments of rock transported by the fast-flowing waters, protecting the measuring equipment installed downstream.

Each well has its own station for measuring discharge, as well as pressure upstream and downstream of the filter. The discharge is measured by devices of the magnetic-inductive type, while pressure is measured by common transducers.

There are small springs around the operating artesian wells. Other springs in the area feed the Torbido Gorge. It is planned to measure the variations in the discharges of these minor occurrences.

To bring out any eventual significant differences in the routes or the water velocities of the main resurgences, it is planned to install three multiparameter sensors, which will provide real-time indications of pollution.

The data measured by the monitoring network are logged and stored every sixty minutes in a 30-day logger. This unit is complete with a thermostating facility and thermal insulation because the winter temperatures can fall to below zero Celsius. Regarding the sensors at the monitoring points, simple thermal insulation of the electronic circuits is all that is necessary because their proximity to the groundwaters elminates any risk of freezing.

Water demand varies from season to season, because of the number of tourists present in the summer, when all available water is consumed. The design of the headworks permits the aquifer to be used as a seasonal balancing reservoir.

The continuous logging of data on recharge, piezometric levels, water quality and especially the amount of offtake ensures control of the system in such a way that there is no waste, thus safeguarding groundwater resources.

7 CONCLUSIONS

It was indicated the role played by the Siliceous Schists which are impervious elsewhere, but are so fissured here that they provide the route for the resurgence of waters from the carbonate aquifer. Tapping the spring waters by means of artesian wells produces a discharge in excess of 300 l/s, with a head of more than 4 bar. The installation of fixed dissipators on the wellheads ensures that all the hydrostatic head is not used. This precaution prevents the risk of pollution and anyway guarantees that the aquifer is invulnerable for an extensive area around the Spring.The production wells have been incorporated in a system for monitoring and managing the water-supply/spring complex in such a manner as to permit the aquifer to be utilized as a "seasonal balancing tank", preventing waste in the months when demand is low, while assuring equilibrium between groundwater availability and abstraction thereof.

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