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EVIDENCE OF THE INFLUENCE OF MAN ON THE NATURAL PROCESSES RELATED WITH SALINIZATION OF GROUNDWATER IN THE WESTERN PART OF THE WEST-NETHERLANDS

1. INTRODUCTION

During the first meeting of this Committee two years ago, a review has been given of the investigations which the Institute for Land and Water Management Research (ICW) in Wageningen was carrying out on the hydraulic backgrounds of the salinization problems in the Western part of the Netherlands bordered by the North Sea in the West, the New Waterway in the South, the Amsterdam-North Sea channel in the North and a line that can be drawn from Amsterdam to Gouda in the East. At that time it was only possible to give a description of the observations. Now, the measurements are almost completed and the results of the studies as well as the explications of some observed phenomena can be given.

2. GEOLOGICAL SITUATION

Hydrological studies should be based on a good knowledge of the geological situation in the investigated region. A modified version of the blockdiagram shown in the first meeting is given in fig. 1 to update the information.
The stratigraphy itself has no significance for hydrologic problems, it is, however, necessary to be able to find the interconnections occurring between different strata with hydrologic significance.

3. HYDROLOGIC SIGNIFICANCE OF THE STRATA

The layers in the subsoil having hydrologic significance have been formed during the upper Tertiairy and Quartairy epoch. The complicated processes during the Pleistocene resulted in a sedimentary basin with a depth ranging from 400 to 600 m, with great differences in hydraulic properties of the strata.
It is evident that for the hydrologic processes near the surface the Holocene and Younger Pleistocene layers have the greatest importance. The influence of the other layers depends partly on the vertical resistance of the stratum with Kedichem clay and partly on the hydrologic properties of the deeper

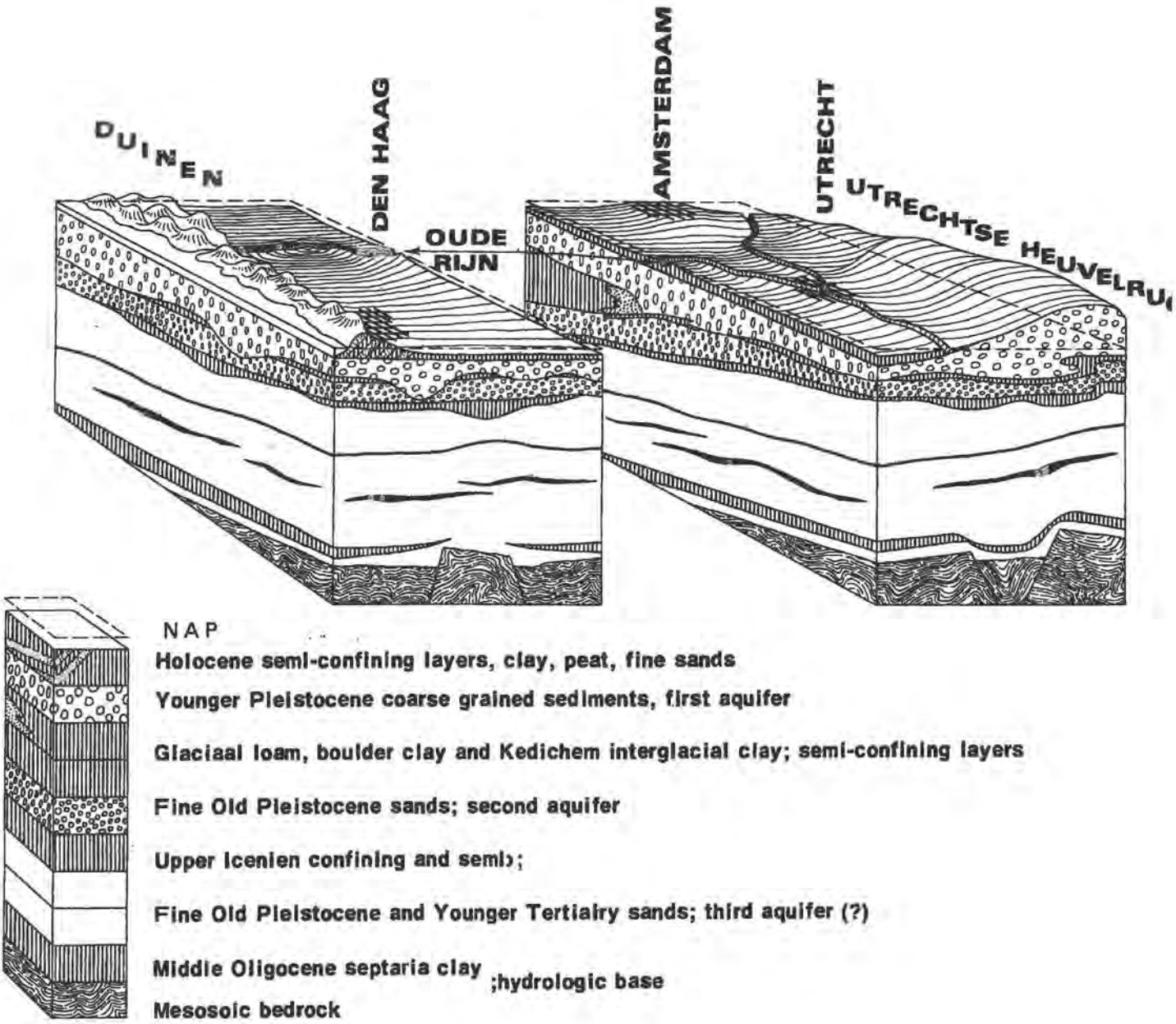

Fig. 1. Block diagram of the geological situation and conspectus of the hydrologically important layers found in the western part of the Netherlands

layers. It can be stated that the aquifers below the Kedichem clay can be disregarded in the explanation of the salinization problem.
The Holocene layers, on which all present human activities are taking place,

are almost without any gap. Owing to the hydraulic resistance of this layer the rate of flow from the deeper layers to the surface in spite of great differences in hydraulic head between deep and phreatic groundwater. To calculate the rate of vertical flow from differences in hydraulic head between covering layers and aquifer, knowledge on the vertical resistance of the covering layers is a prerequisite. In our case it has been measured from core samples. Vertical flow can also be calculated from the transmissibility and the hydraulic head in the aquifer. Both calculations have been carried out. With the aid of the numerous observations of the Archieve of Groundwater observations TNO in Delft maps have been compiled showing hydraulic heads of both phreatic and confined water.

4. SALINITY OF THE GROUNDWATER

Salinity of the groundwater in the subsoil was given in different maps showing:

- the salinity of the groundwater at different depths below soil surface;
- the salinity at different depths below sea level;
- the interface of fresh and salt water ($>$ 500 ppm chlorine)

The topography of the interface of fresh and salt water shows that a very complicated situation exists (fig. 2). The depth varies from zero to more than 90 meters below mean sea level. In some places the interface falls steeply from a depth close to datum level to a very great depth. Such a situation indicates that stability has not yet been reached.

A good illustration of the complexity of the 500 ppm chlorine level is the occurrence of inversions. Very clear examples of this phenomenon can be observed near Delft, South of Alphen and West of Haarlem. Near Delft the inversion has been formed during a post-Roman period of marine sedimentation. After a long period of regression of the sea, the southwestern part of the Netherlands was flooded by the sea. The existing marsh landscape then changed into a tidal landscape. The situation at the other two places mentioned is basicly different from the situation near Delft. There fresh water pockets in the aquifer under salinized Holocene covering layers increased in size. The differences in thickness of the brackish water layer in the subsoil depend on the grain size distribution of the sediment and the flow velocity of groundwater perpendicular to the interface of fresh and salt water. When fresh water is replaced by salt water, differences in flow velocity in larger and smaller pores cause mixing. The larger the flow velocity and the greater the

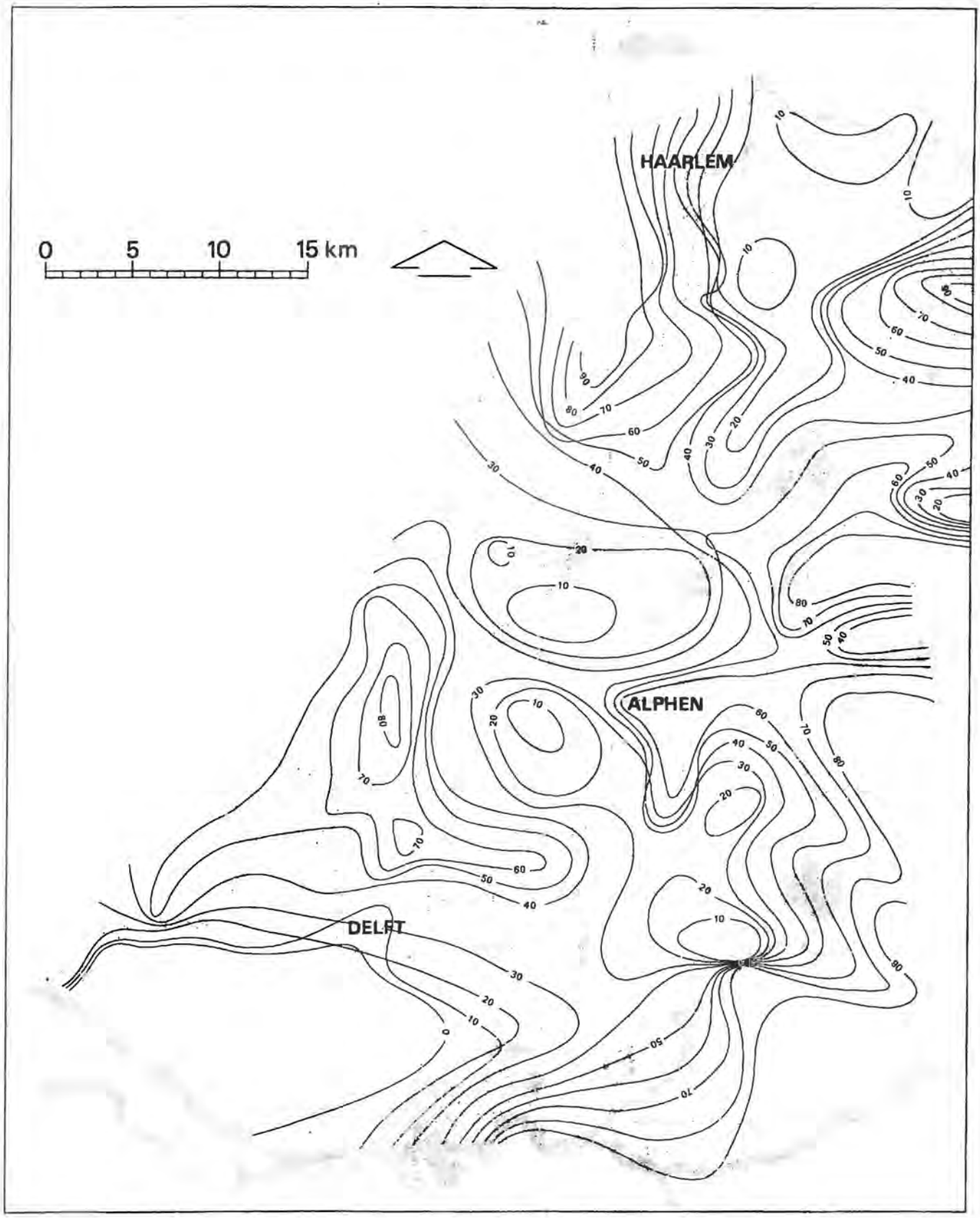

Fig. 2. Contour map of the depth (in m below sea level) of the 500 ppm chlorine concentration in the western part of the Netherlands

inhomogenity in grain sizes, the greater the mixing rate.

The processes of leaching and resalinization of groundwater were influenced by the Pleistocene and Holocene history of the region. A glance at the geologic time table shows an irregular succession of warm and cold periods. The hydrological processes during this succession were as follows (see fig. 3):

- At the beginning of a cold stage a fresh water zone overlies a salt water zone. The depth of the interface is only influenced by precipitation, evaporation and infiltration only. As no human activities existed it may be assumed that no substantial abrupt changes in this situation occurred.
- The growth of the land ice induced a fall in sea level accompanied by a change in position of the interface. Evaporation decreased and fresh water infiltration increased. The fresh-salt water interface came to a new stability at a deeper level.
- At the culmination of glaciation large areas were covered with an ice cap. In this period almost no hydrological activity existed, since the subsoil was frozen to a great depth. The non-frozen groundwater at several tens of meters below surface had a rather high content of dissolved salts caused by freezing of the upper layers. A sharp interface between frozen fresh water and unfrozen salt water may expect to have existed. This situation can be regarded as the starting point of the resalinization phase during the post-glacial period.
- After culmination of the glacial period, a long period of(sometimes interrupted) melting of the land ice and the permafrost soil started. The groundwater had a large hydraulic head caused by the quick rise of the sea level during this period. Evidence of this hydraulic head is found in the presence of pingoes.
- With the rise of the sea level land surface was flooded by sea water, the salt-fresh water interface moving inland.
- This interface then seeks a new equilibrium and precipitation, evaporation and groundwater flow will govern the depth where the interface is to be found.

It is not possible to calculate the time necessary for the interface to reach the new equilibrium in the present interglacial stage, the Holocene epoch. The changes in flow pattern are very slow, so the position of the fresh -

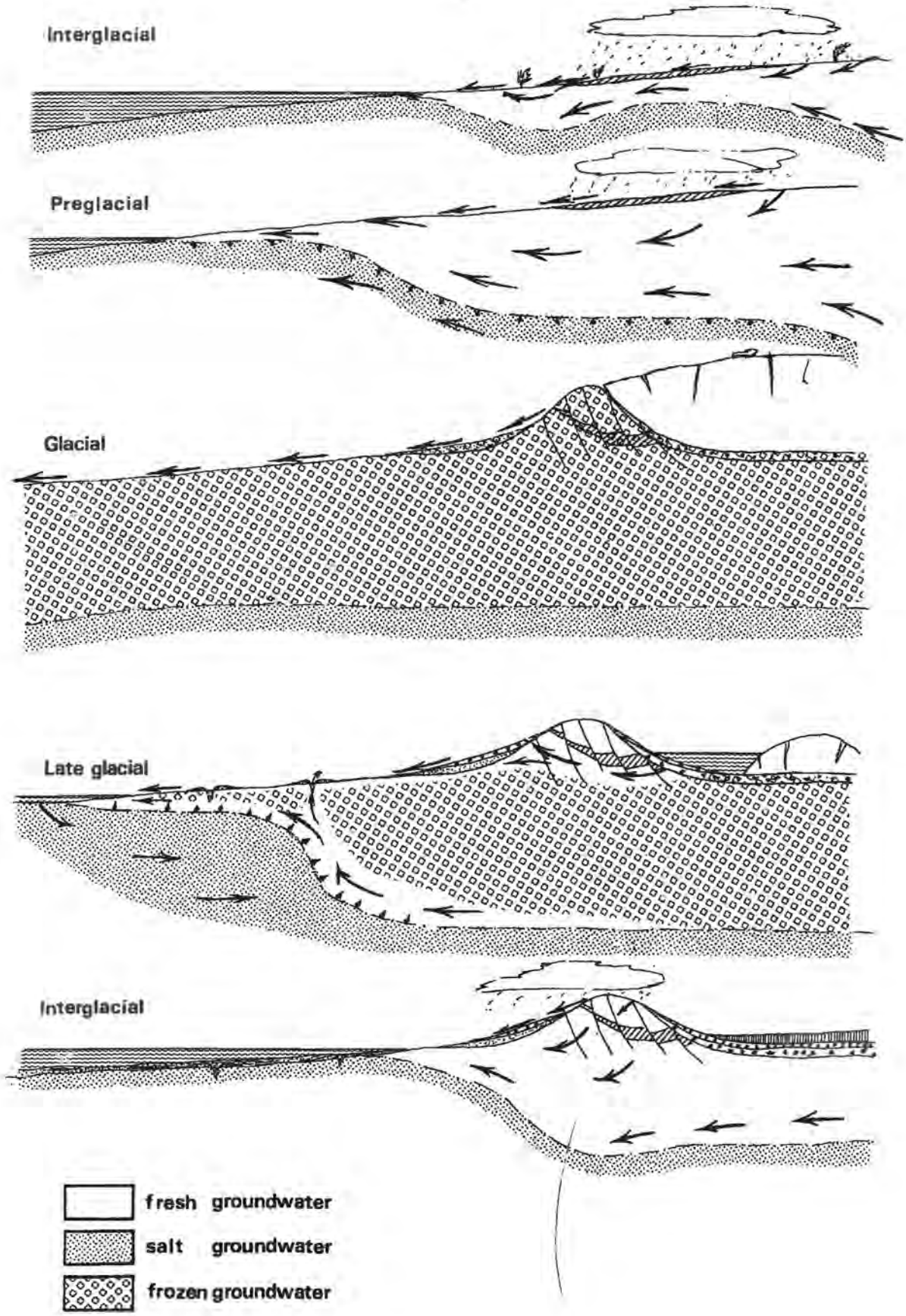

Fig. 3. Sequence of hydrologic situations from interglacial to interglacial as having occurred in the western part of the Netherlands

salt water interface also slowly changes. The very thin layer of brackish water will be conserved in the process. Still very thick brackish layers are observed in the region. This is the case where the deep polders are found, while under the dunes, where infiltration of rainfall occurs, a very sharp interface is found. It follows that the mixing of fresh and salt water at the interface results from human activities in the region.

5. CONCLUSIONS

- Knowledge of the geo-hydrological conditions in subsoil to a great depth is necessary to understand the hydrological background of salinization.
- It is recommended to apply more than one investigation method to compensate for a lack of data from greater depths.
- Knowledge of human activities has essential significance for the explanation of observed salinized regions.
- It may be advisable in regions as the one investigated to stop or limit particular human activities to prevent further salinization.

LITERATURE

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