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SALT WATER ENCROACHMENT IN THE WESTERN BELGIAN COASTAL PLAIN

SUMMARY

In the western part of the Belgian coastal plain the distribution of the water quality groups in the unconfined aquifer has been investigated. A correlation betweem the total dissolved solids, the Cl^--content and the resistivity of the water has been established. The resistivity logging in the area has been calibrated by taking the lithostratigraphy and the hydrochemistry into account. A resistivity profile was obtained through the shore, the young dunes, the polders, the old dunes and the low polders by logging a series of borings along a north-south stretching line. By means of this resistivity the distribution of the water quality groups can be described.

1. INTRODUCTION

The depth of the fresh-/salt-water interface in the unconfined aquifer of the Belgian coastal area has beeen mapped by resistivity surveying and borings [4].

Salt water was defined as having a total dissolved solids content exceeding 1500 mg/l. The resistivity of the fresh-water layer ranges between 50 and 12 Ωm and the resistivity of the saline layer between 2.5 and 1.5 Ωm [2, 3].

In figure 1 a part of the map is shown.

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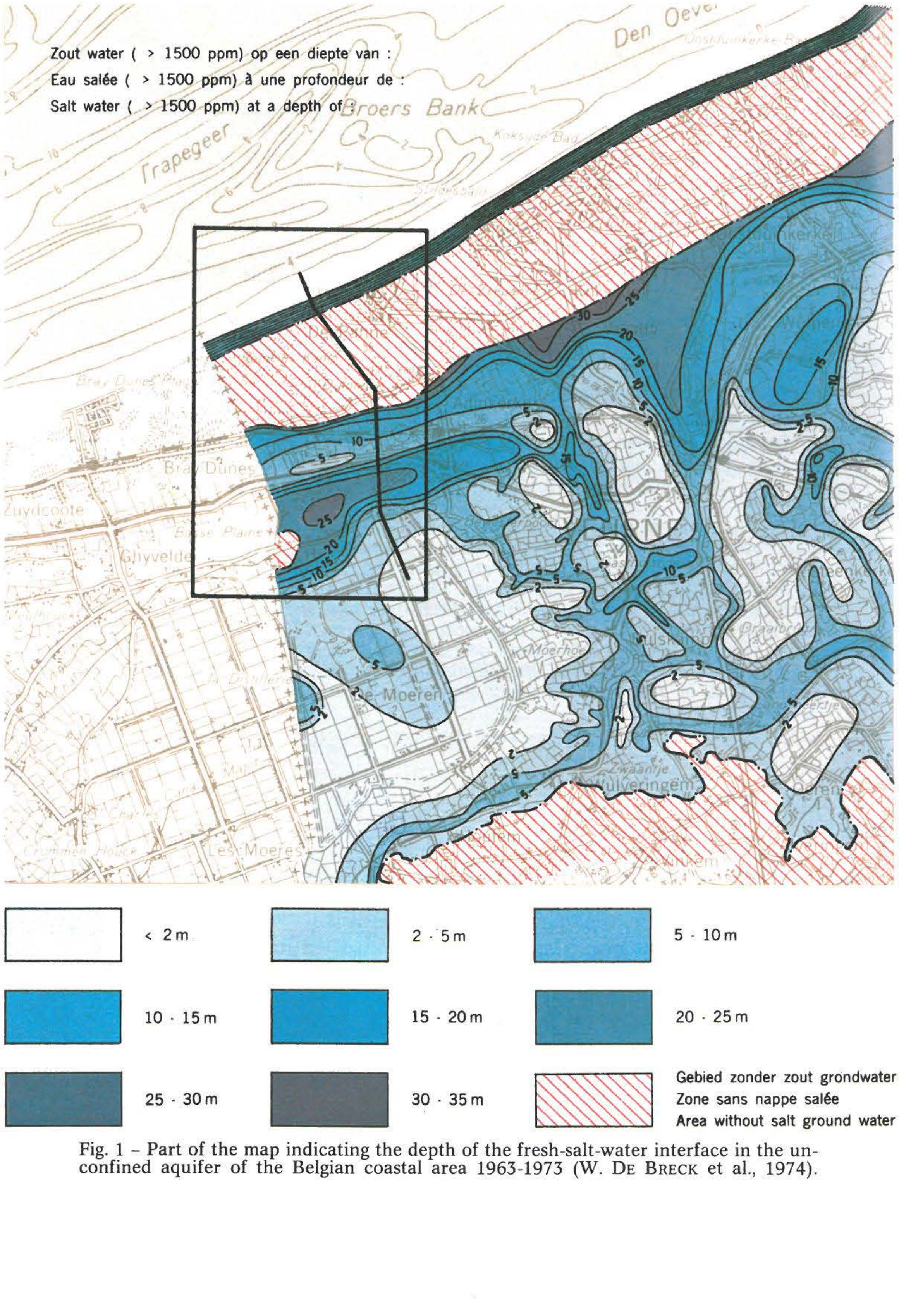

Fig. 1 – Part of the map indicating the depth of the fresh-salt-water interface in the unconfined aquifer of the Belgian coastal area 1963-1973 (W. DE BRECK et al., 1974).

Since then a more detailed study has been carried out in the western part of the coastal area. It comprised a detailed investigation of the lithostratigraphy by cable-tool drilling and grain-size analyses, the hydrochemistry by extensive chemical analyses on water samples from different depths and locations, and the resistivity of the formation and the groundwater by resistivity logging techniques.

By means of long normal logging in boreholes, drilled by the rotary method, a resistivity profile over a length of 5 km and a depth of 30 m was obtained. The resistivity profile has been interpreted in terms of water mineralization and lithostratigraphy.

2. LITHOSTRATIGRAPHY

A series of boreholes has been drilled by cable tool. Samples have been taken every half a meter. Thus a lithostratigraphical section could be drawn along a line, stretching from the beach 3 km landwards (Fig. 2). Grain-size analyses have been made of every layer.

The lithostratigraphical section (Fig. 3) shows the following features.

The unconfined aquifer is bounded below by the Eocene clay substratum (layer 1 ([1])). The undulating top of this clay occurs between – 24.5 and – 31.6 ([2]). Layer 2 consists of medium to coarse medium sands with shells; its thickness varies between 6 and 12 m, its upper boundary being located between – 15.5 and – 18.5; this layer does not occur in the borings 117DB7 and 193DB6.

In the southern part of the area layer 2 is covered by a complex of sand, silt and clay. Two facies can be distinguished: a silty and a clayey one. In boring 117DB7 when layer 2 is absent the clayey facies lies on the Eocene clay and occurs between the levels – 17.3 and – 26.8. In the borings 117DB8 and 117DB6 the silty facies lies on layer 2; it attains a thickness of only 3 to 4 m between the levels – 18 and – 14. In borings 117DB15 and 117DB6 this layer is reduced to silt lenses at level – 16. In boring 193DB5 the clayey facies gradually changes into the layer 2.

In the borings 193DB6 and 193DB7 layer 3 lies upon a very heterogeneous deposit of sand, clay and silt with organic matter. The Tertiary clay substratum has not been attained at these locations. Layer 4 is a rather homogeneous layer of well sorted medium to fine sands. It lies upon layer 2 or layer 3. The basis of this layer is located between the levels – 14.5 and – 17.5; the top between + 1 and + 3. Lenses of different composition can occur: lenses 4.1, 4.2, 4.3 and 4.4 contain fine sand and silt, lenses 4.5 and 4.6 shell-bearing medium sand.

([1]) Indication of the layers in the lithostratigraphical profile (Fig. 3).
([2]) TAW Datum level of the second general leveling (National Geographical Institute, Belgium).

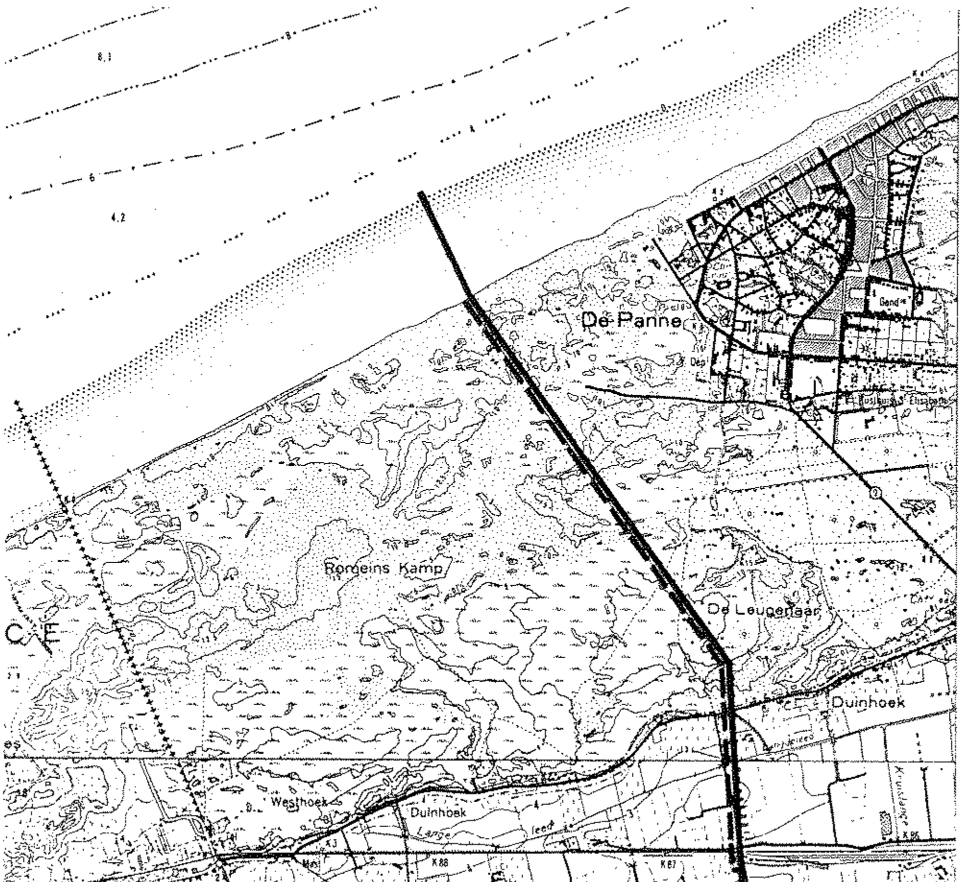

Fig. 2 – Location of lithostratigraphical (dashed) and resistivity (full) profiles.

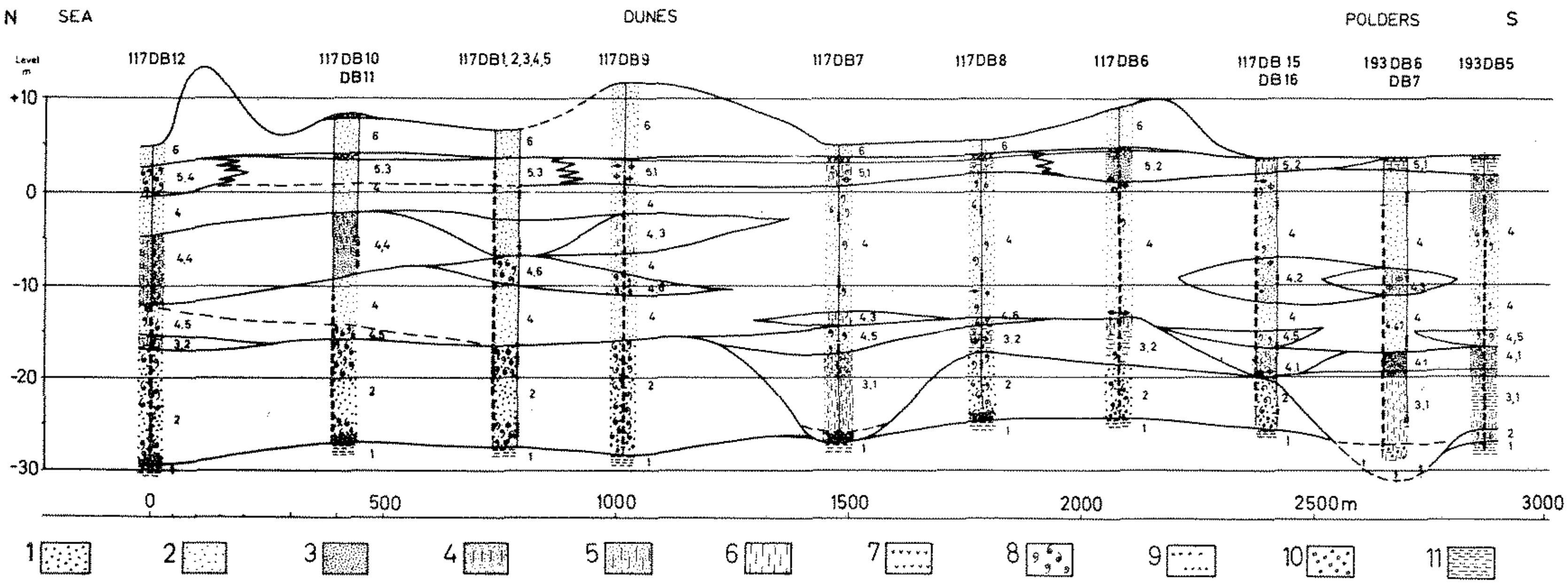

Fig. 3 – Lithostratigraphical profile: 1. medium to coarse medium sands; 2. medium sands; 3. fine sands; 4. slightly silt-bearing fine sands; 5. silt-bearing fine sands; 6. silt; 7. peat; 8. shells; 9. humus; 10. gravel; 11. clay.

A clay-silt-sand complex (layer 5) overlies layer 4 throughout the area. Its top lies at + 4 and reaches the surface in the polder area. Four facies can be distinguished: a clay or a clay-silt layer (facies 5.1) between 0.2 m and 1.0 m thick rests upon silty sands and sometimes upon peat; facies 5.2 mainly consists of silty fine sand with silt and clay lenses (less than 0.1 m thick); in most cases, a humus bearing or peaty soil is found on top; facies 5.3 occurs under the dunes in the northern part of the area and is formed by well-sorted fine sand; facies 5.4 occurs under the fore-dunes and the back-shore in the eastern part; it is formed by a bank of pale, rubiginous shell and shell debris.

Layer 6 consists of well-sorted fine medium sands (layer 6). It occurs in the dunes from the surface to the level + 4. Within this layer brown bands of light humus-bearing sands occur at several levels. Beach sands are less well sorted and finer than the dune sands.

3. HYDROCHEMICAL STUDY

Some of the boreholes have been equipped with a screen over the whole depth of the aquifer. In these boreholes resistivity measurements were made. In other boreholes several piezometers at different depths were installed. These piezometers have a onemeter long screen surrounded by a gravel pack sealed by a clay cover. Besides a series of shallow piezometers were drilled. The piezometers not only served for hydraulic head measurements but also for the collection of groundwater samples.

The analysis of the water samples consisted of the determination in the field of turbidity, smell, taste, temperature of the water and the air, and measurements in the laboratory of temperature, resistivity, pH, dry residue, ash rest, hardness (carbonate and non carbonate), alkalinity, free carbon dioxyde, silica organic constituents, sodium, potassium,calcium, magnesium, ferrous and ferric iron, ammonia, hydrogen chloride, sulphate, nitrate, bicarbonate, carbonate, phosphate, and hydroxyl ion.

Some two hundred water samples have been analyzed. An empirical relationship between the resistivity of water at 11° C (average temperature of the aquifers) and the total dissolved solids has been established:

$$\rho_w = \frac{12{,}000}{TDS} \tag{1}$$

where ρ_w is the resistivity of the water at 11°C in Ωm

TDS is the total dissolved solids in mg/l.

It was found that the relation between the chloride content and the total dissolved solids content was very poor for fresh water (TDS < 1600 mg/l).

For the brackish and salt water samples (TDS > 1600 mg/l), though a simple relation could be established:

$$Cl^{-}\text{-content} = 0.54 \times TDS \qquad (2)$$

where Cl^--content is the chloride content in mg/l
TDS is the total dissolved solids in mg/l.

This relation enables one to extend the table of the water quality groups by G. De Moor & W. De Breuck [5] to the limits for the resistivities at 11°C and for the Cl^--content (Table 1).

Table 1 – Water-quality groups.

Water quality group	Appreciation of water quality	Total dissolved solids (mg/l)	Resistivity at 11°C (in Ω m)	Cl^--content (in mg/l)
G	very fresh	< 200	> 60	–
W	fresh	200-400	60-30	–
V	moderately fresh	400-800	30-15	–
F	weakly fresh	800-1600	15-7.5	–
A	moderately brackish	1600-3200	7.5-3.75	860-1720
B	brackish	3200-6400	3.75-1.88	1720-3440
C	very brackish	6400-12800	1.88-0.94	3440-6880
S	moderately salt	12800-25600	0.94-0.47	6880-13760
Z	salt	> 25600	< 0.47	> 13760

4. RESISTIVITY LOGGING OF FULLY SCREENED WELLS

In fully screened wells the resistivity of the water was measured by a resistivity cell. The resistivity of the surrounding sediments was determined by a normal device with an electrode separation AM of 1 m. The influence of the well screen thus being minimal a good value of the horizontal resistivity of the sediments was obtained. As a first approximation the quality of the water in the well was assumed to be same as that of the pore water in the sediments. This is especially true when the water quality does not vary much over the entire thickness of the aquifer. This is the case in well 117DB9 in the dune area (Fig. 4). The variation of the resistivity of the sediment is mainly due to the variation of the formation factor. The latter varies from 2.5 in fine-grained sediments of layer 4 to 3.3 in the coarser-grained sediments of layer 2.

In the polder area the assumption that the water in the well has the same quality as the pore water in the surrounding sediments does not always hold. This is proved by sequential measurements in well 193DB5 (Fig. 5). The first measurement 193DB5EBM1 was done at the end of the discharge period 1976, the second 193DB5EBM2 at the end of the following recharge period. The two resistivity loggings of the surrounding sediment, ρ_t, do not differ very much. This is not the case for the resistivity of water ρ_w in the well. At the end of the recharge period the water in the upper part of the well has a higher resistivity. The transition zone between fresh and salt water has narrowed and sunk. This can be explained by the higher hydraulic head in the upper part of the aquifer than in the lower part at the end of the recharge period. The sequential measurements of ρ_t also indicate that the transition zone in the sediments does not visibly move.

This phenomenon has already been mentioned by J.F. POLAND & R.H. MORRISON [9]. From resistivity measurements in wells in stratified deposits they conclude that the circulation in a well under non-pumping conditions is ordinarily controlled by difference in head rather than by difference in density. To know the exact quality of the water-producing layers they proposed to make resistivity logs in the well, first in nonpumping conditions and then during

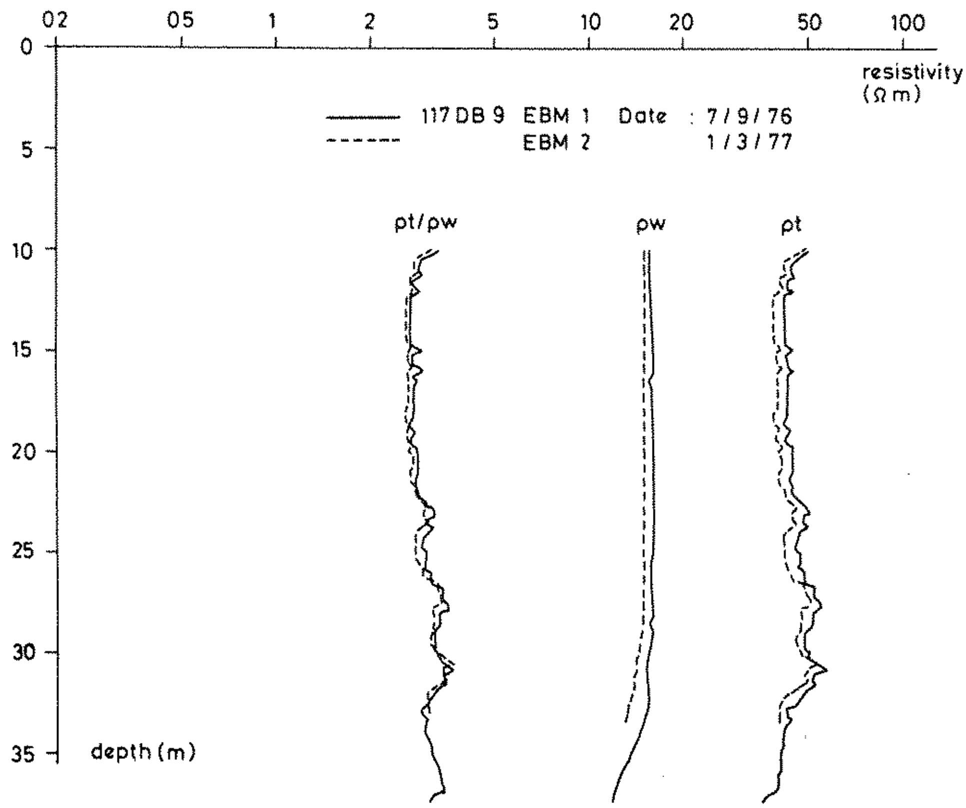

Fig. 4 - Resistivity logs 117 DB9 EBM1 and EBM2.

pumping. It may be necessary to pump a contaminated well for a considerable time before the intruded aquifers are completely flush out. A similar phenomenon was also described by K. R. Rushton [10] in the vicinity of an abstraction well.

Apart from this exception one can assume the ratio ρ_t/ρ_w to be roughly equal to the formation factor. In the study area the formation factor thus varies between 2 in the very silty fine sands and 5 in the medium to coarse medium shell-bearing sands.

In most of the cases the formation factor varies around the average value 2.7. Taking this mean value into account sediment resistivities can be predicted for different water qualities.

Table 2 – Resistivities of sediments filled with pore water of the different quality.

Resistivity group	Appreciation of water quality	Total dissolved solids (mg/l)	Resistivity of the water at 11° C	Resistivity of sediments (11° C)
G'	very fresh	< 200	> 60	> 160
W'	fresh	200-400	60-30	160-80
V'	moderately fresh	400-800	30-15	80-40
F'	weakly fresh	800-1600	15-7.5	40-20
A'	moderately brackish	1600-3200	7.5-3.75	20-10
B'	brackish	3200-6400	3.75-1.88	10-5
C'	very brackish	6400-12800	1.88-0.94	5-2.5
S'	moderately salt	12800-25600	0.94-0.47	2.5-1.25
Z'	salt	> 25600	< 0.47	> 1.25

5. RESISTIVITY LOGGING OF UNCASED BOREHOLES

Along a north-south line from the beach over the polders, the old dunes to the low polders uncased boreholes have been logged. The drilling mud consisted of a suspension of organic additives, that degrade with time. Because of the small borehole diameter (about 100 mm) the resistivity measured with the long normal device (AM = 1 m) was similar to the one measured in a fully screened well (⌀ 80 mm). The resistivities thus measured approximate the horizontal resistivities of the surrounding sediments. This was confirmed by field measurements in a screened well and in a borehole (⌀ 100 mm) not far apart. The data of both series of measurements can thus be combined.

6. RESISTIVITY PROFILE

The results of the resistivity logging on the shore, young dunes, polders, old dunes and low polders are represented in a resistivity profile (Fig. 7). Seven resistivity groups can be distinguished. This resistivity profile provides a picture of the distribution of the quality groups in the unconfined aquifer. The water quality in the unsaturated zone and impermeable substratum, was not studied.

In some places resistivity groups and water quality groups do not coincide. Two explanations can be given. In the first place, the formation factor may differ from the average value of 2.7. This is confirmed from the bore log. In the second place the resistivity may abruptly change, as in the case of a sharp interface. Water samples taken over a limited length of a screened well and short normal measurements show that the long normal measurements tend to enlarge the transition zone on the resistivity profile (Fig. 5).

Under the shore a salt water lens floats upon the fresh groundwater which flows from the dunes in the direction of the sea. The salt water infiltrates on the back shore and the upper part of the fore shore. Under the low-

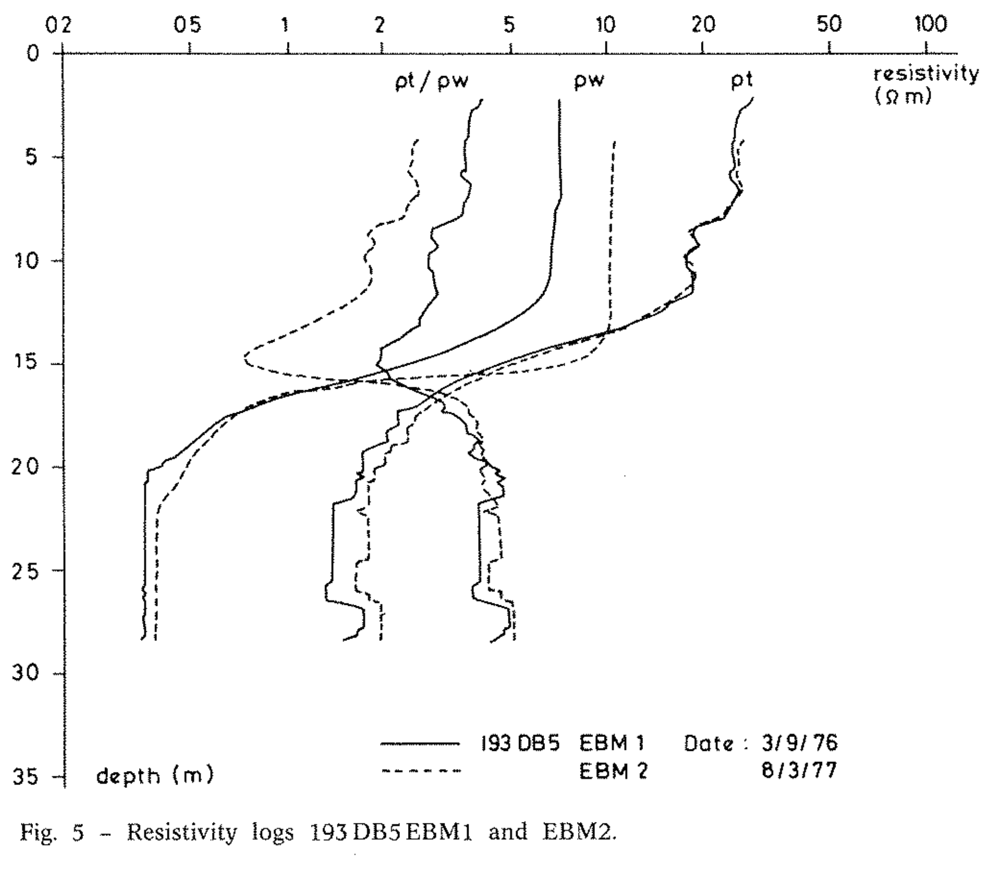

Fig. 5 – Resistivity logs 193 DB5 EBM1 and EBM2.

er part of the fore shore salt water flows upwards resulting in a seepage. The fresh water below the salt water gradually becomes more mineralized when it flows towards the sea. Under the low water line a brackish water foot can occur in the lower part of the aquifer, as mentioned by L. LEBBE [7].

In the young dunes fresh water infiltrates. The chloride content of the rain as measured during a period of thirty months, was approximately 12.0 mg/l. The mean chloride content of 27 samples of fresh water in the young dunes was 32.5 mg/l. Hence one can conclude that about 40% of the rain infiltrates in the young dunes [6]. This value was confirmed by the calculation of the potential evapotranspiration from hydrometeorological data after the PENMAN method [8] and by a balance of the unsaturated zone after the method of THORNTHWAITE, and MATHER [11].

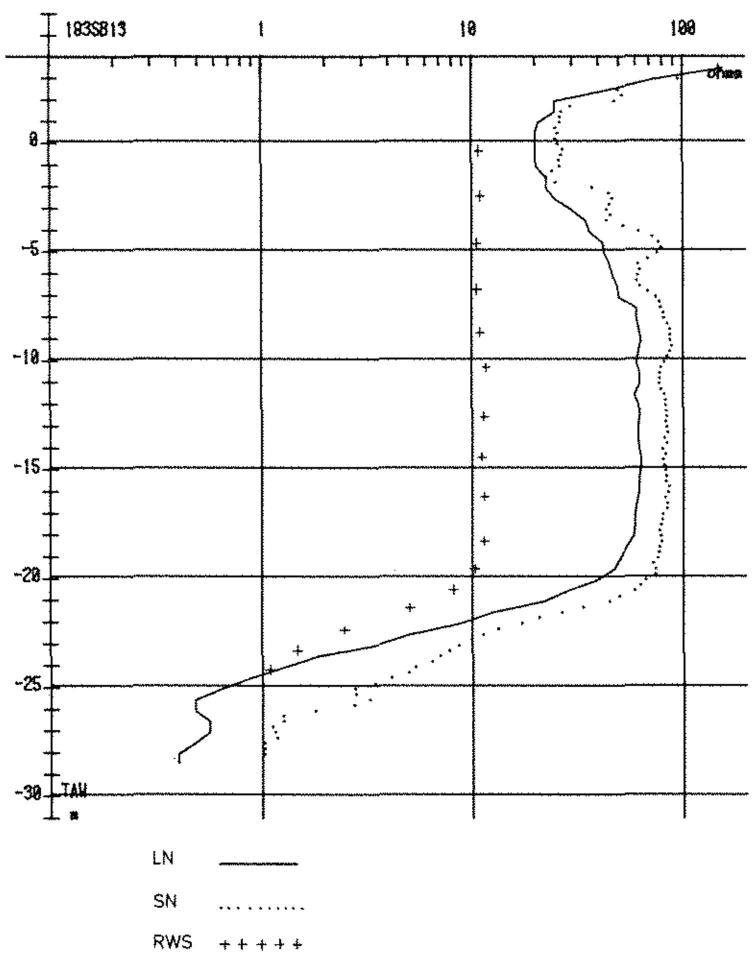

Fig. 6 – Resistivity log 193SB13.

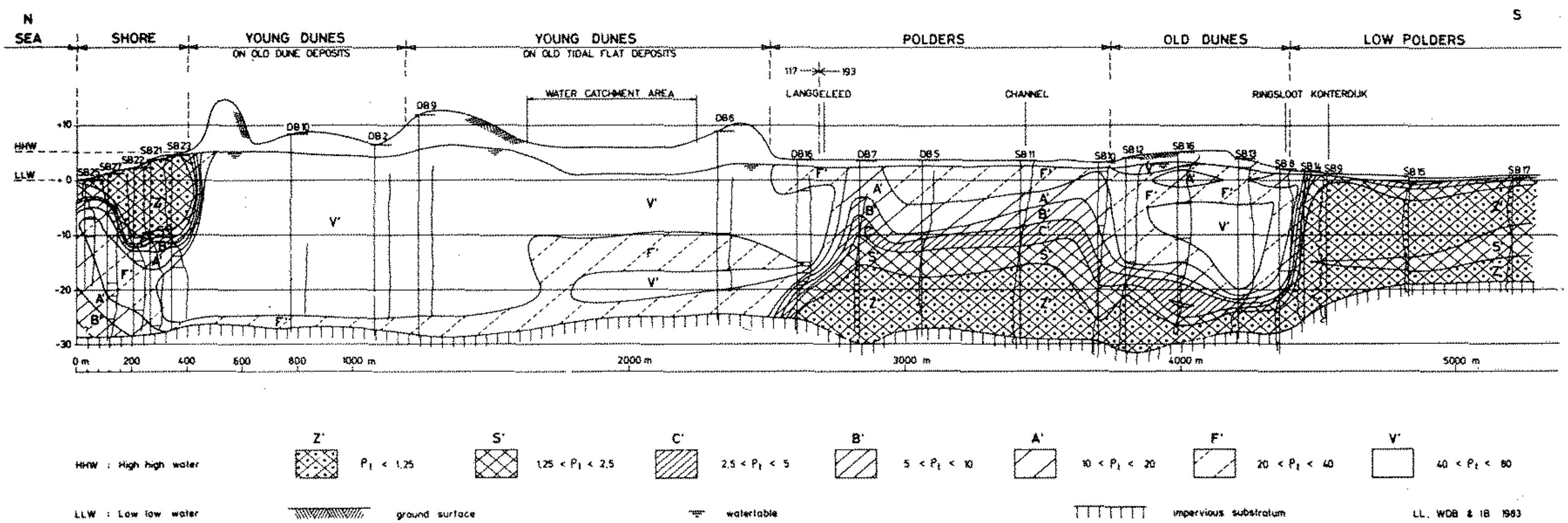

Fig. 7 – Resistivity profile De Panne-Adinkerke-De Moeren.

The young dunes can be subdivided into two parts. In the northern part they rest on old dune deposits and in the southern part they lie on old tidal-flat deposits. Here the fresh-water lens reaches the impermeable substratum. This lens is older in the northern, than in the southern part. As a consequence the water is less mineralized in the north (TDS, 200-500 mg/l) than in the south (TDS, 400-800 mg/l). Near the impermeable substratum the fresh water has a higher salt content. In the southern part the lens of resistivity group F is not only caused by the increasing mineralization of the pore water but also by the smaller formation factor (2.1 in well 117DB6) of the finer sediments.

Under the polder area fresh water rests upon salt water. The fresh water has a higher salt content than the fresh water of dunes and belongs to the water quality group F. Between the fresh and the salt water the transition zone of brackish water attains an average thickness of 12 m. Under the ditches a upconing of brackish water can be seen. The ditch at the foot of the young dunes drains much of the groundwater which flows from the dunes to the polders. This results in an important vertical groundwater flow, which brings brackish water just under the watertable. The upconing of brackish water is less conspicuous at the edge of the old dunes in the south.

Under the old dunes a fresh water lens is present. In the upper part of the aquifer the resistivity is rather small. This is due to a low value of the formation factor of the clay, silt and peat deposits just below the dune sands. The asymmetrical shape of the fresh-water lens can be explained by the different drainage levels of the polders in the north and the low polders in the south. The drainage level in the polder is two meters higher than in the low polders. In the old dunes fresh water infiltrates. Because of the different drainage levels the largest part of the fresh water flows to the low polders. Only a small part flows towards the polders in the north. In the lower part of the aquifer under the old dunes the fresh-water head is at its lowest near the low polders. This explains the presence of fresh water in the deepest parts of the aquifer under the old dunes where the downward vertical flow is maximal.

In the deep polders seepage of salt water occurs. An important vertical flow is directed upwards in the vicinity of the large ditch close to the old dunes. The salt content of the water just below the watertable is that of moderately salt to very brackish water. The higher resistivity in the lower part of the aquifer is due to fine sediments (Very silty fine sand). In the case of very salt pore water the formations factor tends to increase with decreasing grain size [1].

8. CONCLUSIONS

Field observations and laboratory measurements show that the average value of the formation factor is 2.7. Resistivity logging of a line of borings thus provide a 5 km section through the coastal area showing the water quality distribution. This distribution can be explained in view of the topography, the geological history and the groundwater flow.

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