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Exceptional Groundwater Level Fluctuations at the Dutch Island of Schiermonnikoog

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During a hydrological-meteorological investigation at a former beachplain at the Dutch island of Schiermonnikoog, groundwater fluctuations were recorded. Except for daily changes of the groundwater level there appeared to be exceptionally high fluctuations during rainfall. This phenomenon can be explained by the so-called »lisse-effect«.

This implies that the phreatic level can rise rapidly due to an increased pressure of the soilair above the capillary fringe. The increase of the pressure is caused here by the capillary infiltration of rainwater in the soil.

At Schiermonnikoog it became obvious that the depth of infiltration and the extent of groundwater rise were determined by the thickness of a semi-pervious layer at the surface with strong capillary tension.

Introduction

In May 1974 there was a hydrological-meteorological research at the Dutch island of Schiermonnikoog (Fig. 1). The object was the recording of the groundwater level and to give an explanation of the causes of fluctuations, if there were any.

Especially, the relation between groundwater level and meteorological data was an important subject of investigation.

The investigation was carried out at a former beach, which since 1956 had been isolated from the Northsea by means of a dike. During springtides in winter, water reaches this area, flowing from the Waddensea via creeks of a salting. In this way

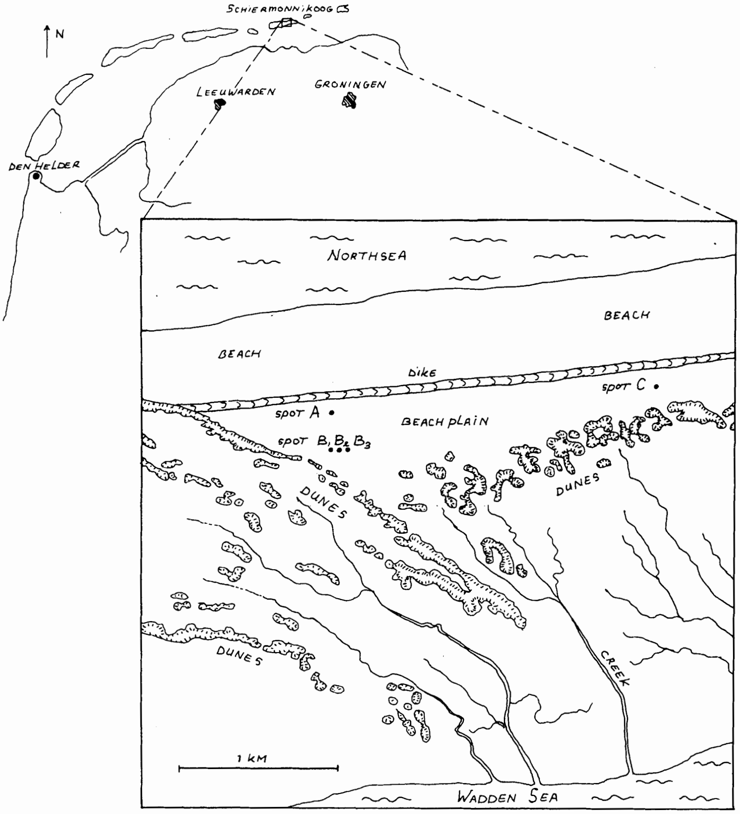

Fig. 1. Location of the investigation.

one or more thin silty layers are sedimented in wintertime, on which algae then start growing.

The area of investigation is very flat, with some isolated little dunes on which beachgrass is growing.

At four locations in the area of investigation groundwater level recorders were installed (drumrecorders in combination with water level sensors) (Fig. 1).

A ; depth of screen: 50 - 150 cm below surface (b.s.) (Ø 2.8 cm)
B_1; depth of screen: 50 - 150 cm below surface (b.s.) (Ø 2.8 cm)
B_2; depth of screen: 200 - 300 cm below surface (b.s.) (Ø 2.8 cm)
C ; depth of screen: 50 - 150 cm below surface (b.s.) (Ø 2.8 cm)

Furthermore, at location B_3, a pipe was installed in the ground (screen depth 50 - 150 cm b.s. Ø 2.8 cm) in which a daily measuring of the groundwater level was done by hand with a steel tape in order to check the registration of the groundwater level recorder at B_1.

Thin Semi-Pervious Bed at the Surface

Except for small daily changes there appeared to be high groundwater fluctuations during rainfall. In explaining the causes of these exceptional groundwater rises the silty layer mentioned before is very important.

This bed is lying at the surface, all over the beachplain and has a thickness varying from 2 mm to 3 cm. In fact, we are not allowed to speak of a silty layer because the amount of fine clastic particles is only a minority.

The components of a representative sample have been analysed (Laboratory of the Institute of Earth Sciences, Free University, Amsterdam-Buitenveldert), likewise those of a sample taken from the underlying material.

Percentages of components (stove-dry)

	moisture	$CaCO_3$	sand 16-2000 μm	U	humus E	particles 0-16 μm (slib)	particles 0-2 μm (lutum)
surface bed	0,61%	2,6%	90,9%	67	1,2%	1%	0,9%
underlying material	0,09%	1,2%	97,7%	61	0,1%	0,4%	0,4%

Notwithstanding the fact, that the difference in composition between both samples is not particularly large, both levels show in the field completely different properties. Unlike the underlying material, the surface bed is very coherent and has a strong moisture-absorbing capacity.

On several places soil moisture probes showed, that the thin surface layer (in all circumstances during the fieldwork) had always been more moist than the sand below (to the capillary surface).

The surface bed appeared to be nearly impermeable to rainwater, so that during rain a sheet of water rose. The humus (swelling colloids) within and the algea mainly upon the thin upperlayer must to a high degree be responsible for its specific properties.

The transition from the coherent upperlayer to the underlying sediment is very sharp. This applies to the coherence (from sticky tight to loose single grains) and similarly to the colour (from blackbrown to yellowbrown).

Exceptional Groundwater Rises

The Beachplain

There was a very distinct exceptional groundwater rise in the period from 11.00 a.m. on May 13th till 11.00 a.m. on May 14th, during which a total of 14 mm of rain fell in the area of investigation. Without taking into consideration the thin

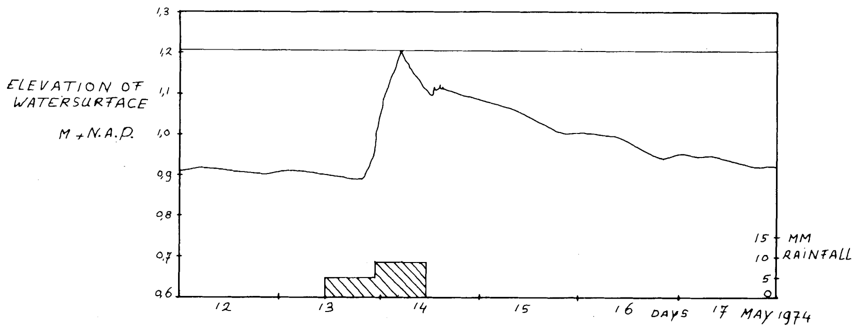

Fig. 2. Location A. Ground surface 1.51 m + N.A.P., depth of screen 50-150 cm below g.s.

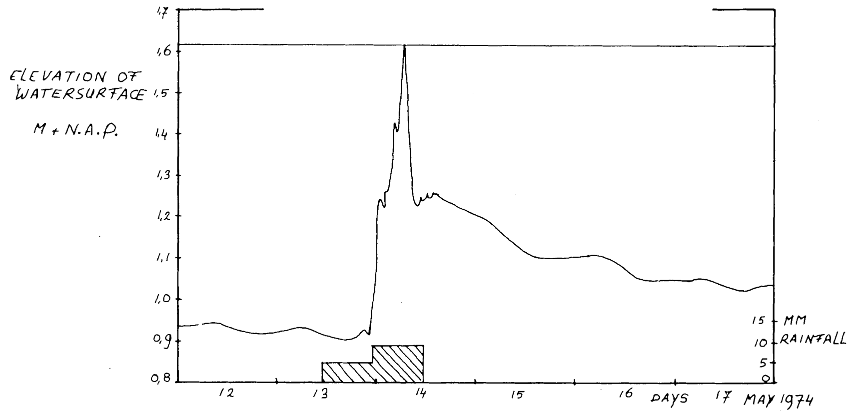

Fig. 3. Location B_1. Ground surface 1.61 m + N.A.P., depth of screen 50-150 cm below g.s.

bed at the surface with its specific properties, the maximum groundwater rise, as a result of complete infiltration of the rainwater, would have been

$$\frac{10}{2} \cdot 14 = 70 \text{ mm} = 7 \text{ cm}$$

(storage coefficient 0.2, as mentioned by Beltman 1960 and Tollenar 1971)

However, we can see that the maximum rise of the groundwater had been much bigger than that (see hydrographs Figs. 2-5), namely

A : 32 cm; this is 4.6 × the value of the max. rise by complete infiltration
B_1: 72 cm; this is 10.3 × the value of the max. rise by complete infiltration
B_2: 36 cm; this is 5.1 × the value of the max. rise by complete infiltration
C : 26 cm; this is 3.7 × the value of the max. rise by complete infiltration

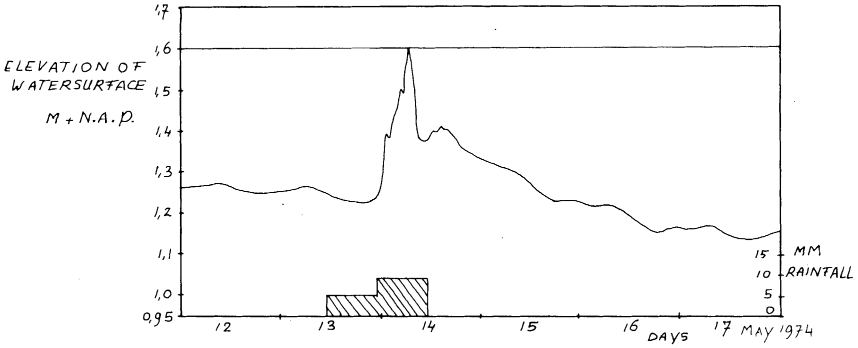

Fig. 4. Location B_2. Ground surface 1.59 m + N.A.P., depth of screen 200-300 cm below g.s.

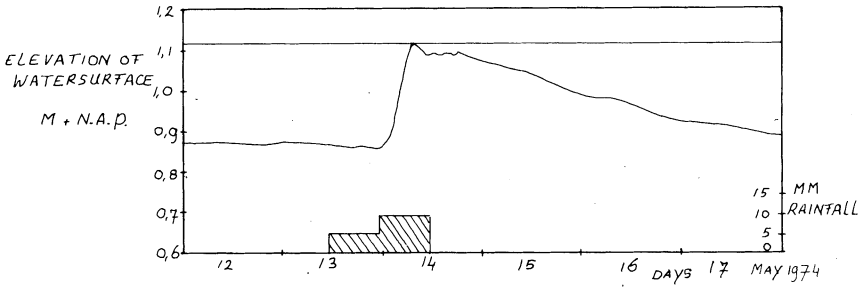

Fig. 5. Location C. Ground surface 1.54 m + N.A.P., depth of screen 50-150 cm below g.s.

The »Lisse-Effect«

We must seek the cause of the exceptional high rises of the groundwater level in the beachplain in an increase of the pressure of the soil-air. Already in 1971 the »Lisse-effect« has been mentioned in this connection by Tollenaar. At the village of Lisse, in the province of South-Holland, exceptional high groundwater fluctuations had been measured. An explanation for this phenomenon has been given by Thal Larsen as mentioned by Beltman (1960):

The capillary infiltration of rainwater in the soil will make a soil-layer in which the pores are filled with water. By this the pressure of the soil-air (above the capillary fringe) will be increased by n/h-n atmosphere (Fig. 6), whereby

n = depth of infiltration of the rainwater
h = depth of the capillary surface beneath the ground surface

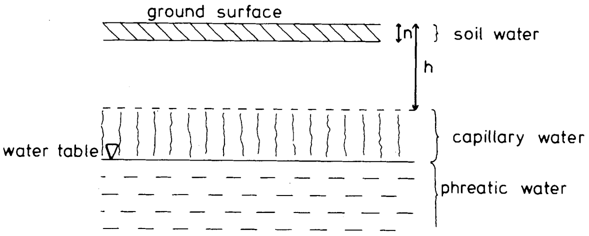

Fig. 6. Soil layer with infiltration. (After Beltman 1960).

The capillary tension, originally being $-H_{cap}$ atmosphere (maximum), will be then $-H_{cap} + n/h\text{-}n$ atmosphere. By this the level on which the hydrostatical pressure is in balance with the atmospheric pressure must consequently be at a depth of $(H_{cap} - n/h\text{-}n)$ 1000 cm beneath the capillary surface.

This implies a rise of the phreatic level of $(n/h\text{-}n)$ 1000 cm.

The general formula, giving the relation between an increase of the soil-air pressure and the rise of the groundwater level is as follows

$$\frac{n}{h-n}\,p = \Delta G \qquad (1)$$

n = depth of infiltration of the rainwater (cm)
h = depth of the capillary surface beneath the groundsurface (cm)
p = atmospheric pressure, in cm waterpressure
ΔG = groundwater fluctuation (cm)

Depth of infiltration

It appeared, that initially the rain, falling on May 13th and 14th, did not percolate through the semi-pervious and strongly moist absorbing surface bed. Only this upperlayer was saturated with rainwater and so its thickness determined the degree of increase of soil-air pressure and groundwater rise.

This was shown by a number of simple calculations. The depths of infiltration n calculated with the use of Eq. (1), at known values of rises of groundwater level, capillary rise, and pressure, are quite similar to the depth of the surface bed.

Example

Location A:

maximum actual groundwater rise 32 cm (Fig. 2, May 14th);

surface level: 1.51 m + N.A.P.; phreatic level: 0.9 m + N.A.P.*

At the surface, sheets of water had been formed with a mean depth of 1 cm.

$$\left.\begin{array}{l}1.51 - 0.9 = 0.61\text{ m} = 61\text{ cm}\\ \text{capillary rise: 30 cm (Tollenaar 1971)}\end{array}\right\} \rightarrow h = 61 - 30 = 31\text{ cm}$$

Practising Eq. (1)

$$\frac{n}{h-n}(1{,}000+1)^{**} = 32 \rightarrow 1{,}001\,n = 32(31-n) \rightarrow 1{,}033\,n = 992 \rightarrow$$
$$n = 0.96 \text{ cm} \rightarrow n \approx 1 \text{ cm}$$

Calculations made in the same way for the other locations and for the same period (May 14th)

B_1; maximum actual groundwater rise 72 cm: $n = 2.8$ cm
B_2; maximum actual groundwater rise 36 cm: $n = 0.2$ cm
C ; maximum actual groundwater rise 26 cm: $n = 1$ cm

In reality the thickness of the surface bed varies from ± 2 mm to ± 3 cm, so we can say, that the calculated values are in the same range.

Conclusion

Exceptionally high groundwater rises at the Dutch island of Schiermonnikoog can be explained with the so called »Lisse-effect«.

It appeared that the heights of the water rises were regulated by a thin bed with specific properties at the surface. Taking into account the limited amount of data on which it is based we could say in general:

– A rise of groundwater level caused by an increase of soil-air pressure is regulated by the thickness of a surface layer, if this layer is saturated by infiltrating rainwater and characterised by semi-perviousness and strong capillary tension. In this case, using the formula of Thal Larsen, we can replace the value of the depth of infiltration (n) for the thickness (d_1) of the surface layer. The atmospheric pressure (p) must be raised by the pressure of a stagnant waterlayer (d_2) at the surface.

In formula

$$\frac{d_1}{h-d_1}(p+d_2) = \Delta G \qquad (2)$$

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[*] N.A.P. = Nieuw Amsterdams peil = reference water level

[**] For the atmospheric pressure the mean value of 1000 cm waterpressure has been used and this was added to the mean thickness of the sheet of water at the surface (1 cm). This has only a slight effect on the calculated values. However, if a stagnant waterlayer should reach a considerable thickness and the rise og groundwaterlevel should be calculated at known values of n (thickness of semipervious surface bed) and h, it may influence the results.

d_1 = thickness of a semipervious layer with strong capillary tension (cm)
d_2 = thickness of a stagnant water layer at the surface (cm)
h = depth of the capillary surface beneath the ground surface (cm)
p = atmospheric pressure (cm waterpressure)
$\triangle G$ = groundwater fluctuation (cm)

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