Monitoring the effects of subsidence of the coastal island Ameland in the Wadden Sea

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Abstract The paper describes the results of 7 to 8 years of monitoring in order to assess the effects of subsidence due to gas extraction. During the first 8 years of gas depletion the observed subsidence in the centre of the shallow depression was 14 cm. The evaluation of the annual measurements showed that, apart from one point all measuring stations are stable. It also showed that the centre is sinking faster than expected and that the flanks are lagging behind. Since the present prognosis of the maximum subsidence is approximated 18 cm, this means the rate of subsidence in the centre of the field is expected to decline soon. During the monitoring period a large number of abiotic parameters was assessed on annual basis. This included coastline development and beach nourishment, day to tidal fluctuations, rain fall and evaporation. Also the fluctuation in ground water was assessed, including its composition. In the neighbouring polder the fluctuation of the water level of a drainage canal was continuously measured during a period of 4 years allowing an accurate prediction of winter flooding and grass production. Most emphasis, however, was put to assessing the effect this subsidence may have on the ecological values with the marsh and dune vegetation as the most sensitive parameters.

INTRODUCTION

Extraction of natural gas from the Ameland-Oost gas field off the West-Frisian islands of the Wadden Sea began in January 1986. In that same year an extensive study into the possible effects of soil subsidence in and around Ameland-Oost as a consequence of natural gas extraction was carried out at the order of the Dutch Petroleum Company (NAM) by the Delft Hydraulics Laboratory (WL) and the (then) National Institute for Nature Conservancy (was RIN, now IBN) (1987).

That study indicated that such activities could possibly have an impact on, among other things, the coast-line, the Wadden Sea itself, the dune vegetation and the salt marshes. To be able to observe the effects, NAM decided to initiate a long-term monitoring programme which would start in 1988 and would continue through to the year 2000.

THE AMELAND GAS FIELD AND SOIL SUBSIDENCE

The Ameland gas field is located under and around the eastern part of Ameland. Tne gas-bearing sandstone layer is located at a depth of approximately 3 kilometres. The geographical extent of the field is about 250 square kilometres. It is estimated that the field originally contained around 60,000 million cubic metres of natural gas. This makes the Ameland gas field the third largest in The Netherlands including coastal waters, after Slochteren and Annerveen.

Production commenced in January 1986. The original pressure in the field was 557 bar; currently pressure stands at 165 bar. This means that a significant drop in pressure has taken place over the past eight years. And since soil subsidence bears a direct relationship to any drop in pressure, this means that at this moment (1994) approx. 75 percent of the total expected subsidence has already taken place.

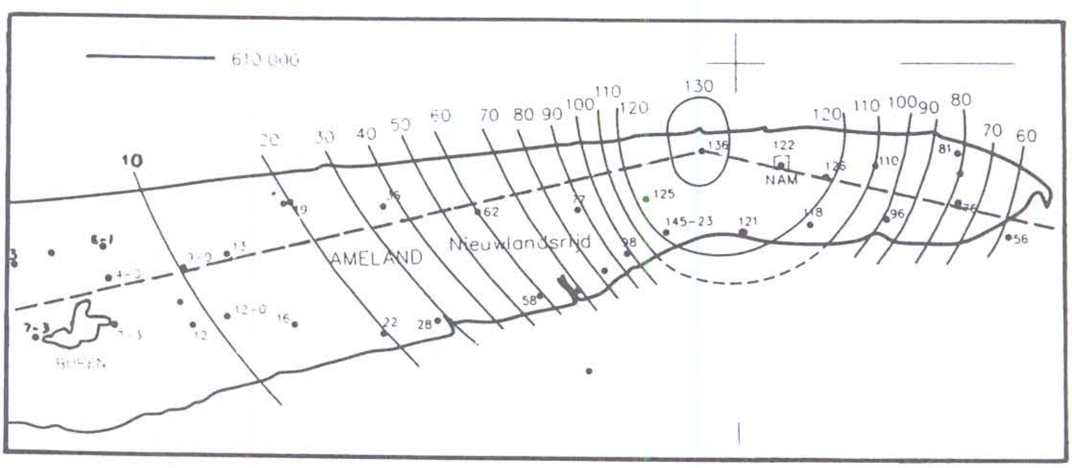

Fig. 1 Observed bottom subsidence (mm) 1986-1994

The form of the soil subsidence is comparable to a shallow depression (see figure 1). Subsidence at the edges is negligible but increases gradually - and completely uniformly - towards the heart of the depression where the highest values can be measured. The original prognosis for the final subsidence value was 26 cm. at the heart of the Ameland dish. On the basis of experience in Groningen (Slochteren field) and on the basis of more recent measurements in 1991, this final value has now been adjusted to 18 + 4 cm (see figure 2). It is not anticipated that the final figures will deviate significantly from the prevailing prognosis.

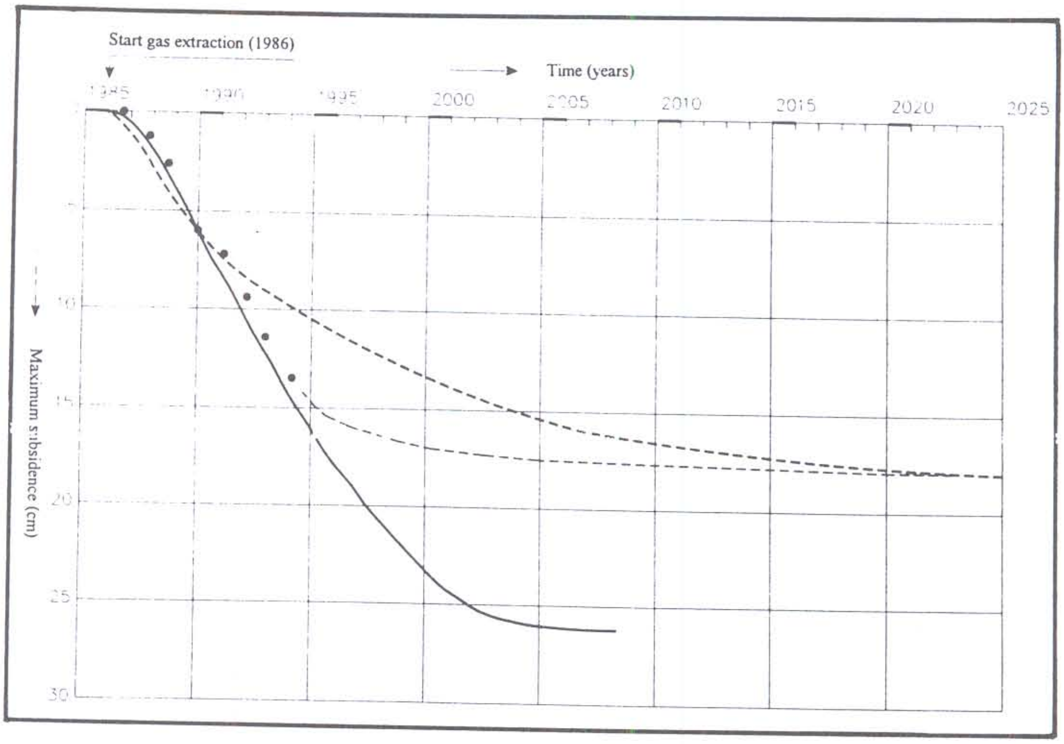

Fig. 2 Predicted and observed maximum bottom subsidence

ABIOTIC PARAMETERS THAT ARE RELEVANT TO VEGETATION

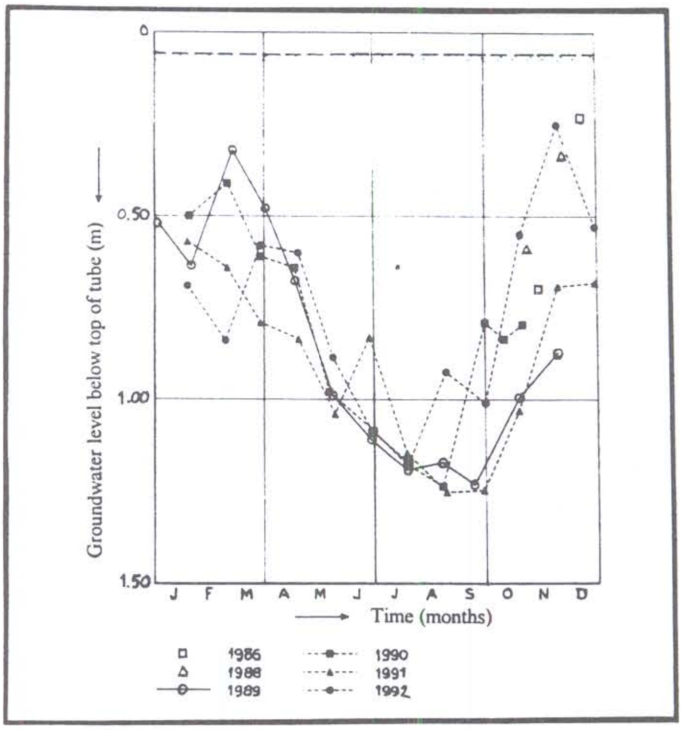

Fig. 3 Observed fluctuations in the groundwater table (example)

The water level data from tidal station at Nes, in particular the data on high water levels, are representative for the water levels in the Nieuwlandsrijd and De Hon salt marshes. Rainfall and evaporation figures are important in the interpretation of any changes in vegetation. A great deal of information has been gathered about and insight obtained into the behaviour of the ground water levels at Ameland-Oost.

Observed annual fluctuations in the ground water table in the different stations are comparable between stations and fairly large: depending on the annual rainfall, data vary between approx. 0.5 and 1 metre (see figure 3). The water table on Oost-Ameland is fairly level with gentle gradients from higher to lower areas. The rise and fall of the water table during the year is more or less the same everywhere (parallel fluctuation). No obvious effect of soil subsidence can be found.

GEOGRAFICAL OBSERVATIONS

North Sea coast

The powerful dynamics in the morphological behaviour of the North Sea coast of Ameland makes it impossible to quantify the relatively minor effect of soil subsidence resulting from natural gas extraction, especially since the process has not yet come to an end.

Frisian tidal inlet and De Hon

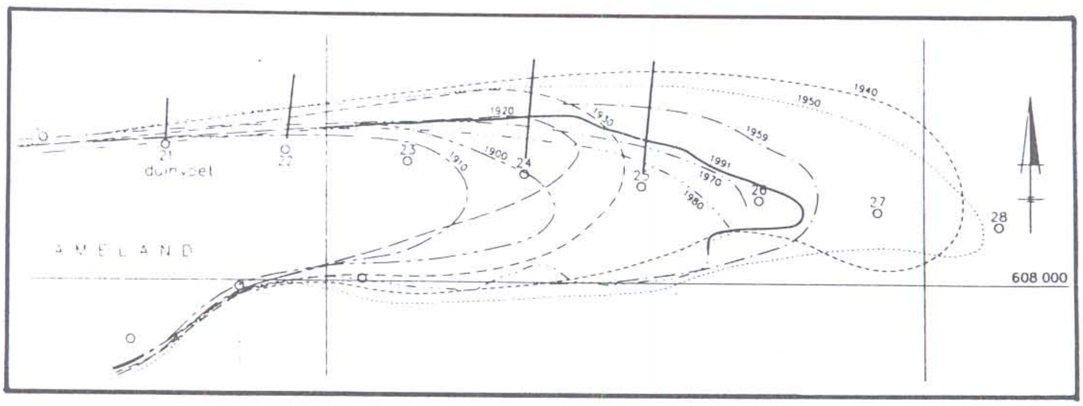

Fig. 4 Developments along a section on salt marsh De Hon

The point of the island, called De Hon has expanded eastward since 1980 (see figure 4), but the process seems to be stagnating at the moment. Stagnation of growth towards the east would appear to be the result of natural channel migration from the Holwerderbalg and the Pinkegat inlet due to erosion of the outer bends. It is impossible to state to what extent the present developments particularly in the Holwerderbalg and in the secondary channel in the tidal inlet, have been accelerated by the subsidence. The possibility that the extra sand requirement of the flood basin of the Pinkegat inlet would be partly compensated by retarded growth of De Hon was in fact predicted in the report of 1987. The total estimated reduction according to the 1985 subsidence forecast was 500 metres and the reduction in accretion was estimated at a maximum of 10 metres per annum. The developments observed to date do not eliminate this possibility.

Wadden Sea

The strong dynamics in the Wadden Sea also make it virtually impossible to recognize relatively minor changes resulting from soil subsidence, both now and in the future. Even if the average surface level changes or the changes in volume of the flood basin are considered, it is difficult to pinpoint attributable changes since they are within the range of confidence limits of the measurements.

Salt marshes

Subsidence can only be clearly demonstrated on land by using surveying methods. A precision levelling survey gives a good impression of soil subsidence resulting from gas extraction. Locally there is some compensation in the ground level due to sedimentation. In January 1994, soil subsidence as a result of gas extraction at Nieuwlandsrijd was measured at approx. 8 cm on the eastern side, decreasing to 2 cm. on the western. This is approximately 35 percent of the original forecast (in 1985) of subsidence. The subsidence of the ground level is generally less as a result of compensatory accretion by marine sediments. Since the banks of the salt marsh at Nieuwlandsrijd have been protected with coastal defences, the salt marsh will not suffer any areal loss by subsidence.

In the natural salt marsh at De Hon, soil subsidence as a result of gas extraction varied in January 1994 from over 12 centimetres near the NAM facility in the west to approx. 5 centimetres at the extreme eastern point. Here, too, deposition of silt has reduced apparent subsidence of the ground level due to gas extraction. On the Wad side the MHW (mean high water level) line has shifted towards the north, mainly as the result of erosion, while the boundaries of the salt marsh have hardly changed.

Deposition of silt in the salt marshes is dependent on the marsh level and (probably) on the distance from the Wadden Sea or a salt marsh creek. In the lower salt marshes (lower than Netherlands average sea level (NAP) +1.25 metres), soil subsidence is generally more than compensated by deposition. In the higher salt marshes, compensation decreases proportionately with increased height and the greater distance to the North Sea. Subsidence here is roughly zero at 2 metres above NAP, relatively close to the shoreline, or 1.7 metres above NAP at somewhat greater distance from the sea. General speaking, the salt marsh becomes relatively flatter (see figure 5).

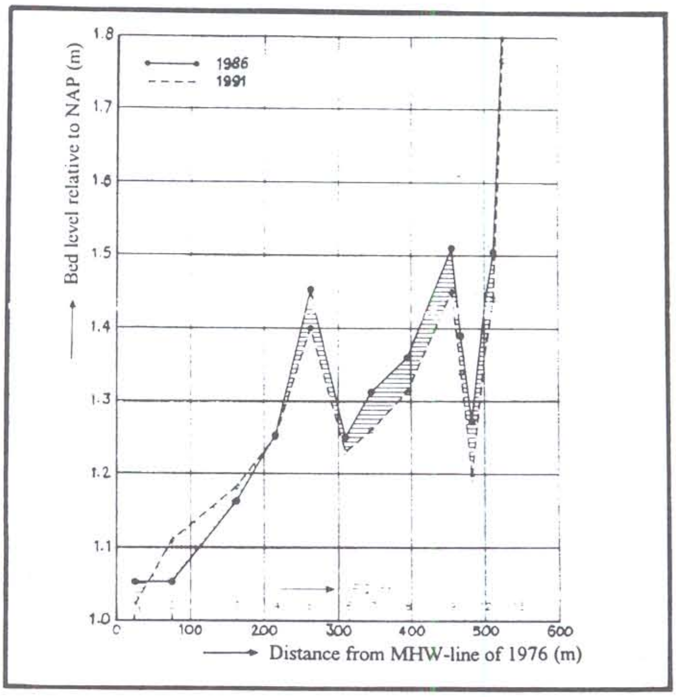

Fig. 5 Dynamic behaviour of the MHW-line of the eastern tip of Ameland

Dune areas and polders

The coastal defences and the new dunes of De Hon are relatively very dynamic and the effects of soil subsidence here are completely subordinate to the natural dynamics.

Vegetation research in the dunes has mainly been carried out in the more mature, inactive dunes with established overgrowth. There is hardly any sand transport in this area, so that the effects of gas extraction will be fairly accurately reflected in the subsidence of the surface level. Subsidence of the dune landscape will therefore be irreversible. Since marine sediment is unable to enter the Buurdergrie polder, the subsidence here will also be enduring and the ground level will be permanently lowered as a result of gas extraction. Soil subsidence in this area was less than 2 centimetres in January 1 994.

Storm surge

The data available and panoramic photographs taken from three locations on De Hon do not suggest any real danger of the sea breaking through as a result of soil subsidence. Only in one location was there any (non-alarming) development as a result of flooding over De Hon during a heavy storm.

ECOLOGICAL RESPONSE MEASUREMENTS

Bird-life

The possible effects of soil subsidence on the bird population of Oost-Ameland was evaluated after factors other than subsidence had been eliminated as far as possible. Firstly the fluctuations in the bird population were compared with developments in other areas where there is no subsidence. Next a study was made into other circumstances in the Ameland salt marshes which might have altered, and into the possible effects that these changes might have had on developments in the bird population. The figures which then remained were those which might be attributable to soil subsidence.

The fluctuations in the populations of the various species of birds found on Oost-Ameland were found, by and large, to correspond to more general trends found elsewhere and in the vast majority of cases these fluctuations could be attributed to developments which are unconnected with soil subsidence. The same can be said of developments in the benthic community. The main changes can be adequately explained on the basis of data concerning spat fall of mussels and cockles and the effects of shellfish harvesting.

As far as the birds are concerned, there were found to be differences between the various areas themselves, even when there was no soil subsidence factor (in this case between Terschelling and the entire Dutch Wadden Sea, for instance). Therefore it can be concluded that any fluctuations in the bird population of Oost-Ameland, in comparison with other areas, fall within the scope of natural variation.

Salt marsh vegetation

The factors which determine the type of vegetation in a salt marsh are the surface height, soil drainage and the salt content of soil-borne moisture. The salt level is determined by the amount of rainfall and the number of inundations per year or growing season. More rain produces fresher moisture, more flooding produces salty moisture. The number of inundations is related to the height of the marsh surface and (more or less) to the MHW level.

The height of the surface of the salt marsh is influenced in a negative way by soil subsidence. This does not, however, apply to the lowest zones of the salt marsh and the sections which are closest to the Wadden Sea or the creeks, because that is where the most accretion occurs. The fact that accretion occurs at a slower rate than soil subsidence has had little impact on the salt marsh vegetation in 51 test areas (pq's), because:

- the average annual high water had receded simultaneously and
- the soil subsidence generally stopped short of the lower critical point for salt marsh zones.

With the help of simplified vegetation charts it was possible to establish whether major changes had taken place in the salt marshes.

Such changes were not found. Most of the changes can be attributed to differentiation in the interpretation of vegetation in 1988 and 1993. Soil subsidence has had no major part in the vegetation changes, at most it might be responsible for several hectares of regression (i.e. a shift in the vegetation from higher to lower zones) in the centre of De Hon. Without soil subsidence there might possibly have been succession (i.e. shifts in the vegetation from lower to higher salt marsh zones).

The simplified vegetation charts resulted in the loss of some information. More detailed information can however be found in the analysis of the pq's. If the changes in the pq's give any cause for concern, it could be considered including a detailed chart comparison in a future report. In that case it would be necessary to include an updated interpretation of the 1988 chart.

It will depend on the combination of the on-going soil subsidence and the future annual average high water levels whether and how the salt marsh vegetation will react to ground level changes in the near future. The monitoring programme incorporates the necessity to follow these results.

Dune vegetation

The vegetation in the dunes in the salt marshes was also studied in 54 permanent quadrats (pq's) in 1986 and in 64 pq's in 1989 and 1992. In all, 185 species were found. There were no significant changes in the number of finds. Species which were not found in one or two years, were generally found in only one or two pq's in other years. In the cases where this difference was larger (up to 5 or 6 finds in a single year), these species were generally found to be annuals. The only exception was the perennial Atriplex portulacoides (orache) which was found only in 1992 and in just 6 pq's.

No major discrepancies which might be attributable to the estimation method used in the various years were found between the change in the number of finds per species and the change in the average abundance. Changes in average ground coverage have proved to be relatively minor. Only for 34 species was the relative change in average coverage higher than about 15%.

It has proved impossible to attribute the changes found in vegetation to either soil subsidence or changes in the sea water level. There appears to have been a minor change in vegetation between 1986 and 1989 and a more substantial change between 1989 and 1992. The changes in the frequency of inundation run roughly parallel: a slight reduction between 1986 and 1989 and quite a strong increase between 1989 and 1992. This pattern is probably due to the fact that the frequency of inundation and the relative height were mutually compensatory between 1986 and 1989 (both decreased) whereas in the years between 1989 and 1992 each reinforced the effect of the other (more flooding in combination with soil subsidence). It cannot therefore be ruled out that the changes in the vegetation of the saline dune valleys are at least partly due to soil subsidence. At the same time it should be noted that the changes observed in 1992 could also be the result of the hot summer of that year.

The changes found are too minor to be characterized as favourable or unfavourable from a nature conservancy point of view. It can however be stated that the overall forecast made in 1987 with regard to a general coarsening, flattening and lowering of the natural value of the area as a result of soil subsidence in the dune valleys has not been validated.

Nieuwlandsrijd

As a result of soil subsidence, the inundation frequency of the Nieuwlandsrijd salt marsh increased on average in the grazing season of 1994. As a result the production loss of the farmers due to soil subsidence can be set at maximum 2% of the capacity in an unchanged situation (excluding compensation through silt deposition).

The above loss is based on average circumstances over many years. In view of the substantial variations which occur from year to year in the frequency at which mean high water levels are exceeded, it cannot be ruled out that the variation in the annual yield of the salt marsh might be greater than the damage caused by soil subsidence alone. For this reason it may be difficult to formally establish such losses.

Buurdergrie polder (Zwartwoude)

The impact of soil subsidence on the chances of inundation near Zwartwoude during a westerly storm and on the grass production was thoroughly researched and reported in Boer and Eysink (1993). This report is based on the effects of 10 cm subsidence. The true effects can be estimated by a process of linear interpolation.

The actual soil subsidence in the Buurdergrie polder in January 1994 varied from 0.4 to 0.5 cm near Buren to a maximum of 2 cm at the extreme eastern point of the polder. Soil subsidence in the Zwartwoude area was then recorded at between 1 and 1.5 cm. Under these circumstances, the effects of soil subsidence on grass production - even in the low-lying parts of the area - remain within one percent (no noticeable effect).

Also the frequency of inundation hardly alters. The number of days in excess of a level of NAP + 1.30 metres (original level) is increasing in Zwartwoude on average from 0.5 days per annum to approx. 0.65 days per annum. At a level of NAP + 1.35 metres these figures are lower by a factor of 2 to 3.

Drinking water extraction in the Buurderduinen

Available data show that coastal shifts of 40 to 50 metres have no noticeable impact on the chlorine content of the water extracted from the Buurderduinen. This, in combination with government policy aimed at maintaining the present coastline, leads to the conclusion that the Frisian Drinking Water Company will experience no detrimental effects which can be attributed to soil subsidence resulting from gas extraction.

Moreover, by constructing a drink water pipeline from the mainland the Frisian Drinking Water Company has created a considerable margin in the drinking water capacity on Ameland. This is one more reason why no problems are anticipated. It is proposed that this subject should be considered closed and that further data collection should be suspended.

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