

Relation between temperature and intensity of groundwater circulation in Alpine massifs as a tool for predicting water inflows in underground works

Numerous long tunnels have been and will be drilled at a large depth in mountainous alpine massifs. Water inflows temperatures in five existing long alpine tunnels (Vereina, Gothard-N2, Mont-Blanc, Simplon and Gothard-AT) have been studied and compared with the discharge of water inflows.

The Vereina railway tunnel drilled in Austroalpine nappes encountered little water inflows. The linear discharge rates vary between 0,003 and 0,006 l/s/m (Figure 1). Two different water temperatures series have been observed in both northern and southern parts of the tunnel trace. The northern thermal gradient is equal to 0,018°C/m while the southern thermal gradient is not very different with a value equals to 0,016 °C/m. No special thermal anomaly has been observed on this site.

The Gothard-N2 road (National number two) tunnel intersects the Aar and Gothard External Crystalline Massifs. A general thermal gradient equal to 0,015°C/m is observed in the southern part of the tunnel trace in the Monte Prosa massif (Figure 2). Two positive thermal anomalies have been measured in both northern and central parts of the tunnel trace. They are due to topographical effects : in this region, the tunnel is situated beneath the Reuss river valley. Water inflows are weak in this tunnel : about 0,020 l/s/m in the Monte Prosa zone for example.

The Mont-Blanc road tunnel intersects the Mont-Blanc External Crystalline massif. A water thermal gradient equal to 0,016 °C/m has been observed on the northern part of the massif, at depths inferiors to 1000 meters (Figure 3). This region corresponds to a low-permeability crystalline schists zone. The linear discharge rate is equal to 0,008 l/s/m in this zone. A large negative thermal anomaly has been measured during the drilling of this tunnel. The water temperatures decreased from 32°C to 11,5°C beneath the Pointe Helbronner. It corresponds to large water inflows (about 1000 l/s) in a strongly fractured zone. A second water thermal gradient (very weak : 0,007 °C/m) corresponds to the granitic unit which is globally more permeable than the schists with a linear discharge rate equal to 0,193 l/s/m.

The Simplon railway tunnel (Figure 4), drilled through the Penninic nappes, is also characterised by such a negative thermal anomaly situated in the very permeable marbles of the Teggiolo zone. In this tunnel, the water temperatures decrease from 55°C in the Berisal gneissic zone to less than 15°C in the Teggiolo zone. The water thermal gradient in the northern part is high, in conformity with the weak water inflows (linear discharge rate inferior to 0,001 l/s/m). A third zone is observed in the Veglia marbles : it is characterised by a water thermal gradient equal to 0,010 °C/m for a linear discharge rate equal to 0,203 l/s/m.

The Gothard-AT gallery has been drilled in Penninic gneiss. A water thermal gradient equal to 0,013 °C/m has been measured during the first 3000 meters (Figure 5). A negative thermal anomaly has been encountered at the end of the gallery. This is due to the presence of very permeable metasedimentary rocks with important water circulation.

The results show that the water temperature in underground works is strongly dependent on the massif permeability and the existence of groundwater flows (Figure 6). Cold waters coming from high infiltration zones have a refrigerating effect on the massif. Thus, measuring water temperature during drilling constitutes a predicting tool of water inflows. Two cases are possible : the observation of a local thermal anomaly due to a very localised aquifer zone or the decrease of the water thermal gradient due to diffuse water inflows in the massif.

Local thermal anomalies, correlated with large water inflows along discrete zones have been shown in Simplon, Mont-Blanc and Gothard-AT tunnels. Such thermal anomalies can be measured hundreds meters before the intersection of tunnel with the aquifer zone : the temperature monitoring constitutes thus a predicting tool of large water inflows localized in a particular aquifer zone. The use of 3D numerical simulations permits to improve quantitatively the prediction, by taking into account the problem geometry, the heterogeneity and anisotropy of thermal and hydrogeological properties of rocks and the boundary conditions.

The comparison of water thermal gradients at the massif scale with linear discharge rates in the tunnels through the massif allows us to determine a mathematical relationship between these characteristics of the massif. This relation permits to predict the water quantity expected during drilling, knowing the water thermal gradient,.

These results show that water temperature measurements during drilling of an underground work constitutes an efficient and cheap predicting tool of water inflows. Anomalies due to relief must be taken into account ; these ones can be very important in such mountainous massifs. A 3D modelisation of heat transfert in the massif is, in all cases, necessary to improve the precision of predictions.

Keywords

Temperature, Alps, underground work, hydrogeology, mountain

References

- BAIR, E.S., PARIZEK, R.R., 1978. Detection of permeability variations by a shallow geothermal technique. *Ground Water*, 16(4), 254-263.
- BUSSLINGER, A., RYBACH, L., 1996. Prognosis of rock temperatures and water inflow zones in deep tunneling - examples from the NEAT-project, Swiss Alps. IN « *Tunnels for People* », GOLSER, HINKEL and SCHUBERT (Ed.), pp. 9-14.
- BUSSLINGER, A., RYBACH, L., 1997. Sondiersystem Piora-Mulde. Geothermische Untersuchungen. 3D-Modellierungen, *Interner Bericht Nr 2007*. Institut für Geophysik. ETH Zurich. 27 p.
- CARTWRIGHT, K., 1968. Thermal prospecting for groundwater, *Water Resour. Res.*, 4(2), 395-401.
- DONALDSON, J.G., 1962. Temperature gradients in the upper layers of the earth's crust due to convective water flows. *J. Geophys. Res.*, 67, 3449-3459.
- GOY, L., FABRE, D., MENARD, G., 1996. Modelling of Rock Temperatures for Deep Alpine Tunnel Projects. *Rock Mech. Rock Engng.*, 29(1), 1-18.
- GUDEFIN, H., 1967. Observations sur les venues d'eau au cours du percement du tunnel sous le Mont-Blanc. *Bull. B.R.G.M.* 4, 95-107.
- GUICHONET, P. et BERNIERI, U., 1966. Historique de la percée du Mont-Blanc. La réalisation. Aoste II, 400 p.
- KELLER, F., LOCHER, T., 1994. Die Geologie des Zugwald- und Vereinatunnels. *Schweizer Ingenieur und Architekt*, 44, 892-896.
- KELLER, F., WANNER, H., SCHNEIDER, T.R., 1987. Geologischer Schlussbericht. Gotthard-Strassentunnel. *Beiträge zur geologie der Schweiz*. Geotechnische serie 70.
- KEYS, W.S., BROWN, R.F., 1978. The use of temperature logs to trace the movement of injected water. *Ground Water*, 16(1), 32-48.
- MARECHAL, J.C., 1998. Les circulations d'eau dans les massifs cristallins alpins et leurs relations avec les ouvrages souterrains. Th. Doct. Ecole Polytechnique Fédérale de Lausanne, no 1769, 296 p.
- MARECHAL, J.C., PERROCHET, P., TACHER, L., 1999. Long-term simulations of thermal and hydraulic characteristics in a mountain massif as a tool to predict water inflows in underground works: the Mont-Blanc case study. *Hydrogeology Journal*, 7(4), (1999), 341-354.
- SCHARDT, H., 1905. Les eaux souterraines du tunnel du Simplon. *La Géographie, bull. Soc. Géograph.*, 11, 82-96.

- RYBACH, L., PFISTER, M., 1994a. How to predict rock temperatures for deep Alpine tunnels. *J. Applied Geophys.*, 31, 261-270.
- RYBACH, L. et PFISTER, M., 1994b. Temperature predictions and predictive temperatures in deep tunnels. *Rock Mech. Rock Engng.*, 27(2), 77-88.
- SCHNEIDER, T.R., 1992. Geologie Gotthard-Basistunnel. *Schweizer Ingenieur und Architekt Dokumentation D 085.*, 15-24.
- SCHNEIDER, T.R., 1997. Rapports géologiques sur la galerie AlpTransit Gotthard. Rapports Inédits.
- SMITH, L., CHAPMAN, D. S., 1983. On the thermal effects of groundwater flow, 1, Regional scale systems. *J. Geophys. Res.*, 88, 593-608.
- STALLMAN, R.W., 1963. Computation of groundwater velocity from temperature data. *U.S. Geol. Surv. Water Supply Pap.*, 1554-H, 36-46.
- TANIGUCHI, M., 1993. Evaluation of Vertical Groundwater Fluxes and Thermal Properties of Aquifers Based on Transient Temperature-Depth Profiles. *Water Resour. Res.*, 29(7), 2021-2026.
- WOODBURY, A. D., SMITH, L., 1985. On the thermal effects of three-dimensional groundwater flow. *J. Geophys. Res.*, 90, 759-767.

<i>Ouvrage</i>	<i>Gradient thermique des eaux [°C/m]</i>	<i>Débit linéaire [l/s/m]</i>	<i>Situation</i>
Vereina	0,018	0,003	Tronçon nord
	0,016	0,006	Tronçon sud
Gothard N2	0,015	0,020	Monte Prosa (PM 0 - 5500-S)
Mont-Blanc	0,016	0,008	Schistes cristallins
	0,007	0,193	Granite central
Simplon	0,023	0,0004	Gneiss Berisal
	0,010	0,203	Zone de Veglia
Gothard ATG	0,013	0,0015	Gneiss Leventina (PM 0 - 2500)

*Table 1 : Water thermal gradients calculated in some alpine underground works.
Comparison with linear discharge rates.*

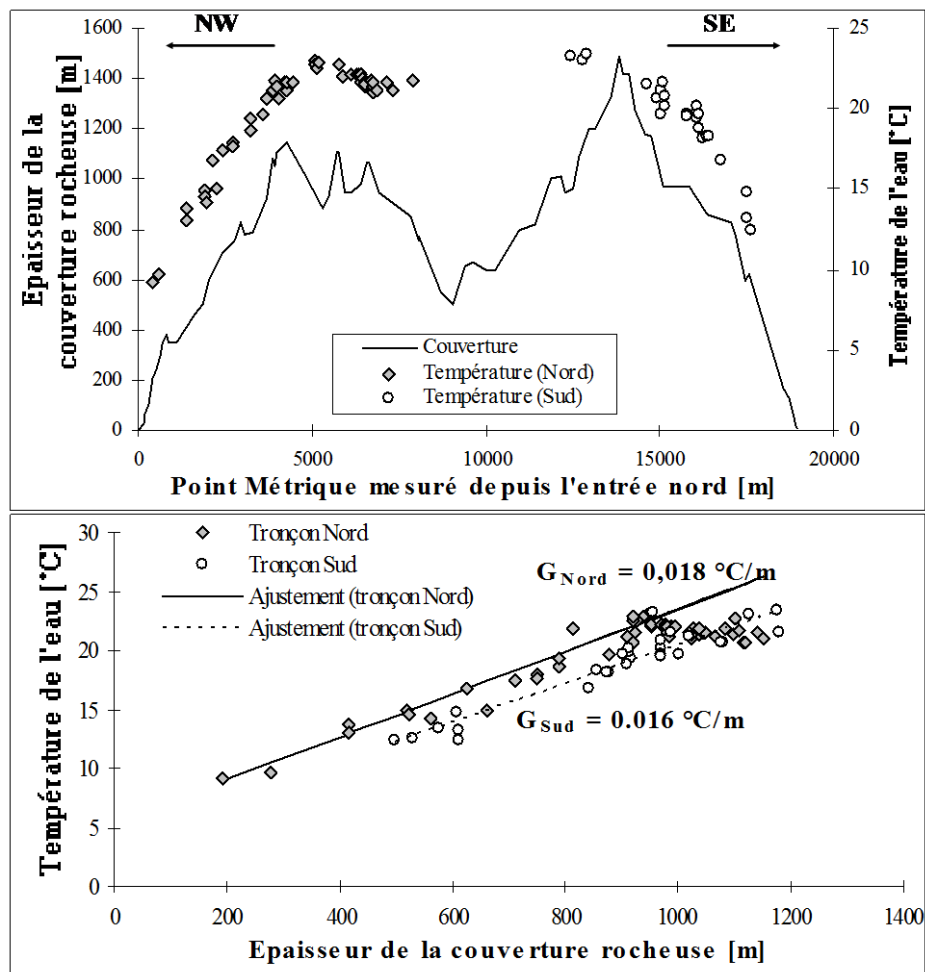


Figure 1 : Vereina case. Profiles of water inflows temperatures and rock cover thickness (a). Water temperature as a function of rock cover thickness (b).

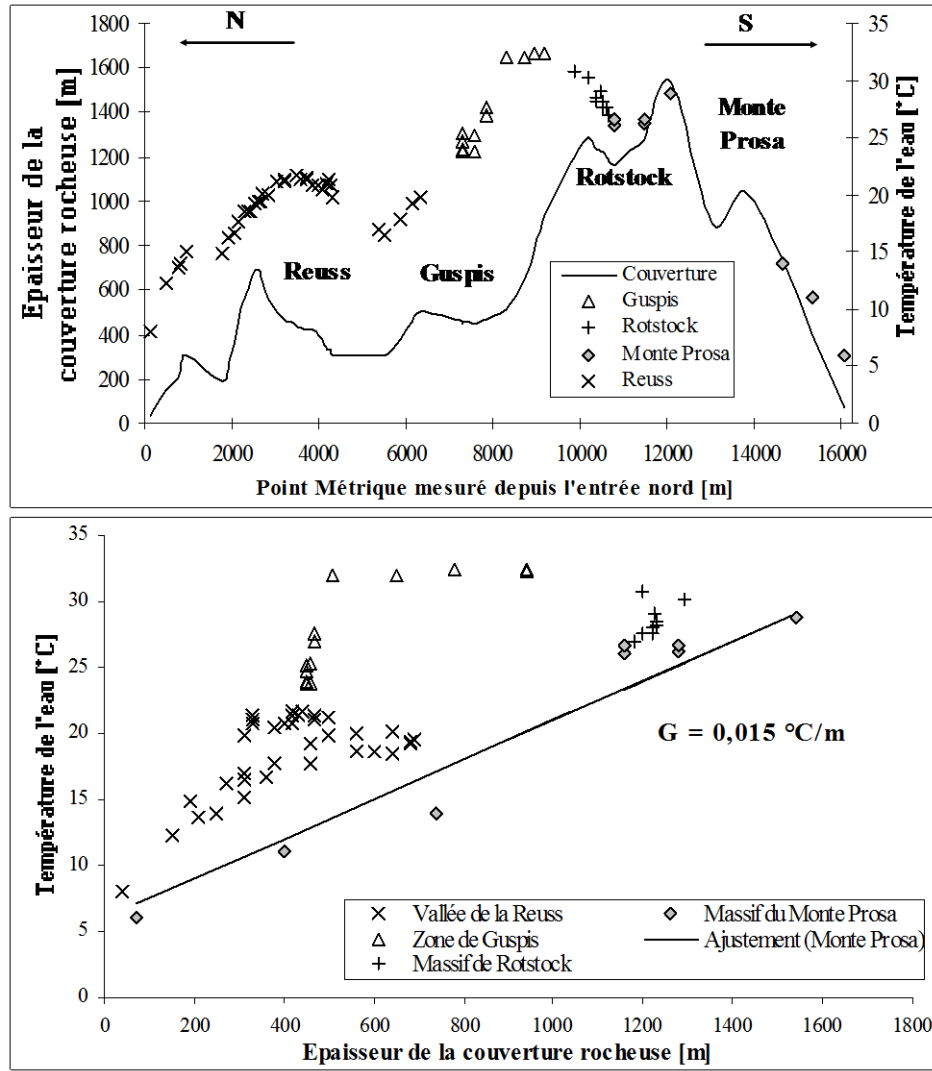


Figure 2 : Gothard-N2 case. Profiles of water inflows temperatures and rock cover thickness (a). Water temperature as a function of rock cover thickness (b).

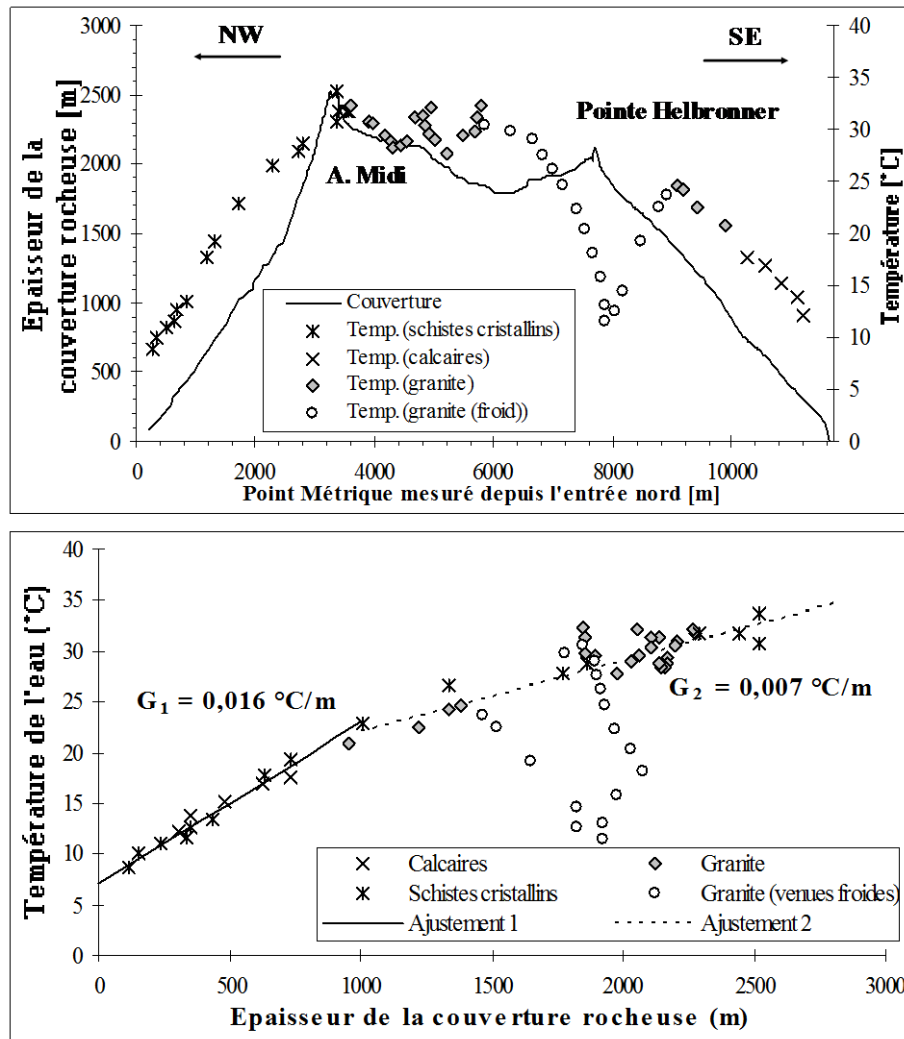


Figure 3 : Mont-Blanc case. Profiles of water inflows temperatures and rock cover thickness (a).
Water temperature as a function of rock cover thickness (b).

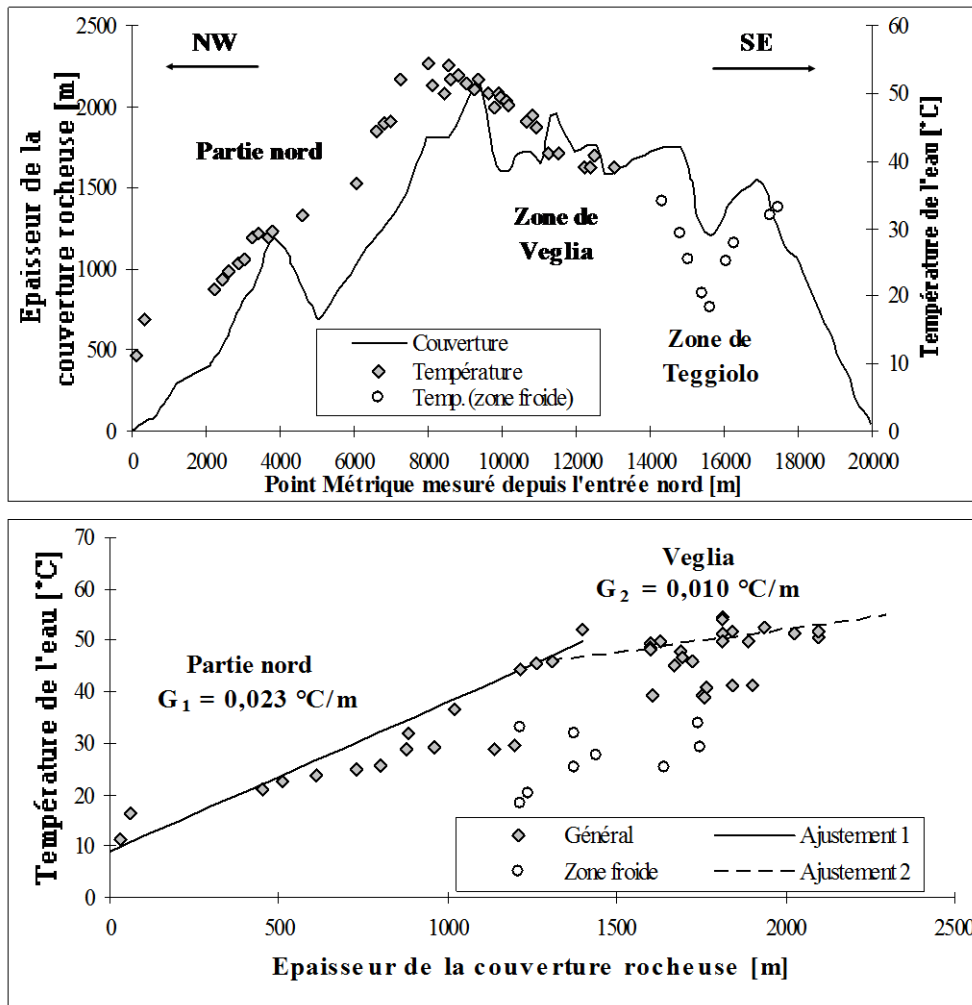


Figure 4 : Simplon case. Profiles of water inflows temperatures and rock cover thickness (a).
 Water temperature as a function of rock cover thickness (b).

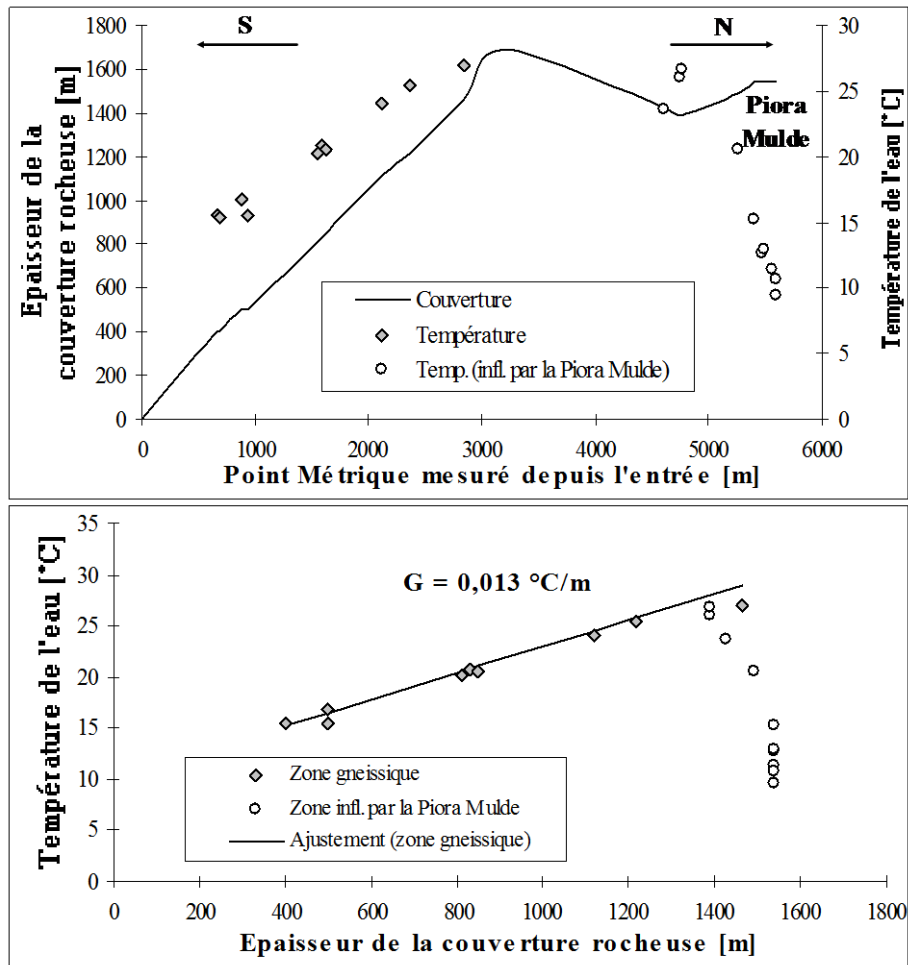


Figure 5 : Gothard Alptransit case. Profiles of water inflows temperatures and rock cover thickness (a). Water temperature as a function of rock cover thickness (b).

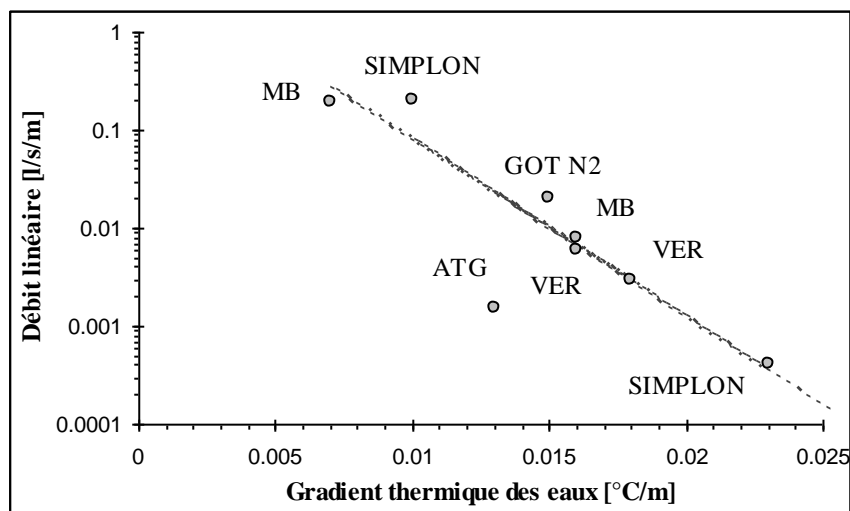


Figure 6 : Relation between linear discharge rate and water thermal gradient in some underground works. (MB : Mont-Blanc ; GOT-N2 : Gothard-N2 ; VER : VEREINA ; ATG : Gothard Alptransit).