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WATERINGUES AQUIFER - A PARTICULARITY IN SALT WATER INTRUSION: LOW SLOPED COAST WITH HIGH VARIATIONS OF TIDE LEVELS

SUMMARY

The Wateringues region, in north of France, located between Calais, Dunkerque and Saint-Omer, is one of the scarce French polder. The Wateringues groundwater transits in a sandy aquifer which substratum is at about 30 meters in depth. The variations of tide levels are between + 3 NGF and − 2.5 NGF. Under the coastal dunes, the water level reaches + 3 NGF. In these conditions, and according to the theory, if we consider the salt reference level as the standard level of the sea, the aquifer should not be affected by a salt intrusion. In fact we can observe a massive and generalized invasion. The reason of this particularity is due to the existence of a very flat shore which delays the flow and the influence of high sea level.

Another interest of this study is to give evidence that the utilization of geophysics can be an excellent way of investigation of the salt-fresh water interface.

1. DESCRIPTION OF THE WATERINGUES AQUIFER

The Wateringues groundwater, on the north coast of France, consists of a coastal aquifer directly influenced by the variations of sea levels. This aquifer is made up of quaternary sands on a depth of about thirty meters lying on an impermeable substratum, the clay of Flandres. As a topographical point of

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view, from the sea to inland, we cross the beach (uncovered zone at low tide), a dunes area (maximum height of 10 meters) and a flat plain (average height of + 4 meters NGF). The variations of tide levels are between – 2.5 m NGF at low tide and + 3 m NGF at high tide; the mean sea level is at about 0 m NGF.

2. IDENTIFICATION OF SALT INTRUSION BY GEOPHYSICS

Salt intrusion in the aquifer has been shown by electrical soundings and confirmed by tests of water salinity on point wells. The geophysical prospection allowed to precise the position of the interface salt water-fresh water (Fig. 1), giving evidence of great irregularities in the depth of the interface. Nowhere fresh water reaches the substratum.

3. INTERPRETATION OF THE RESULTS

The coastal zone has been studied carefully to estimate the alimentation of the aquifer by sea water. The theorical depth of the interface under the piezometrical ridge has been calculated by the equation of Ghyben Hersberg. The horizontal reference plan was estimated as the average sea level (0 m NGF). The hydraulic ridge, at the boarder of the sea, being at + 2.5 m NGF, the calculated interface level should be at about 100 m. But as the substratum level is at – 30 m NGF, the fresh water should prevent any salt intrusion. In fact the interface found by geophysics seems to be much more shallow than the calculated value.

Complementary studies had to be carried out to solve this problem.

4. COMPLEMENTARY STUDIES

The purpose of these studies was to control the vertical repartition of salinity (interface level) and the alimentation from the sea. The confimation of the interface level was carried out by four electrical logs to calibrate the electrical soundings. On the other hand, four observation wells of different depth

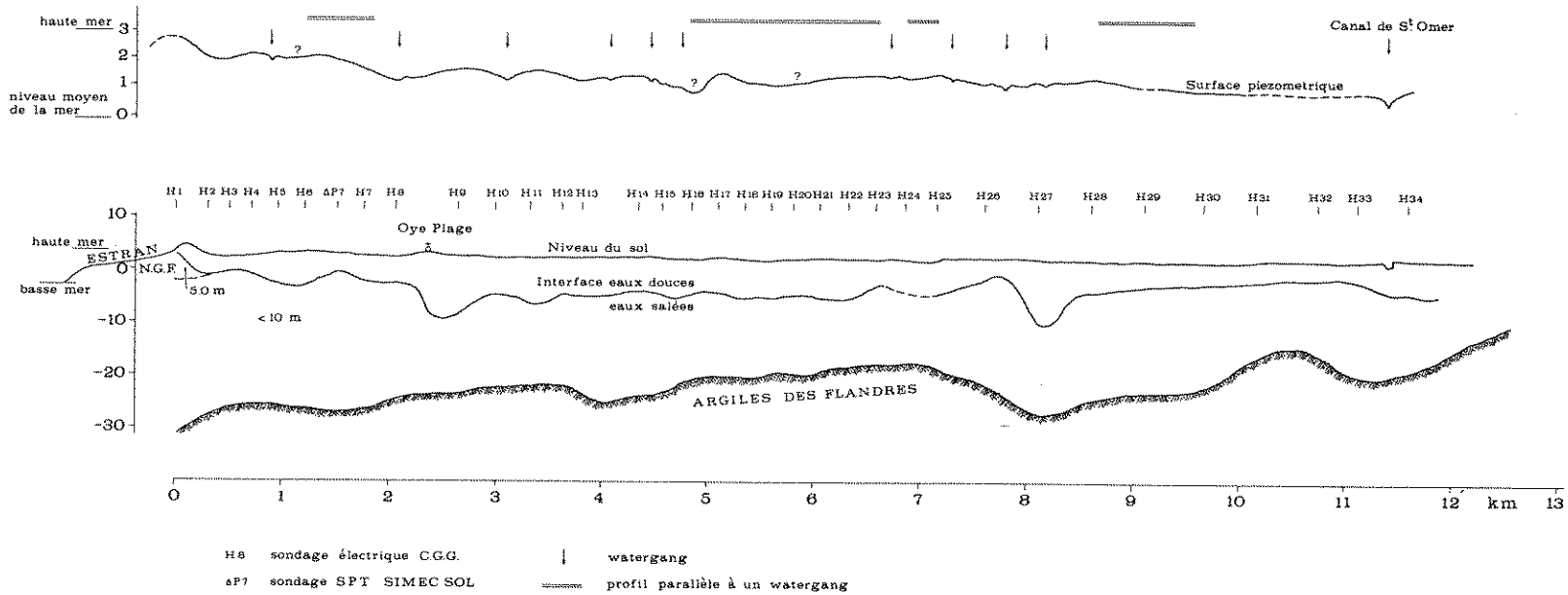

Fig. 1 – Interface and phreatic surface section, corresponding to the geophysical profile H.

have been realized to correlate direct salinity values and electrical measures. A very good correlation was found between the electrical logs (pseudo-normal) and the tests of salinity (Fig. 2).

These results were used to calibrate the electrical soundings. The comparison between electrical logs and electrical soundings proved that the interface level given by the electrical soundings was the upper limit of a transition zone between fresh water and salt water, with a high gradient of salinity.

On the other hand, the direct alimentation by sea water was investigated by comparing piezometrical level, interface level and vertical gradient. These

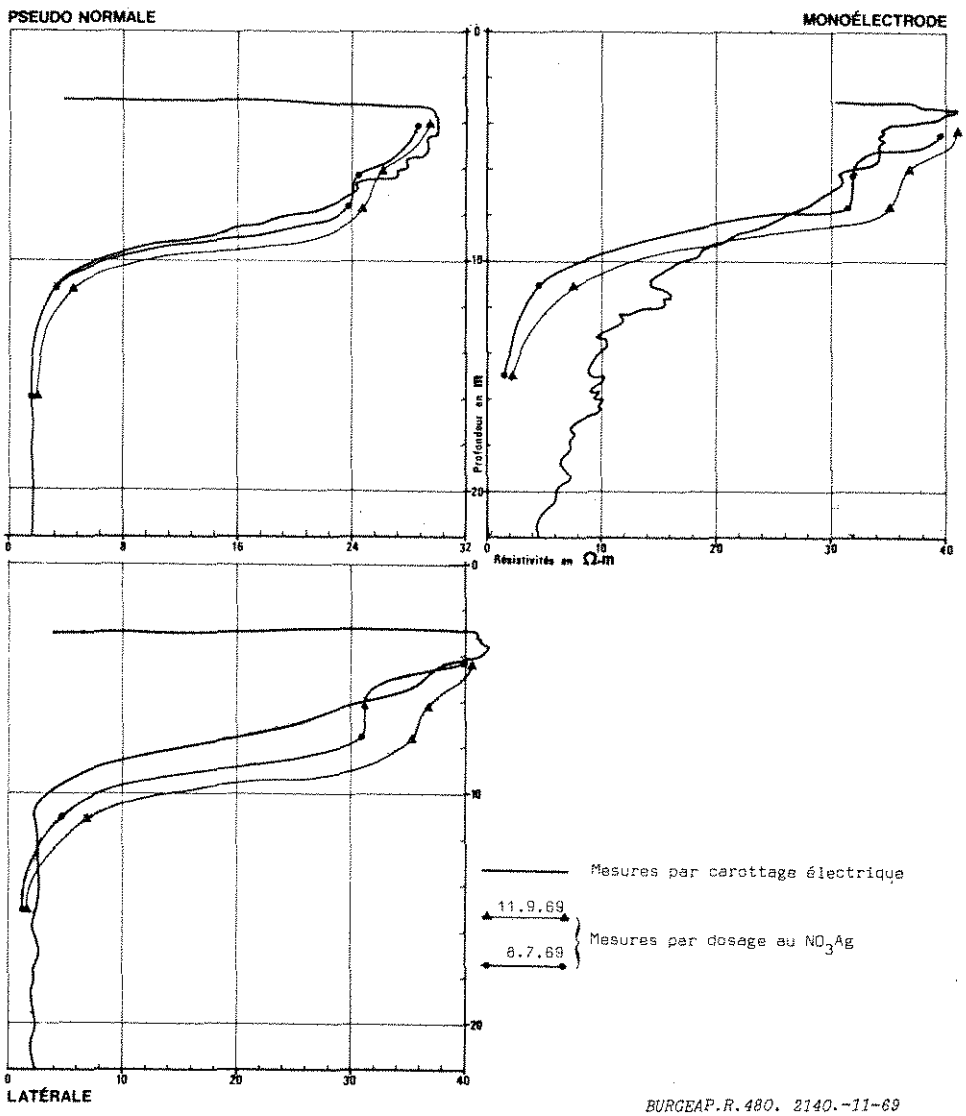

Fig. 2 – Electrical soundings and conductimetric measurements (x22). Comparison of the results.

gradients, near the sea, were observed thanks to littoral observation wells reaching the groundwater at various depths and positioned along a perpendicular line from the coast. The measures of water level are shown on Fig. 3 which indicates the interface level and the piezometrical levels. The analysis of the results gives evidence that the Wateringues aquifer is alimented by the sea, with a salt front at the level of + 2.8 m NGF. The comparison of measures carried out, the same day, at low and high tides proved that the salt front level was not influenced by the tides.

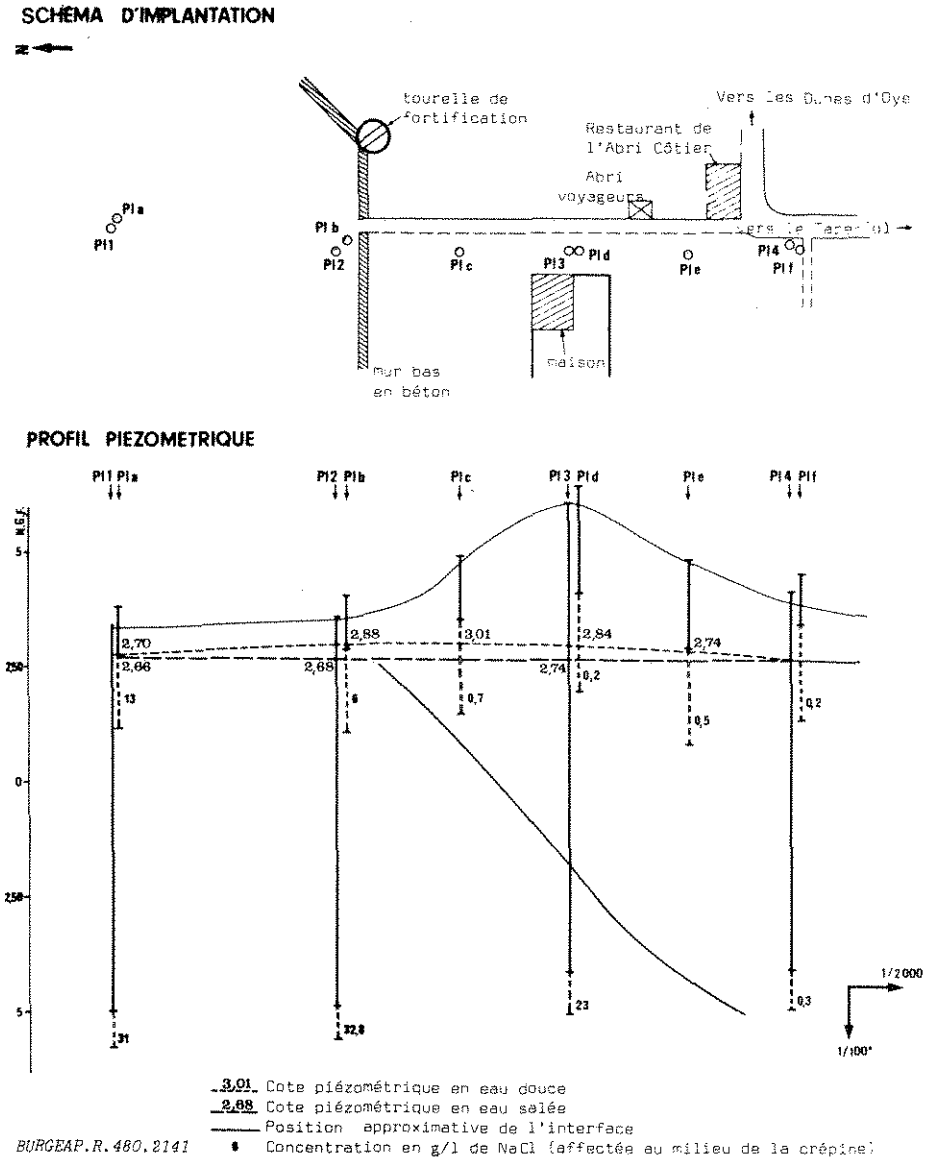

Fig. 3 – Coastal piezometers.

5. FINAL INTERPRETATION: INFLUENCE OF THE COAST'S SLOPE

Evidence of saline intrusion has been shown. This intrusion seems to occur at high tide. The hydraulic ridge of fresh groundwater near the coast has little effect for preventing salt water intrusions. The reason seems to be an injection of salt in the aquifer at high tide. This salt cannot be completely expelled at low tide under the pressure of groundwater flow. In fact the delay of elimination of a tracer by an underground flow is usually far more important than the time of its introduction. The flow occurs, in the present case, on a very long distance due to the low slope of the coast which involves a great delay of flow at low tide. As a confirmation of the primordial influence of high waters on salt water intrusion, it is of interest to note that the theory of Ghyben-Herzberg gives the real position of the interface if high level, instead of average sea level, is taken as reference for calculating salt water level.

Evidence of sea water intrusion in an aquifer theorically protected by an hydraulic barrier has been shown. The confirmation of the interface position by complementary studies proved the reliability of the previous geophysical results. The influence of high sea level and low slope of the coast may give an explanation of the processes which control salt water intrusion.