Salinization above sea level on the Dutch Wadden Islands

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Abstract **The Wadden Islands are a string of several sandy islands lying off the coast of The Netherlands, Germany and Denmark. Under these Islands a freshwater lens has developed according to the 'Ghijben Herzberg principle'. The depth of the lens depends upon the size of the dune and height of the groundwater table (convexity) above sea level in the dune areas. The depth of the fresh / saltwater interface can be more than 100 metres.**

Water abstracted from the lens pumped with pumping wells is used for drinking water production. Salinization caused by upconing or a lateral groundwater flow towards abstraction boreholes is, of course, a known risk.

On the islands of Vlieland and Terschelling there has been measured a slow but steady increase of chloride in groundwater abstracted for the water supply. In 50 years the concentration has changed from 40 mg/l to an average value of 100 mg/l.

The cause of this increase is not upconing or lateral ingress of brackish or saline groundwater. The explanation for the increase can be found at the top of the hydrological system, in the phreatic aquifer above sea level. Salinization of the shallow aquifer is produced by what is called the 'salt spray mechanism'.

At the beginning of the last century parts of the dune areas on Vlieland and Terschelling were planted with pine. Sea salts, carried on prevailing west winds, are continuously deposited on the relatively large leaf surface of the pines and washed down in precipitation to the phreatic groundwater. Thus the chloride level in phreatic groundwater below the forest has increased to 300 mg/l whilst in phreatic water in the open dune areas it has remained below 50 mg/l.

I. Introduction

Surrounded by salty seawater lie the Wadden Islands for the Dutch, German, and Danish coasts. For the drinking-water facilities, a great part of these islands are dependent on the fresh groundwater that is to find in the freshwater lens under these islands. The division between fresh and salt groundwater on the islands is complex on the whole in which a number of factors are of influence. A special aspect is that the presence of a pine forest on the island has an influence on the chloride-concentration of the shallow groundwater. By the entrapment of sea salt, there are locally high concentrations found. This salting mechanism is interpreted as the so-called saltspray-effect. In this article there will be focus on the division of fresh and salt groundwater on the Wadden Islands in general and the saltspray-effect in particular.

Manuscript received September, 2006
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II. Fresh & Salt Groudwater

As a consequence of the prevailing rainfall surplus and the specific weight differences between fresh (rain)water and salt (sea)water, there is under the Wadden Islands for the coasts of the Netherlands, Germany, and Denmark an existing freshwater lens. This phenomenon is not new and already discovered and described by the Dutchman Badon Ghijben (1888) and later by the German Herzberg (1901).

Completed hydrological research, drillings, and measurements in the last 50 years have further detailed the Ghijben-Herzberg principle.

A. The Ghijben – Herzberg principle

The dunes along the Dutch, German, and Danish coasts rise until a maximum of dozens of meters above sea level. As a consequence of the rising rainfall surplus, the groundwater in the dunemass can rise (swell) to above the sea level. The resulting formed hydrostatic pressure is in a state to push the salt groundwater away.

In the Ghijben-Herzberg principle it is concluded that the vertical flow of the groundwater can be neglected. Also it is concluded that the dunemass exists from a homogenous sand packet. In figure 1 is the Ghijben-Herzberg principle with the above mentioned pre-conditions solved.

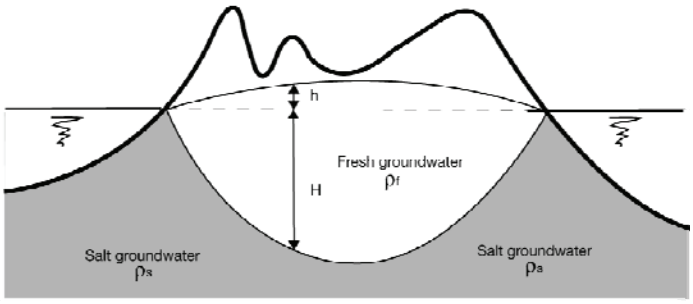

Figure 1: The Ghijben-Herzberg principle.

H: Depth of the freshwater lens [m]
h: Size of the freshwater swelling [m]

ρ_s: density of salt groundwater [kg/m3]
ρ_f: density of fresh groundwater [kg/m3]

In a balance situation is the following formula of Ghijben-Herzberg valid:

$$H = \frac{\rho_f}{\rho_s} - \rho_f \times h$$

$H = \rho_f / \rho_s - \rho_f * h$

Based on the density of 1025 kg/m^3 for seawater and 1000 kg/m^3 for freshwater this means that: H=40h. This formula is based on the fact that the vertical flux can be neglected and the dunes are a homogenous sand packet. In practice for the values of H and h is the theoretical relationship of 40:1 only seldom found. In the sub-soil of the dunes on the islands there often passes through bad clay, loam, or peat layers. These disturb the above described principle of Ghijben-Herzberg. On the Frisian Wadden Islands there is a relationship found of a maximum of approximately 25:1, see table 1.

TABLE 1: THE RELATIONSHIP BETWEEN THE DEPTH OF THE FRESHWATER LENS (H) AND THE HEIGHT OF THE GROUNDWATER LEVEL (H) IN THE MIDDLE OF THE DUNE AREA

Island	h [m]	H [m]	H / h
Vlieland	4	60	15
Terschelling	5/3	95/80	19/27
Ameland	2,5	60	27
Schiermonnikoog	3	85	28

A. Brakish groundwater above sea level

For the drinking-water facilities on the island Vlieland is the fresh groundwater from the freshwater lens used. The yearly extractions on Vlieland amount to approximately 200,000 m^3 per year. Extraction finds, traditionally, place from the first aquifer. The filters of the pump wells are found in the middle of this aquifer. Considering that much less water is found than by way of the rainfall surplus delivered is salting by upconing or the shifting of the fresh-salt boundary excluded.

Yet there is in all individual pumpwells a light salting to establish. From the start of the extraction the chloride-percentages of the drawn groundwater on average have increased from 40 mg/l in 1953 to 110 mg/l in 2005.

From the point of view of the drinking-watersupply is this salting not a direct problem, because the limited value of chloride is 150 mg/l. Yet there was already in 1987 a first research conducted about the cause of the salting. The explanation for the increase can be found at the top of the hydrological system, in the phreatic aquifer above sea level. Salinization of the shallow aquifer is produced by what is called the 'salt-spray mechanism'.

III. SALT-SPRAY MECHANISM

The salt-spray mechanism is based on the principle that by the common westerly sea wind a continuous supply of chloride happens. The sea wind comes in contact with the on the dunes present pine forest, where deposition of salt happens. This process goes with conifers throughout the year. Furthermore is the contact surface large by the relatively large leaf surface of the pine forest. As a consequence of rainfall the deposited salt loosens, infiltrates in the bottom and reaches the groundwater. There is especially talk of vertical groundwaterflow (downward infiltration) that rather slowly mixes with the underlying fresh groundwater. The result occurs in the phreatic packet, directly under the groundwater level of a light brackish zone. As it reaches increasing depth the chloride-percentage gradually decreases until "normal" values of fresh groundwater on the islands. Probably the interception of precipitation in combination with the higher evatransporation in the forest area plays a roll in the effect of high chloride concentrations in the shallow groundwater. Figure 2 gives the principle of the working of the saltspray-effect again. In figure 3 for observationwell 04FP0044 on Vlieland is the chloride-distribution in depth to see for different time steps.

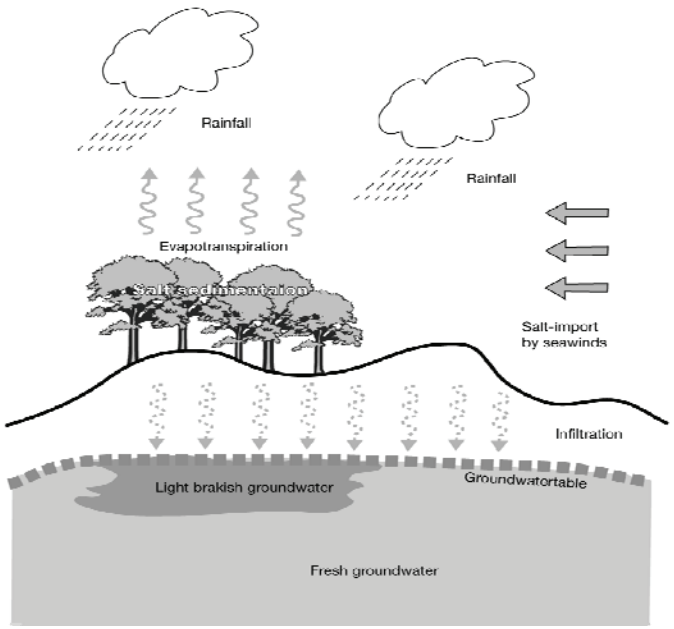

Figure 2: Salt-spray effect

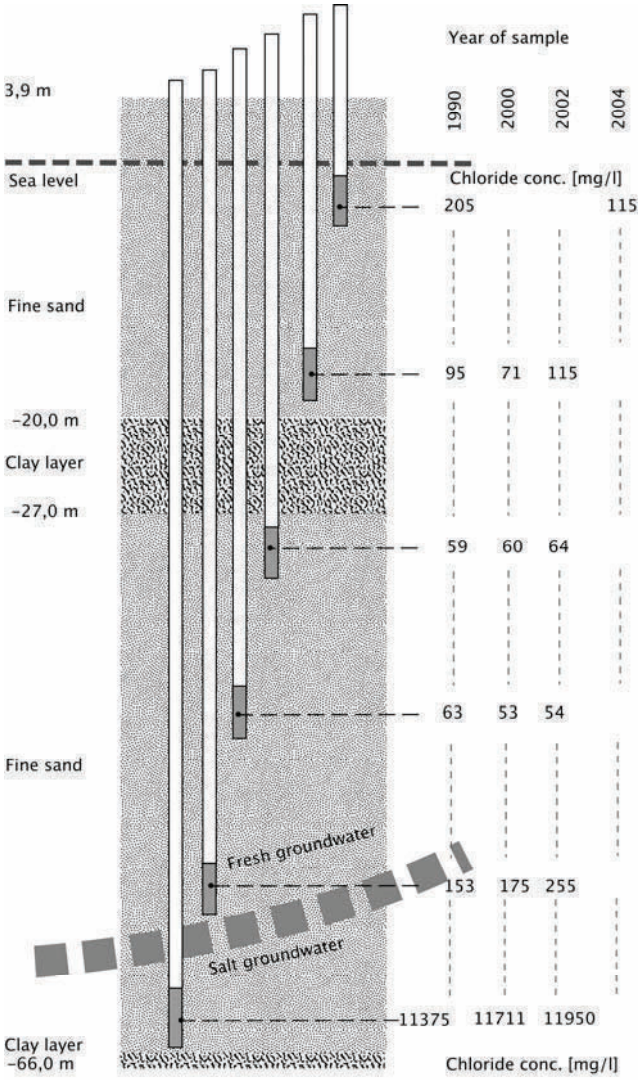

Figure 3: Vertical division of chloride at observation well 04FP0044 at Vlieland

IV. Salt-spray and phreatic groundwater quality

A. Results Vlieland

Based on the conclusions of the research of 1987, in 2004 there is further research done about the saltspray-effect on Vlieland. For this purpose there were 33 filters supplied of different observation wells completely sampled and analyzed. With the analysis data from the past there were in total 220 chloride-analysis available.

For 3 different timeslots, 1985-1990, 1990-2000, and 2000-2004 is the chloride distribution in the open dune area and the forest area researched. By means of the spline interpolation-methodology within ArcGis 9 are the results translated to a spatial image, see figures 4 through 6.

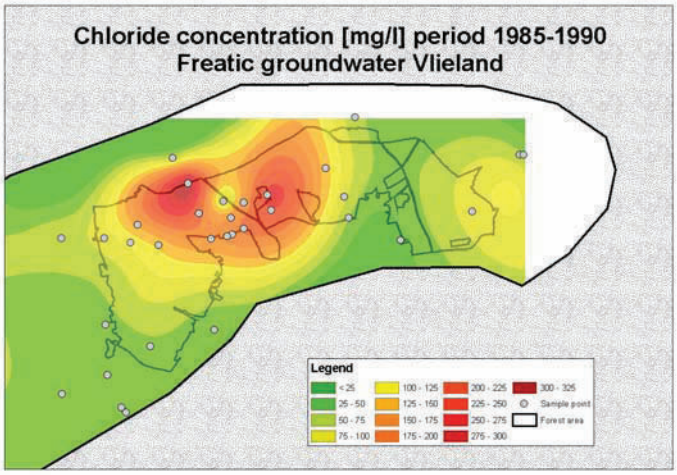

Figure 4: Chloride-distribution phreatic groundwater Vlieland, period 1985-1990

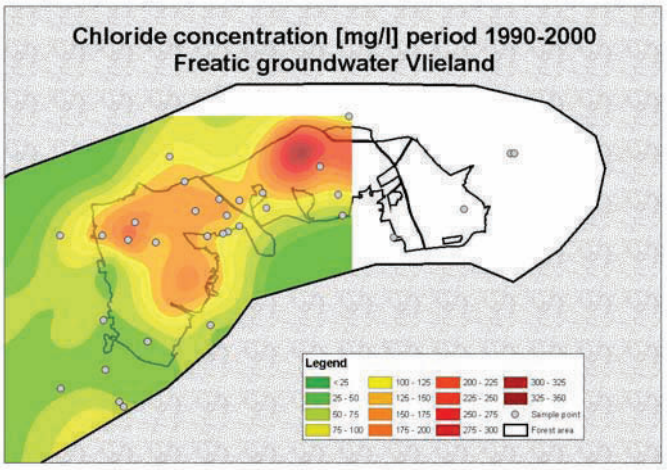

Figure 5: Chloride-distribution phreatic groundwater Vlieland, period 1990-2000

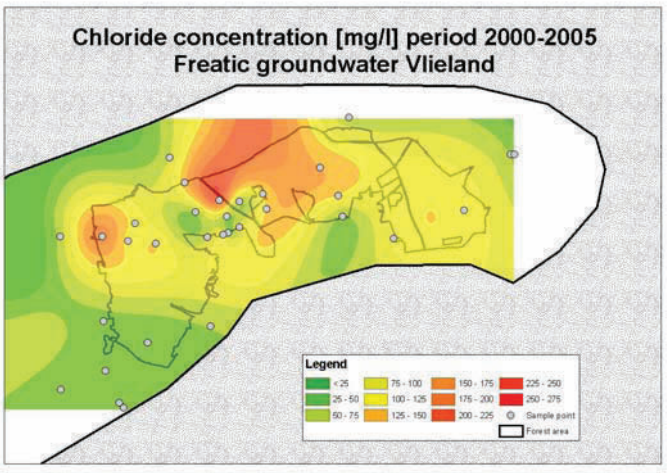

Figure 6: Chloride-distribution phreatic groundwater Vlieland, period 2000-2004

The general conclusion that can be drawn from these figures is that the chloride-percentage of the phreatic groundwater in the forest for all timeslots is higher than in the open dune area. This is a consequence of the saltspray-effect.

When the timeslots were compared with each other there were differences to establish. These differences are not with all measurement points consistent and unique. However it can be specified that in the timeslot 1990-2000 taken on average the highest chloride-percentages were found. In this period there was a maximum chloride-concentration found at 4 meters depth of 340 mg per liter.

B. Results Terschelling

It is interesting to see how the salt-spray mechanism is working on similar Wadden Islands. A supplementary survey started at Terschelling in 2006. In total 20 phreatic observation wells, located in- and outside the pine forest area where sampled. The interpolated results of these measurements are
shown in figure 7.

Also on Terschelling a higher chloride concentration, in the phreatic groundwater, can be found in the forest area. The average value in the forest area is 144 mg chloride per liter. Outside the forest, in the open dune area, the average value of the chloride concentration is still 41 mg per liter. Also for the island Terschelling the conclusion is that the salt-spray has effect on the saline concentration of the shallow groundwater quality

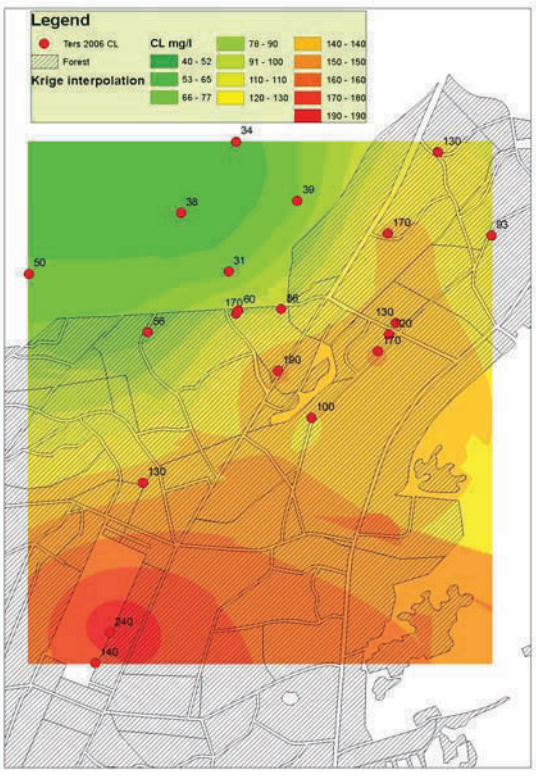

Figure 7: Chloride-distribution phreatic groundwater Terschelling, in 2006

V. Conclusions

1. Salanization of fresh groundwater not only found at the border of the fresh waterlens, but also at the top of it, in the phreatic groundwater.
2. This phenomenon is found in the forest area and not in the open dune area.
3. This salinization is caused by the salt-spray mechansim. Sea salts, carried on prevailing west winds, are continuously deposited on the leaf surface of the pines and washed down in precipitation to the phreatic groundwater.
4. The effects of the salt-spray are found in the islands Vlieland and Terschelling. Also on the other Wadden Islands at the Dutch, German and Danish coast must be an effect of salinization caused by salt-spray when there is forest on the island.

VI. Recommendations

1. The present image of the saltspray-effect is based on chloride-determinations of samples of groundwater taken on three to four different time steps in the last 20 years. A more detailed image is desirable.
2. This can be done by a more frequent sampling (yearly or 2-yearly) of the groundwater in specific, representative observation wells.
3. High frequent (daily) measurements of the conductivity of the groundwater in different observation wells are available. Watersupply company Vitens has set up a monitoring plan about this with the CTD-datalogger. These completed measurements will provide more clarity in the working of the saltspray-effect in time, and which external factors such as wind and rainfall amount can influence this.
4. At this moment these different time-series are to short to make final representative conclusions.

References

[1] BAKKER, T.W.M, “Dutch coastdunes, Geohydrology”. PUDOC Wageningen, 1981.
[2] BEUKEBOOM, TH.L,“The hydrology of the Frisian Islands”. Thesis Vrije Universiteit Amsterdam, 1976.
[3] GROOTJANS, A.P, E.J. LAMMERTS & F. VAN BEUSEKOM, “Lime-rich dunes on the Wadden Islands”. KNNV publishing house Utrecht, 1995.
[4] PETERSEN. J, R. POTT, P. JANIESCH & J. WOLFF, “Umweltverträgliche Grundwasserbewirtschaftung in hydrageologische und ökologische sensiblen Bereichen der Nordseeküste”. Husum, 2003
[5] WESTHOFF, V & M.F. VAN OOSTEN, “The plantgrowth of the Wadden Islands”. KNNV publishing house Utrecht, 1991.
[6] WIT, G.J. DE , “Groundwater map of the Netherlands, Wadden Islands”. DGV-TNO Delft, 1987.
[7] Research program & reports Vlieland & Terschelling, period 1990 2006. Vitens, Leeuwarden.