B. KOZERSKI (*)

PROBLEMS OF THE SALT WATER ORIGIN IN THE VISTULA DELTA AQUIFERS

SUMMARY

In the Delta of the Vistula there occur three aquifers containing both fresh and salt water. The upper aquifer presents complex hydrodynamic conditions. Its salinity is due to the littorina transgression to be followed in the western part of the Delta by freshening as a result of an intensive fresh ground water inflow from the moraine hills area. The lower aquifer appearing in the Pleistocene loam interbeds contains fresh water. The Cretaceous aquifer is saline in the central and eastern part of the Delta. The salinity originates from Mesozoic fossil water. Along the coast over an area covered by bay-bar dunes there appears fresh water salty only in places of intensive exploitation.

1. INTRODUCTION

The geological structure of the Polish Baltic coast causes that the occurrence of salt ground water is confined to several zones and does not extend too far landwards (Fig. 1). The salt water areas are mainly flat and usually separated from the open sea by bay-bows.

Up to now all papers devoted to hydrogeology of the coastal area have associated the problem of saltness with the sea water intrusions into the coastal

(*) Hydrotechnics Faculty, Technical University of Gdańsk. Poland.

aquifers. The intrusions are generally caused by an intensive exploitation of the ground waters along the coast-line. The salinity may also result from the ascension of mineralized relict waters of the Mesozoic era which commonly appear in northern Poland.

Much less attention has been concentrated so far to the hydrological importance of the coast shaping and the evolution of the coast line during the postglacial period. The necessity of taking into account the above problems referring to the origin of salinity has already been pointed out by Dutch authors, e.g. I. A. Boswinkel [1], A. B. Pomper [6], J. J. De Vries [8] and others.

In view of their publications it seems purpose-full to revise the salinity genesis in those coastal zones where the image is particularly complex and simultaneously some new geological or hydrogeological data have appeared.

The hydrogeological investigations of the salinity coastal aquifers have up to now been limited and connected with the search for fresh water for the supply of towns and agriculture. Most often the zones, which had been regarded earlier as salty, were neglected in further investigations, while subsequent explorations referred to fresh water areas. Thus, the amount of data dealing with the salinity water-bearing strata is rather insignificant. In most cases the data come from a dozen or even some scores of years ago and then the ideas on the spread and the origin of sea-water in the coastal aquifers were also conceived. In the recent years the problem has again acquired some importance. A process of collecting new data has begun but their amount is still insufficient to provide a full explanation regarding the occurrence of salt ground water along the Polish coast-line.

Therefore the considerations contained in this paper should only be looked upon as an attempt aiming at a presentation of new approach to the problems the solution of which still requires investigations and time.

The Vistula Delta has been chosen for this presentation since the problem of salt ground water has been of great interest for years and it is of serious practical importance.

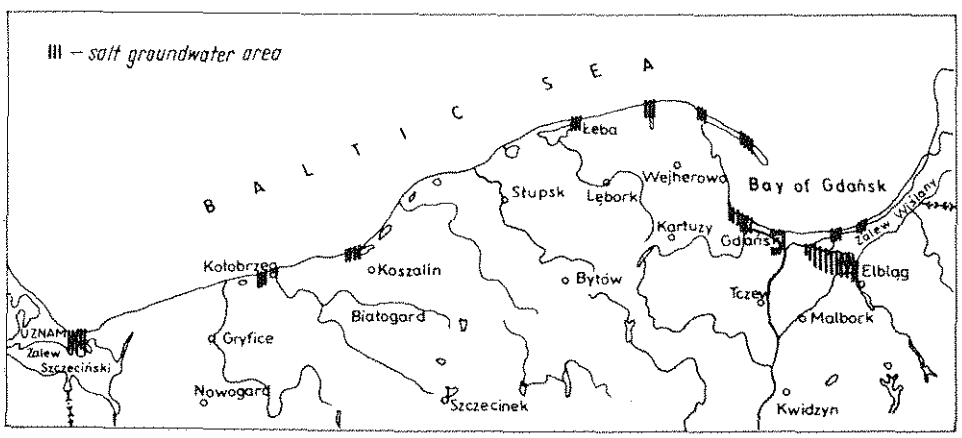

Fig. 1 – Salt groundwater occurrence on the polish coastline.

2. HYDROGEOLOGICAL CONDITIONS

The Delta of the Vistula River extends over an area of 1700 km^2. It is a flat area surrounded to the east and west by moraine hills (Fig. 2). The height of the moraine hills in the vicinity of the boundary to the Delta plain reaches over 100 m above sea-level. The hills descend steeply. To the north the Delta is separated from the sea by belt of the Vistula bay-bar the length of which is over 40 km and width from 1.0 to 3 km. The bay-bar is a dune area rising at some points up to 30 m above the sea-level.

The Delta surface deposits are composed of fluvial sediments whose thickness amounts to 30 m, while the roof consists of peats and muds above fine

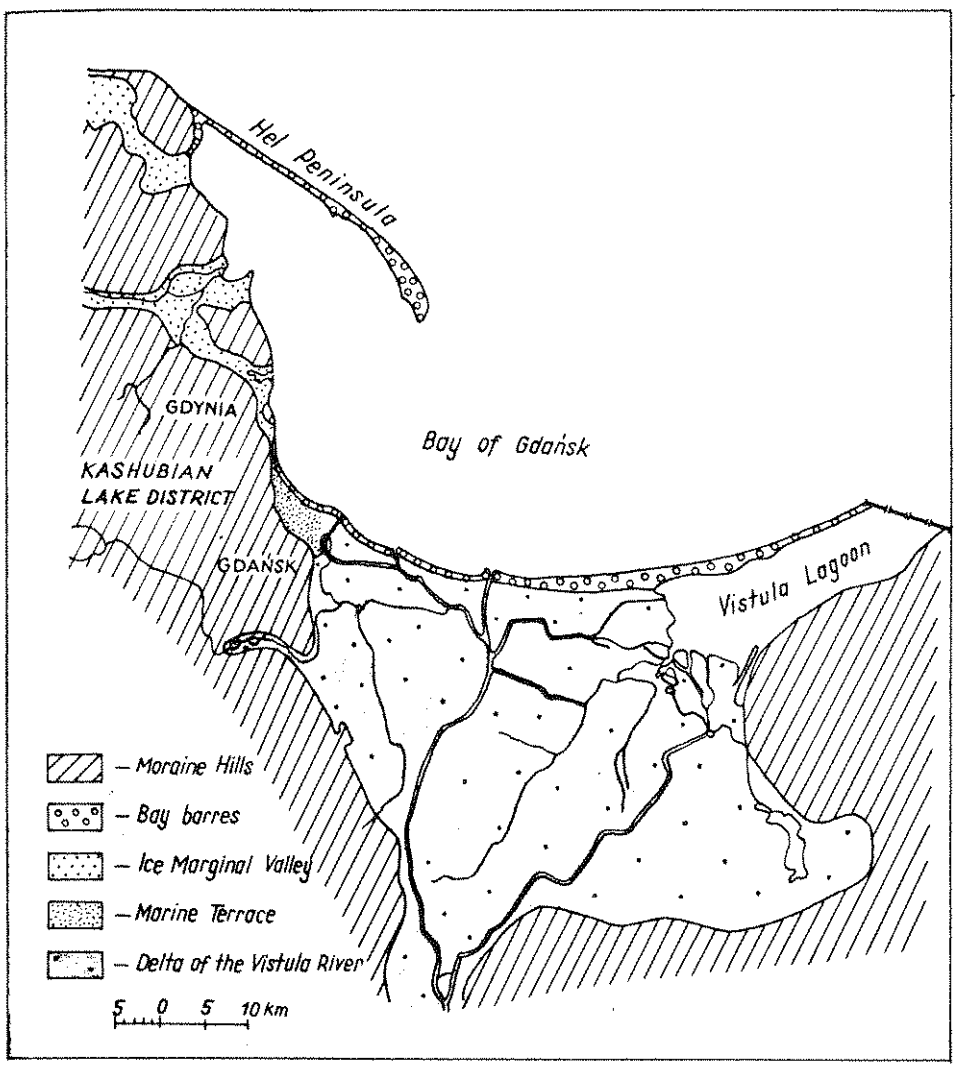

Fig. 2 – Geomorphological structures.

grained sand (Fig. 3). Below the Holocene sediments there appear fluvioglacial medium-grained and coarse sands of approximately 30 m thickness decreasing southwards. This sand series of Pleistocene together with the pervious materials of Holocene creates in the Delta a widely spread upper aquifer. Its level is underbedded with loams of up to 50 m thick which the bottom sometimes reach 100 m below the sealevel. The loams are separated by sands creating vast interbeds and lenses of about 10 m thick.

The permeable deposits occurring between the loam strata create so called lower aquifer. Isolated layers of Pleistocene or Oligocene permeable matter found below the loams just upon the upper Creataceous deposits are of minor importance.

The Cretaceous formations extend all over the Delta area and are composed of marl and limestone to be followed by fine grained sands. The limestone and marl aquifer have some local significance. The waters of the sand aquifer are more broadly spread. The original piezometric surface of the Cretaceous aquifer is situated several meters above the sea-level. In older than Cretaceous formations of Mesozoic composed mainly of impervious materials there have been found very mineralized waters in the Triassic sandstone. In the Delta area the investigations were carried out in Krynica Morska.

3. SPREADING AND GENESIS OF SALT WATER

All the above mentioned water-bearing strata are characterized by the appearance of both fresh and salt waters (Fig. 5). In the upper aquifer made up of fluvial and fluvioglacial sand the fresh water spread in a belt for several or more kilometers wide along the Kashubian Lake District (Fig. 4). Other areas mainly the central part of the Delta are characterized by the appearance of salt water containing Cl^- up to 2500 ppm. The genesis of that salinity was associated by both E. Ostendorf [4] and Z. Pazdro [5] with the intrusions of the Gdańsk Bay sea water in the direction of the Delta low-lands. This point of view has been maintained for many years, but at present it seems to be only partly right.

The published later investigation results on the evolution of the southern coast line of the Baltic Sea make it possible to interpret the existing data in a different way. B. Rosa [7] stated that the Littorina Sea transgression included the northern and central part of the Delta, while in the east it reached still farther southwards. During this period the Pleistocene sediments of the upper aquifer constituted the bottom of the sea. Its fresh water was displaced by diffusion or driven out by salt sea water whose salinity was similar to today's Baltic water. At that time the differentiation of the mineralization of water might have already occurred in consequence of different degree of mixing up the Vistula fresh water with the water of the created Littorina Bay. After the withdrawal of the sea an intensive Delta sedimentation process took place in the lagoon enclosed by the bay-bar which helped the salt walter of the aquifer to last.

Another favourable circumstance acting on behalf of the survival of these waters was a low or zero hydraulic gradient owing to which the ground water

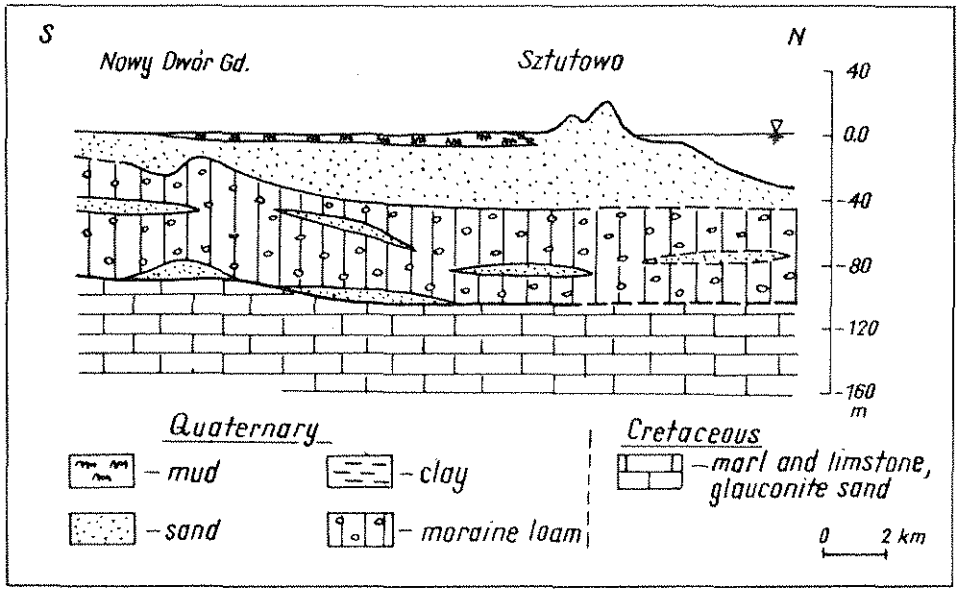

Fig. 3 – Schematic geological cross-section.

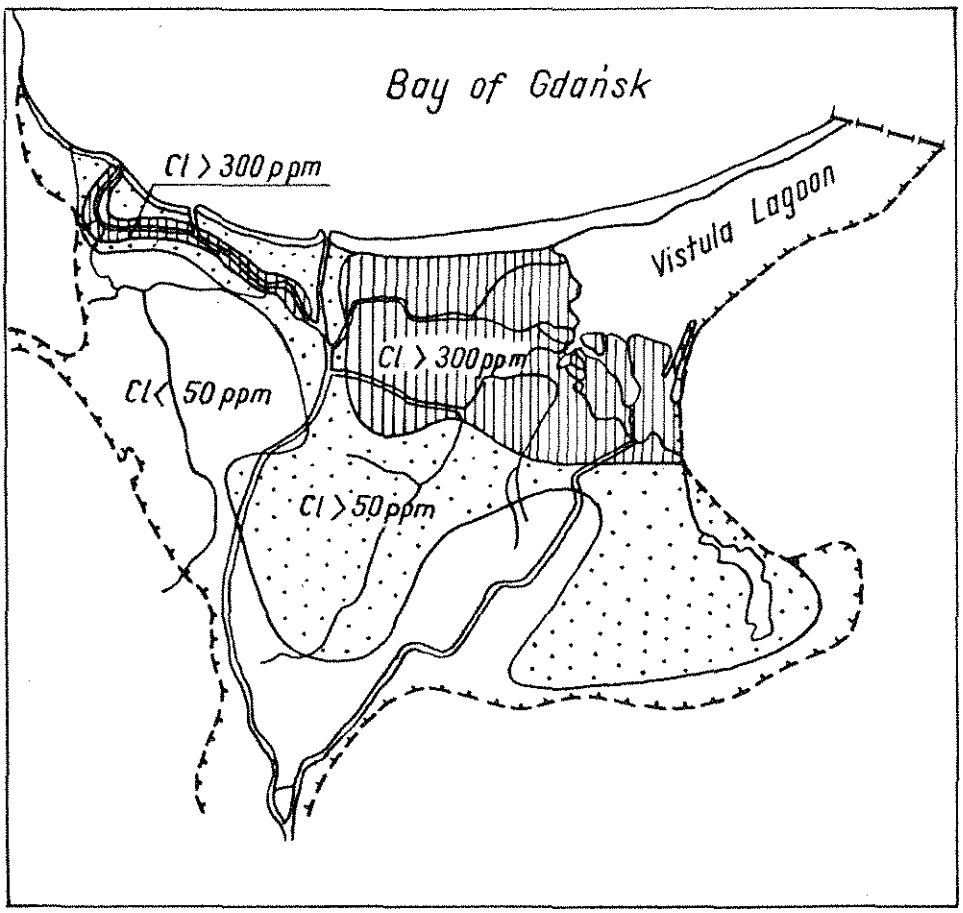

Fig. 4 – Salt water in the Quaternary aquifer.

flow has been extremely slow and at some places the waters are of stagnant nature. This fact has been pointed out by B. KOZERSKY [2] who raised the question of the possible existence of young fossil waters in the Vistula Delta aquifers.

In favour of the relict littoral origin of the salinity is the fact that at some points the range lines of transgression correspond to the southern boundary of an increased content of chloride ion in the upper aquifer. An indirect argu-

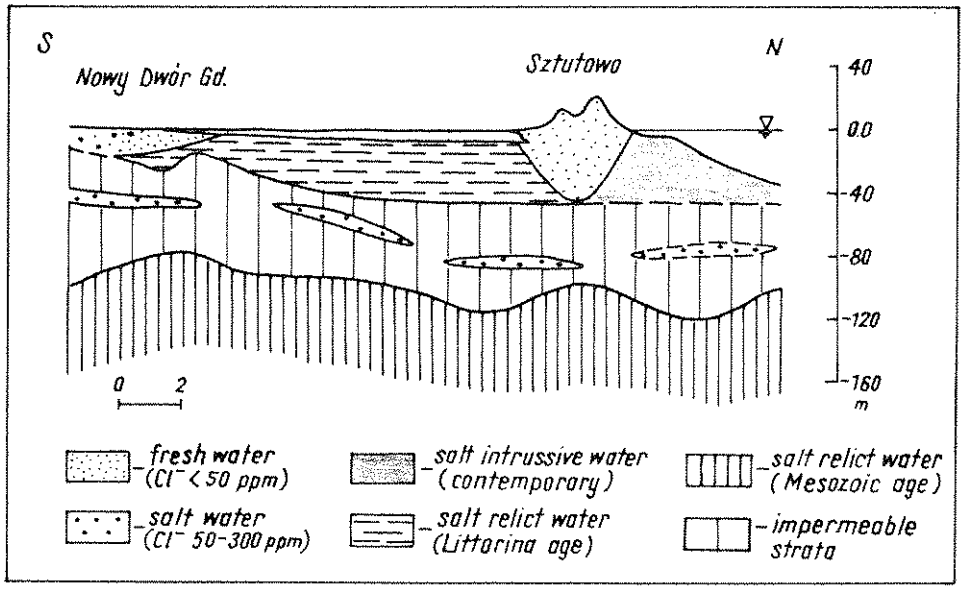

Fig. 5 – Salt and fresh water distribution.

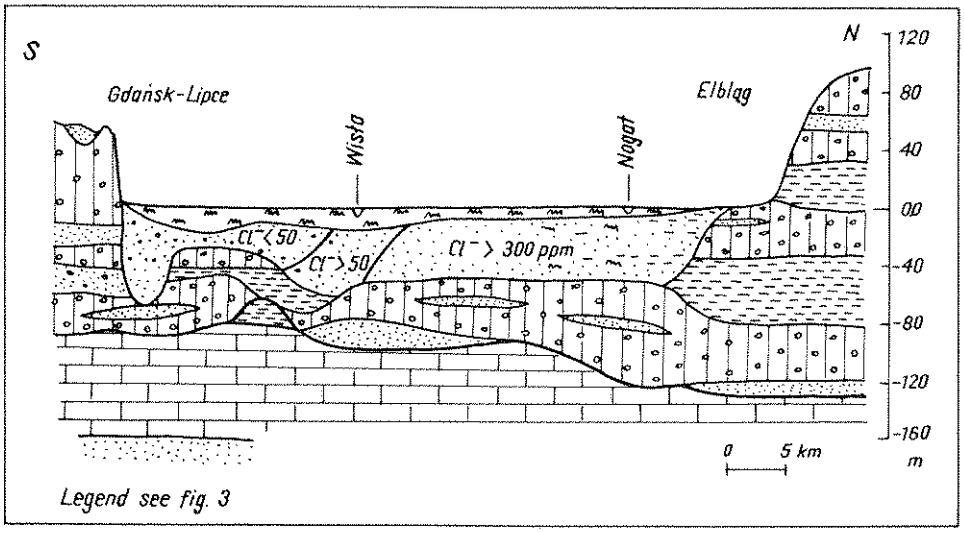

Fig. 6 – Schematic geological cross-section.

ment is also the occurrence of salt waters amounting to 25 km southward of the present coast-line. It is difficult to prove assuming only the encroachment during a historical period.

Quite different hydrodynamical conditions have appeared in the Vistula Delta in the neighbourhood of the Kashubian Lake District. A high hydraulic gradient as well as a great value of transmissivity of the formations in the contacting zone of these two units result in a constant inflow of fresh water into the Delta upper aquifer, which in the period of 3-4 thousand years might have exchanged the salt waters for fresh water in the edge zone (Fig. 6). The lack of lateral recharge on the eastern Delta border makes it possible that the salt waters have preserved up to now. The low value of the upper aquifer transmissivity to the east of the Vistula River is also of significant importance.

Local freshing of waters in other sectors of the Delta might have taken place in time of the Delta formation when accumulation processes went on together with erosion facilitating contact and the mixing of the river waters with the ground salt water. This phenomenon can also be observed today.

Some significance in the water freshening have also had frequent floods in the area of the Vistula Delta.

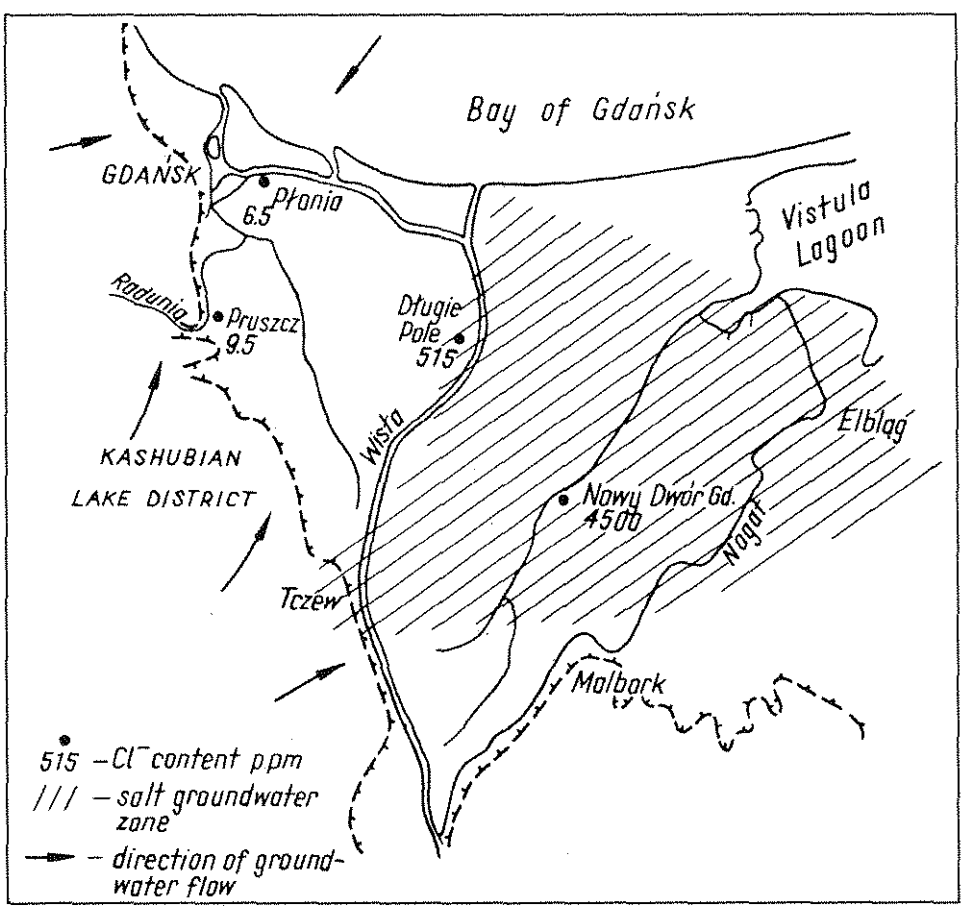

Fig. 7 – Salt water in the Cretaceous aquifer (after [3]).

The salt water of the upper aquifer in the neighbourhood of the saline water of rivers and canals is of an intrusive character. This feature refers in particular to the exploited parts of the aquifer causing an increase of the chloride content up to 1500 mg/l.

The lower intermoraine aquifer does not spread continuously. It is separated from the upper level by a layer of loams of thickness up to 20 m.. A stratum of loam featuring similar thickness separates the lower aquifer from the below lying Cretaceous one. The lower pleistocene aquifer contains fresh water with Cl^- 50-240 mg/l, while the content of iron is very high and reaches 10 mg/l Fe.

Apart from low salinity attention should be drawn to the great amount of iron characteristic for the upper level. The chemical composition and the genesis of the water in lower aquifer are hard to be explained. However, it is possible that due to insufficient surveying the problem of recharge and discharge of these waters has not been defined yet. At some places these waters may contact indirectly either with the water in the upper Pleistocene level, or the Mesozoic fossil water occurring below.

The water of the Cretaceous aquifer is salty all over the Delta area situated to the east of the present Vistula valley (Fig. 7).

The Cl^- content upon the depth of 100-150 m amounts to 500-3000 mg/l and rises with the depth. The salinity is of relict nature but ascension of highly mineralized Jurassic and Triassic waters might also be possible here.

On the left hand of the Vistula in the western part of the Delta one can find quite different conditions. The water of the Cretaceous aquifer is fresh here, and the quantity of Cl^- is 10-50 mg/l. The original piezometric surface is descending steeply from south-west towards the Gdańsk Bay and the Vistula mouth. Out of the Kashubian Lake District is directed a stream of fresh ground water which has driven the salt water out of the Cretaceous formations, whereas the high piezometric head counteracts ascension of deeper mineralized waters.

In consequence of an intensive exploitation of the Cretaceous aquifer the situation is at present disturbed resulting in the shifting of the salinity boundary towards the left bank of the Vistula.

Typical hydrogeological conditions for the coastal dune areas exist along the bay-bar belt. The aquifer of 40-50 m thick is composed of sands of marine and eolian accumulation while at the bottom of fluvioglacial.

The water table is upon 1 m above sea level. The whole thickness of the aquifer contains fresh water. Only in areas of more intensive exploitation there appear salinity up to 1500 mg/l Cl.

REFERENCES

1 - BOSWINKEL I. A., *Spatial salinity variations in the Netherlands*, Proceedings of 7th Salt Water Intrusion Meeting, Uppsala, 1981.

2 - KOZERSKI B., *Salt water intrusions into coastal aquifers of Gdańsk region*, 7th Salt Water Intrusion Meeting, Uppsala, 1981.

3 - KOZERSKI B., PREJZNER, J., SUKOWSKI, T., *Zmiany rezimu wód podziemnych w północnej części delty Wisły*, Archiwum Hydrotechniki, 1983.

4 - OSTENDORF E., *Die Grundwasser in nordösthsehen Weichseldelta mit besonderer Berücksichtigung der Verzalzung: Bd 1*, Sehr. Landesk. Forsch. Danzig, 1944.

5 - PAZDRO Z., *Wody podziemne regionu gdańskiego*, Przegl. Geol. Nr. 6, 1958.

6 - POMPER A. B., *Hydrochemical observations in the subsoil of the western part of the Netherlands*, 7th Salt Water Intrusion Meeting, Uppsala, 1981.

7 - ROSA B., *O rozwoju morfologicznym wybrzeza Polski w świetle dawnych form brzegowych*, Studia Societatis Scientiarum Torunensis. Toruń - Polonia, 1963.

8 - VRIES J. J. de, *The distribution of fresh and salt groundwater in the Dutch coastal area and the Quaternary - geological evolution*, 7th Salt Water Intrusion Meeting, Uppsala, 1981.