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A MICROTUNNEL IN A HIGH ENVIRONMENTAL IMPACT AREA

Ugo Lazzarini[1], Antonio Guerini[2], Michele Montoni[3], Umberto Stefanel[4]

[1] Ugo Lazzarini, SNAM Rete Gas S.P.A.
[2] Antonio Guerini, ICOP S.P.A.
[3] Michele Montoni, ENERECO S.P.A.
[4] Umberto Stefanel, Geologist

ABSTRACT: For the new Flaibano-Gonàrs 750 ND (30 inches) pipeline installation to cross the "Paludi di Gonàrs" great care was needed to avoid risks of polluting or altering the groundwater. The "Paludi di Gonàrs" is a marsh area, protected by the European Community, near Gonàrs, a small village in Northeastern Italy, near Udine.
In fact, the water table system in the area features several groundwater levels, and they had to be kept separate as any comingling would have modified the existing water balance. Furthermore, in an area of such relevant environmental interest, disturbance to the fauna had to be kept as low as possible.
The use of trenchless technology has been considered the best possible method to achieve the desired result. The choice — influenced by the local ground lithology where soils of different layers of gravel are separated by more waterproof layers — required creating a microtunnel 815 meters in length with an internal diameter of 2 meters (6.5 feet).
Imposing a number of technical requirements on the contractor and careful monitoring and mapping of the water table system, both before and during the course of microtunneling, ensured that the microtunnel could be constructed without interfering with the surrounding environment and the groundwater. Once again it is demonstrated that a correct project, using trenchless technologies, allows environmental interests to coexist with the demands for gas pipeline renovation.

1. INTRODUCTION

Crossing bodies of water and environmentally sensitive areas is a major problem in the design of gas pipelines. The need to create new works with a careful eye to the surrounding environment has long been a part of the Snam Rete Gas philosophy. To this purpose, trenchless technologies are increasingly used to cross the main critical points by going underground. In the case discussed here, the Flaibano-Gonàrs section of the natural gas pipeline interfered with the S.I.C. Site "Paludi di Gonàrs" (Natura 2000 code: IT3320031) and the "Paludi del Corno" wetland biotope present in the area. The fact that the section was linear made it possible to keep the pipeline within the existing technological corridor and, at the same time, avoid significantly extending the section which would have led to greater territorial consumption and greater interference with the local homes and industries.
The use of trenchless technologies was given top priority and a geognostic survey was initiated to determine what drilling method was best suited to the geotechnical features of the land to be

crossed. Besides the geotechnical characteristics of the soil itself, this survey also revealed two water tables, separated by limited impermeable layers. Therefore, the choice fell to the microtunneling technique, deemed most able to safeguard the complex hydrogeological balance in the area.

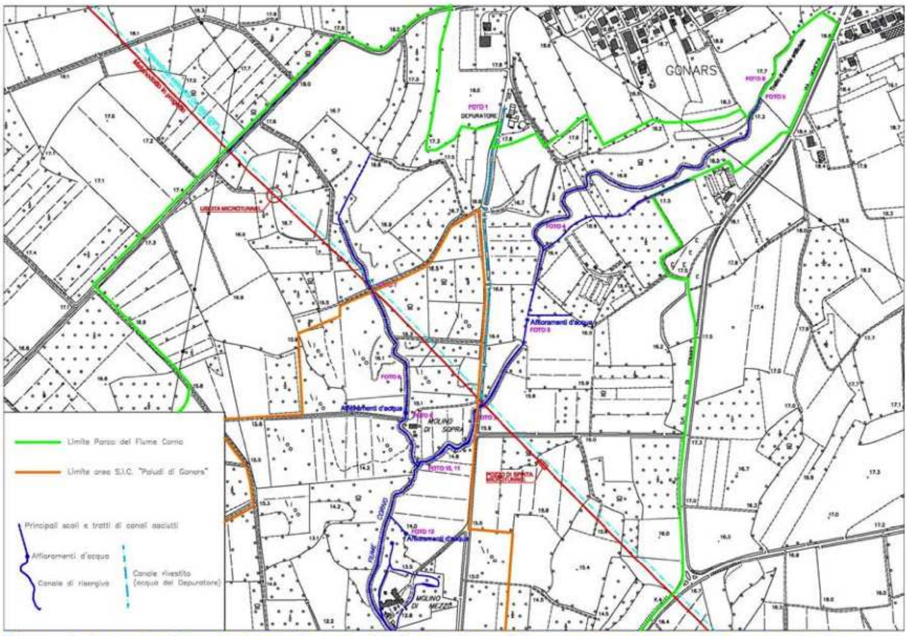

Figure 1. Layout of the protected area with indication of the water points and the gas pipeline.

2. MORPHOLOGICAL AND LITHOLOGICAL CONSIDERATIONS

Morphologically and lithologically, the area under the Gonars municipality — a plain sloping ever so slightly from North to South — falls in a transition zone between the "Upper" and "Lower" Friuli Plains.

Extending from the foot of the Morenic Hills southward approximately 20,5 km to the so-called "Linea delle Risorgive", the Karst spring line where groundwater emerges at the surface, that separates it from the "Lower Plain", the "Upper Plain" is made of alluvial sediment from the Torre River to the East and the Cormor River "megafan" to the West. Such deposits are characterized by gravel and pebbles with local spots with an abundance mostly of sandy, and in some places, silty-sandy matrices. Further to the south, as the transport capacity of the water wanes, the area features finer gravels and sands (transition zone) as well as silts and clays.

To the south of the Castions di Strada – Gonars directrix we find alluvial sediments of fine sand and clay in the "Lower Plain". At the gravely level, these sediments alternate with irregularly distributed gravely-sandy sediments running mainly in long strips that wind their way into the fine alluvial body running North-South, the result of an increase in the transport capacity of the channel currents. To the south of the town of Gonars, within the gravely alluvial complex, runs a surface district with soils typical of a natural groundwater marsh (the Corno wetlands).

In this wetland zone, where the "S.I.C. Area" is located, the surface is made up mainly of clayey, organic submarsh soil; the characteristics of this soil vary depending on whether it is constantly wet or only indirectly affected by the waters. Here we have saturated gravely soils, muck soils

and humus soils; the thickness of the latter layers varies greatly from just a few centimeters to more than a meter.
On the basis of the geological-geotechnical images taken in the S.I.C. “Paludi di Gonàrs” area, the soils found in the area covered by the project comprise a surface approximately 6 m thick made up of clayey silts and sandy silts, at times organic. Below this, a major sandy-gravely deposit containing rounded stones, with the maximum size of 8-10 cm, runs to at least the maximum depth of 34 m used for the survey.

3. HYDROGEOLOGICAL CONSIDERATIONS – GROUND WATER MONITORING

The ground water in the “Upper Plain” (which, north of Gonars, shows an underground flow running predominantly NNW-SSE) emerges at the surface in characteristic “rogge” or artificial channels and groundwater channels (Corno) along the so-called “Linea delle risorgive” or Karst spring line.
To the south of this major hydrogeological limit, the aquifer is made up of “highly permeable” gravely-sandy alluvial sediment. This “porous” medium thins as it moves south to approximately Porpetto, as it is interwoven with “impermeable” or “semi-permeable” levels of clayey silt and sandy silt. The continuity of these levels increases, thus separating the various levels of the aquifer. The permeability of the aquifer also decreases due to variations in the particle size distribution of the sediments which progress from gravels to sands.
The hydrogeological profile of the “Paludi di Gonars” area presents a surface aquifer with phreatic water kept in place by levels that range from “permeable” (sand and gravel) to “poorly permeable” (fine, silty sand) and which are supported by continuous “impermeable” and “semi-permeable” (aquicludes - aquitard) levels of clayey silt and sandy silt.
This surface aquifer, which feeds the “wetland zone”, is in communication with the table water in the “Upper Plain” outcropping to the north (phreatic water). The main aquifer is an alluvial, “hydrogeological formation” of sandy gravel which is “highly permeable” because of its porosity. It is confined (or semi-confined) to the roof by “semi-permeable” (aquitard) and “impermeable” (aquicludes) limits and there are frequent points of local exchange with the surface aquifer as a result of variations in permeability (drainage).
In the area, there are widespread outcroppings of water (“springs”) that set the two water tables into communication until they emerge at the surface.
To obtain further statistical information, some piezometers were installed at significant points along the section. Monitoring began in June 2006 and continued until December 2007, well beyond the end of the micro tunnel drilling operations.

3. CHOICE OF THE EXCAVATION METHOD AND DISPOSITIONS

Having decided on the microtunneling method — deemed particularly effective in preserving surface “wetlands zones” — and a drilling depth of -16.5 meters below the ground surface (-10.0 m below the switchover point between surface and deep deposits), the crossing profile was determined that guaranteed the least possible interference with the aquifers.
Use of this system does not alter the delicate lithostratigraphic and hydrogeological balance of the surface portions characterized by sandy silt, clayey silt, at times organic, submarsh soils with levels of gravely sand and surface water.
To this purpose, the following technical insights were applied:

- A totally sealed starting pit was created to prevent any communication between the surface and deep aquifers;
- Plastic baffles were arranged at the points crossing through the clayey-silty layer, located above the gravely-sandy aquifer;
- A variable hydraulic balance was maintained during the various phases of excavation; in fact, the machine ensures that the drilling head operating pressure is kept in equilibrium according to the external pressure detected along the route, pressure which varies according to the lithology and depth;

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- During excavation a betonite film was created to insulate the dig. Particular attention was paid at the points of lithological changes, thus preventing the various aquifers from intermingling;
- The cavity between the pipeline and the microtunnel was completely plugged, thus preventing any possible passage of water on the inside;
- The walls of the well were removed and the work areas reinstated to their original condition.

Moreover, in order to prevent any disruption to the fauna present in the "Corno Biotope", highly sound-proofed equipment was used and the entire yard area was marked off with sound-proofing panels.

GEOLITHOLOGICAL PROFILE ALONG "AREA S.I.C" Scales 1:2000 / 1:200

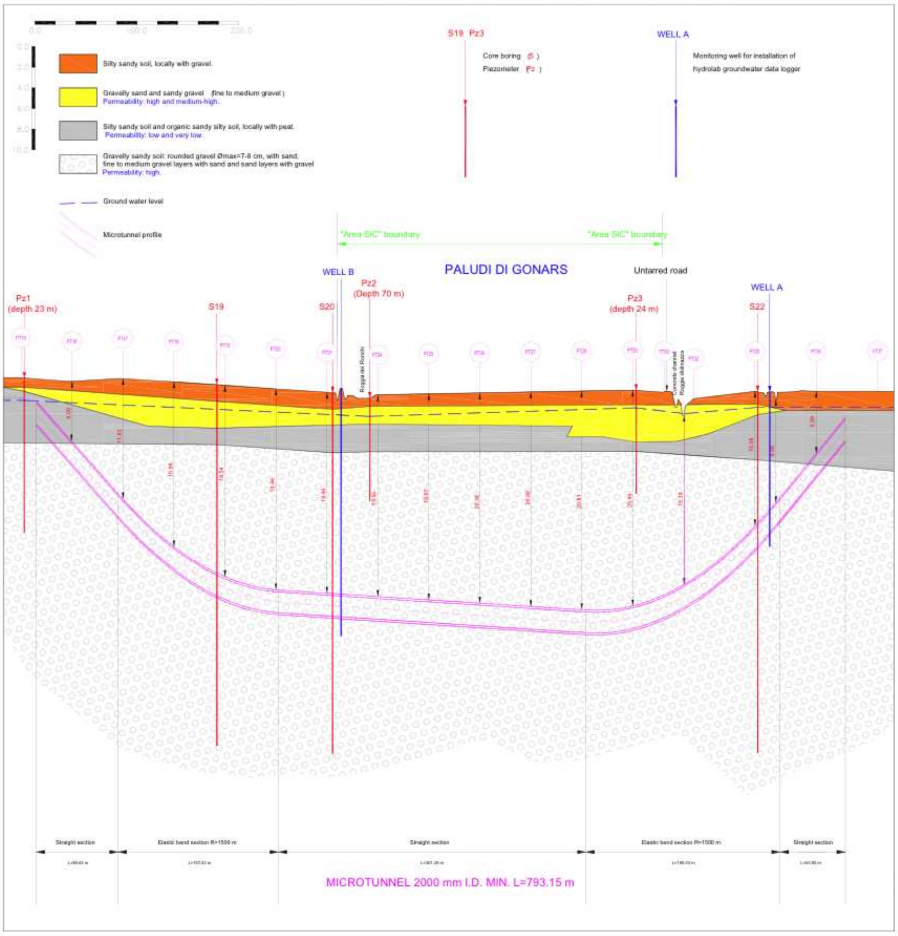

Figure 2. Crossing section

4. EQUIPMENT AND DRILLING

On the basis of the project data reported in Table 1, the AVN2000 tunnel boring machine was selected as the best unit for drilling and the working place and the jacking shaft (fig.5) were proportioned in compliance with Customer's recommendations. The cutting head — designed according to the characteristic particle size distribution curve (fig.3) — was a mixed head with special partialization plates to ensure better control over excavation front stability (fig.4)

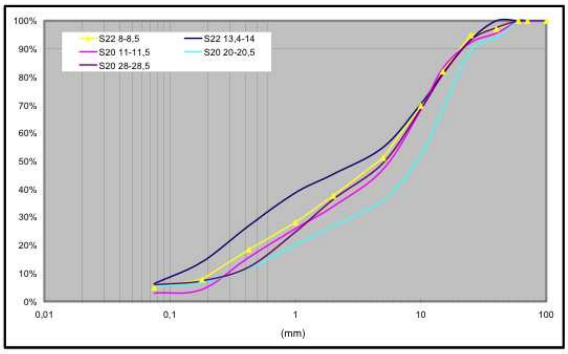

Figure 3. Particle size distribution curve

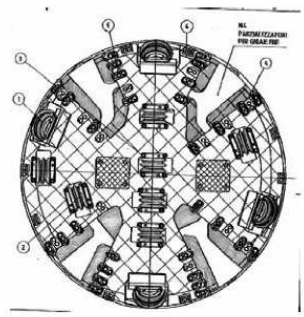

Figure. 4 Cutting head

Table 1. Main technical data

MICROTUNNEL PROJECT DATA	
Total length	815 m
Maximum depth below ground surface	16,5 m
Internal diameter of reinforced concrete segments	2 m
Thickness (indicative) of reinforced concrete segments	0,2 mm
Length (indicative) of reinforced concrete segments	3 m
Vertical microtunnel bending radius	1500 m
Entry angle	9°
Exit angle	9°

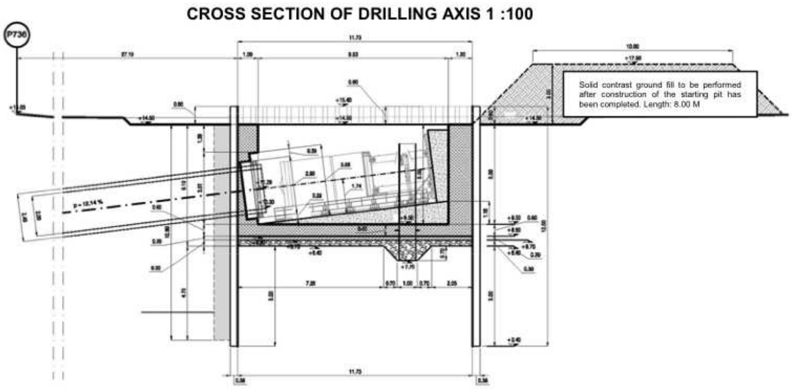

Figure 5. Jacking shaft

All phases of drilling were performed with great regularity, paying particular attention to compliance with the project parameters. For this reason, in order to prevent any risk of drilling being blocked, work shifts were set to guarantee steady work 24 hours a day (fig.6). The drilling operations were, therefore, completed quickly jacking from the back and without needing to use the intermediate jacking stations that were set up for any eventuality (fig.7).

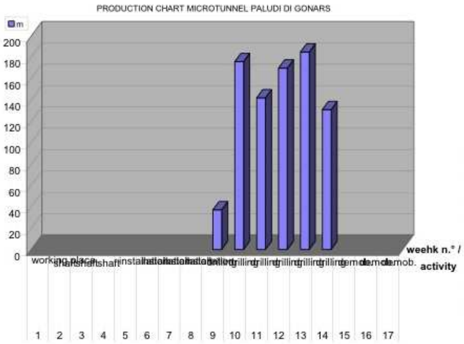

Figure 6. Production chart

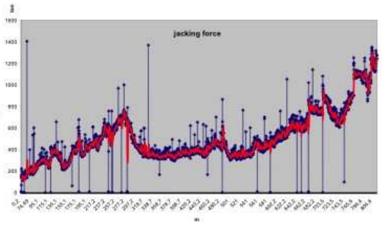

Figure 7. Jacking force diaghram

Likewise, to limit interference with the aquifers, drilling was completed without the need to create an exit pit and the drilling head was only recovered after the microtunnel and the soil had been fully sealed with special plastic mixtures.

Figure 8. Recovery of the drilling head

Figure 9. Jacking pit, jacking phase

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5. MONITORING OF THE AQUIFER

The groundwater aquifer — sustained by impermeable clayey silt levels — and the deep aquifer — highly permeable alluvial sediment of sandy gravel — were monitored using an open end piezometer set upstream and downstream of the crossing site outlined in the project. The level was measured once a month. The trend in the depth of the groundwater (Piezometer Pz1 A) and the piezometric level of the underling alluvial aquifer (Piezometers Pz1 B, Pz2 and Pz3) are reported in the graph showing the seasonal fluctuations with minimums (minimum aquifer depth) and maximums (maximum relative filling).

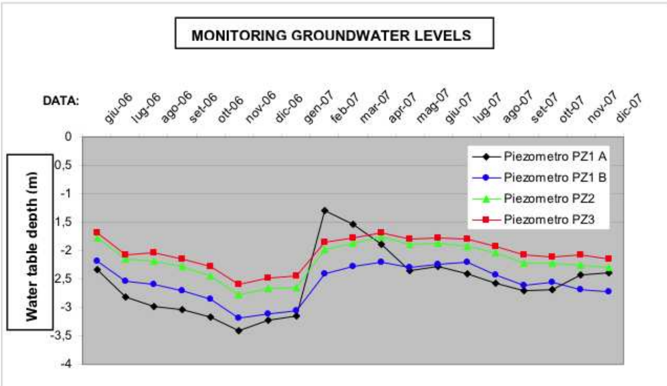

Figure 10. Aquifer monitoring diagram

From a maximum (June 2006) — where the depth in Pz3 was -1,68 meters below ground level (b.g.l.) — there was a steady drop in the piezometric level, the minimum recorded in November 2006 with a depth in Pz3 of -2.,8 meters (b.g.l.). The piezometric level of the main aquifer started increasing again, reaching a depth in Pz3 that hovered around -1,69 / -1,77 meters b.g.l. (in Pz2 the depth remained between -1.75 and -1.87 meters b.g.l. while in Pz1 B it reached levels between -2,20 and -2,40 meters b.g.l.). Likewise the groundwater aquifer (recorded at piezometer Pz1 A) showed a general, seasonal trend similar to that of the underlying aquifer. However, a peak situation (minimum aquifer depth) was recorded in the month of February 2007 (-1,30 meters b.g.l.) and anomalous piezometric levels were seen in March 2007 (-1,54 meters b.g.l.) and in April 2007 (-1,89 meters b.g.l.)
This trend, recorded in February, March and April 2007, was due to concentrated rainfall which quickly filled the groundwater aquifer. Figure 10 reports the trends in groundwater for the period in which it was monitored.

6. MONITORING GROUNDWATER QUALITY DURING THE DRILLING

Besides monitoring of piezometric oscillations in the surface water, ongoing monitoring of the quality of the groundwater was also performed in the highly permeable aquifer located below the point where excavation was being performed with the microtunnel equipment, consisting of microtunneller with sludge pressure at the head and 2,4 m diameter reinforced concrete pipes, fit with suitable valves for injection of betonite sludge lubricants.
Thus, to check for any significant variations in the chemical-physical properties of the underground waters, in October 2007, two PVC monitoring wells "Well A" and "Well B" diameter

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3" were created at a distance of 5.0 meters from the drilling axis, downstream of the underwater runoff component, as shown in the figure below for Well A.
At Well B, drilled up to the depth 24 m with fissuring from 18 m to 24 m, the depth of the microtunnel axis was 20.8 m b.g.l.
Self-regulating multiprobes such as the "Hydrolab Minisonde" were installed at Wells A and B and fit with the following sensors: Temperature, Conductivity, pH, Dissolved Oxygen, Redox Potential and Depth (fig.12).

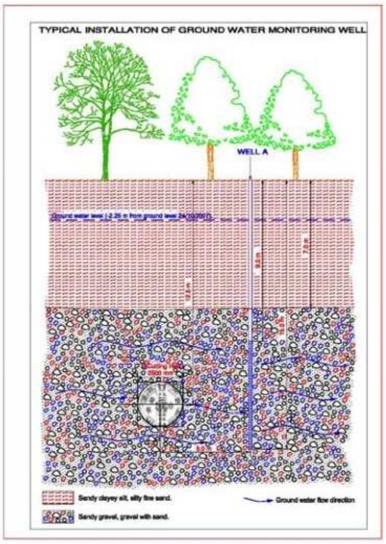

Figure 11. Monitoring well typical installation

Figure 12. Hydrolab Groundwater Data Logger

An ongoing series of measurements were taken at both wells to evaluate the effects the mechanized drilling had on the soil and the groundwater at the points where the drilling equipment passed (fig.11).
The multiprobe was set in Well A, at a depth of 11,5 m b.g.l. — i.e. 9,25 m below the phreatic level, and remained operative from October 24, 2007 to November 22, 2007.
During this period the probe took readings every two and three hours. In the period of passage of the microtunnel "boring shield running from 7:00 a.m. November 7, 2007 and 8:00 a.m. November 8, 2007 the probe took readings every 5 minutes.

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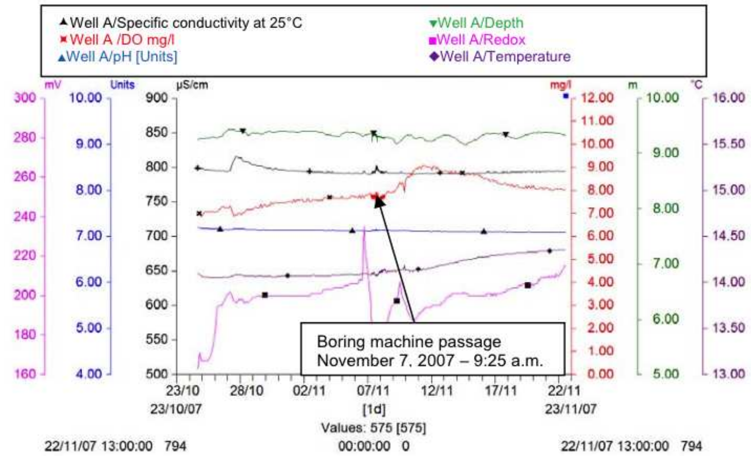

Figure 13. Data graph

This automatic reading probe was then set in Well B, at a depth of 21,74 m below the phreatic level for the period from November 22, 2007 to November 29, 2007.
During this period, the probe took readings every two hours.
In the period of passage of the microtunnel "boring shield" running from 7:00 a.m. November 26, 2007 and 7:00 p.m. November 8, 2007 the probe took readings every 10 minutes.

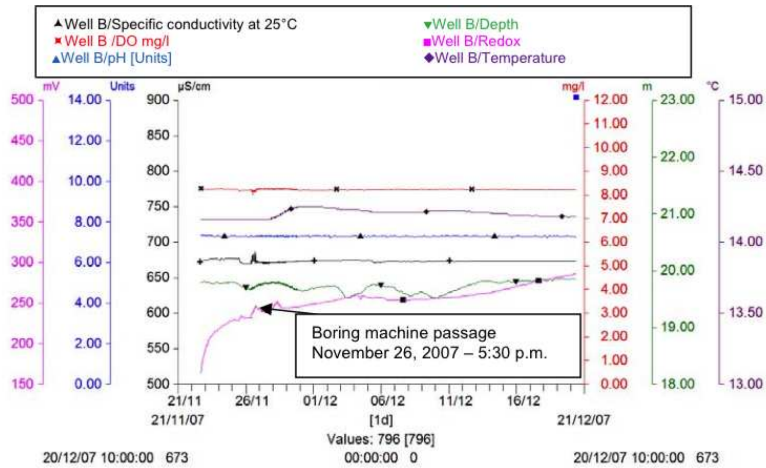

Figure 14. Data graph

Ongoing monitoring of the quality of the groundwater with the multipurpose probes revealed the following (tab. 2).

Table 2. Chemical-physical parameter of the water

Chemical-physical parameter measurements before drilling operation					
	Temperature (°C)	**Conductivity (µS/cm)**	**pH**	**Dissolved Oxygen (mg/l)**	***Redox Potential (mV)***
Well A (11.5 m)	14.06 - 14.10	790 - 810	7.1 - 7.2	6.90 - 8.20	*195 - 205*
Well *B (21.7 m)*	*14.16*	*670 - 680*	*7.2 - 7.3*	*8.20 - 8.25*	*220 - 250*
Chemical-physical parameter measurements during the drilling operation					
	Δ T (°C)	Δ CE (µS/cm)	Δ pH	Δ OD (mg/l)	*Δ Redox (mV)*
Well A (11.5 m)	+ 0.25 - 0.29	+0 - 3	0	+ 1.3 - 2.2	*+ 15*
Well *B (21.7 m)*	*+ 0.09*	*+0 - 10*	*0*	*0*	*+ 40 - 50*

In particular, the groundwaters underwent a more than moderate increase in Temperature and this was more evident at Well A where the variation (ΔT=0.29 °C) was maintained throughout the entire drilling period.
At Well B the increase in Temperature, due to the flow of heat induced by the reinforced concrete piping, in turn, heated on the inside by the drilling equipment, was lower: ΔT=0.09 °C.
Twelve days after drilling was completed, the Temperature of the groundwater in Well B was still 14.18 °C or 0.02 °C higher than the natural Temperature, as the microtunnel was still being affected by internal works to remove the equipment.
As regards the other parameters, ph showed no variations, remaining steady at values of 7.1 – 7.2 (Well A) and 7.2 – 7.3 (Well B).
Modest variations were seen in Conductivity as the "shield" passed and these values quickly returned to the norms.
Besides Temperature, Dissolved Oxygen was the parameter that showed the most significant variation. A look at the graph for Well A shows a natural increase in Dissolved Oxygen, most likely linked to the inflow of water infiltrations (rainwater) into the circuit, on the whole, rather fast (remember the circuit is made up of "permeable" and "highly permeable" aquifers). At Well A the mechanized excavation (passage of the "tunnel boring machine" with the input of a water-betonite mixture) initially caused the values of Dissolved Oxygen to fluctuate (from 7.4 to 7.9 mg/l) which then increased to 9.09 mg/l and subsequently slowly returned to the natural values.
This phenomenon was not so evident at Well B where the readings were more constant, fluctuating between 8.20 and 8.25 mg/l.
The Redox Potential had difficulty stabilizing the values, particularly during the measurements taken every 5 minutes (Well A). These measurements showed a trend toward increases in the values as a result of the increased Dissolved Oxygen concentrations. At Well B, this increase was 40 – 50 mV.

7. CONCLUSIONS

In view of the parameters monitored, the study showed that none of the parameters were permanently affected by the drilling. In fact, ongoing monitoring — through installation of multiprobe units in adequately built monitoring wells set at 5 meters from the drilling axis — showed the absence of any significant variations in the chemical-physical parameters of the waters. No anomalous situations (i.e. variations in pH or reduction in the Redox Potential and/or Dissolved Oxygen) were found due to contamination and/or alteration induced by the mechanized drilling. The parameters monitored tended to return to their initial conditions.
As regards the outside environment at the surface, the precautions adopted were able to prevent any disruptions and the works were performed without any objections from the control authorities. Moreover, the pre-existing hydrological system was perfectly intact when the works were completed.
Thus the drilling method adopted, together with the insights applied during execution, ensures full respect for the surrounding territory.

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