IS THE DUTCH WADDEN SEA AREA DROWNING?

HAND-ON-THE-TAP AND COMPENSATORY ACCUMULATION CAPACITY

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In Dutch society the alarming perception is spread widely that the Dutch Wadden Sea region is drowning due to salt and gas extraction [1]. After all sea level is rising whereas the seafloor is subsiding due to mining activities. With the recent discussion 'whether or not to extract gas under the Wadden Sea rom the Frisian Ternaard', these concerns are raised again [2]. However, in addition to sea level rise and subsidence a third factor has to be considered: the amount of sand and mud that is being deposited in the Wadden Sea area.

As long as sand and mud fill up the space created by seafloor subsidence and rising sea level, the intertidal shoals will not submerge. This is called the ***compensatory accumulation capacity****. The estimated size of this potential is included in the Hand-on-the-Tap Principle [3] as a fixed value per tidal basin. However, these estimates are based on the geological past, whereas as a result of human interventions the current and future situation of the Dutch Wadden Sea region is significantly different.*

The Hand-on-the-Tap Principle is used to assess whether mining activities can be allowed. TNO argues that the currently used values for the compensatory accumulation capacity in the Hand-on-the-Tap Principle should be adjusted.

The Wadden Sea, a dynamic system

By nature the Wadden Sea area is a dynamic system. It is constantly changing: both tidal channels and shoals prograde as a result of the rise and fall of the tides. During the turning of the tides (dead tide), and also when two opposing water currents meet (slack tide), the water stagnates for a moment. Especially at that moment sedimentation takes place; not only sand but also mud is deposited. As long as sediment deposition fills the space created by seafloor subsidence and rising sea level the tidal shoals retain their morphological characteristics. Complete filling of this space provides a minimum value for the *compensatory accumulation capacity*.

The compensatory accumulation capacity is an important factor in the so-called Hand-on-the-Tap Principle [3, 16] that is used to assess whether mining activities in the Wadden Sea can be permitted. If the tidal shoals are in danger of submerging -which is the case when the combined effect of sea level rise and seafloor subsidence exceed the compensatory accumulation capacity- [4], it can be decided to reduce or stop the gas or salt extraction ('hand on the tap').

Human influence

What about sediment deposition in the Wadden Sea? Before the closure of the Zuiderzee with a dam, at Westhoek (located at the border of the Wadden Sea in Friesland) was a popular swimming spot. Not anymore: the clean sand of the seabed is covered by meters of mud. Instead of bathing you can go for a walk on the mudflats. Consequently, the local beach pavilion closed down decades ago [5]. What is going on? The closures of the Zuiderzee (1932) and Lauwerszee (1969) have had a major impact on water circulation and sedimentation.

Actually, this strong human influence started in Roman times when the local population started to construct dikes and mounds. From the Middle Ages the living-working area along the coast was expanded by turning salt marshes into polders. About forty years ago another measure with a major impact was taken: in order to preserve the current Wadden Islands, the erosion of the North Sea coast was halted by large-scale coastal nourishments [6].

Year after year millions of cubic meters of sand are being supplied. In recent decades the resulting sediment influx into the Wadden Sea area causes major problems. Nowadays it is almost impossible to keep the waterways open by dredging [7,8]: for every ferry that crosses to Ameland, two dredgers set sail. This is so expensive that Rijkswaterstaat considered building a tunnel to Ameland [9].

The actual compensatory accumulation capacity of the Wadden Sea

In 2001 polder Noaderleech (Friesland) was returned to nature. The dikes were breached, turning this polder into a salt marsh. Several times a year these are being flooded, providing the opportunity for sediment deposition. As a result the elevation of this salt marsh has increased more than a centimeter per year in average[10] in a period of 10 years. Clearly sedimentation was easily capable to compensate for subsidence and sea level rise. The same can be concluded from measurements on several tidal shoals over the past 6 to 19 years: the height of the shoals increased by 0.5 to 10 millimeters per year [11].

How is that possible? The dynamics of the tides, aided by wind-driven wave action, continuously set large amounts of sediment in motion throughout the Wadden Sea area. In the period 1999-2006, this added up to more than 50 million m^3 of sediment being moved around per year [12]. As a result, the bathymetrie of the Wadden Sea is constantly changing; channels in the Wadden Sea can shift tens to a hundred meters per year.

Flood currents bring more sediment into the Wadden Sea area than the ebb currents remove. That is an important fact. Between 1935 and 2005, in average 8.6 million m^3 of sediments were imported into the Wadden Sea each year [13]. As a result, parts of the Wadden Sea area are emerging. This process is well known: after all, this is how the salt marches of Groningen and Friesland came into being. However, turning these salt marches into polders is a relatively new phenomenon causing a significant decrease in surface area of salt marshes [14]. As a result, the available mud can no longer be deposited on these salt marshes. Instead it settles in large quantities in the Wadden Sea area itself. Now, the elevation of the mudflats outside the dike is higher than the mainland behind the dike.

Since 2010 accurate laser measurements have been taken by aircraft twice a year, as reported in April 2021 [15]. In this study the tidal shoals could be monitored during their natural eastward migration. The total intertidal shoal area remained constant. According to model calculations significant subsidence should have occurred in the studied area during this period due to gas extraction. However this has never been observed because of rapid compensatory sediment accumulation.

Even in the Pinkegat where the subsidence due to gas extraction is the largest, sediment accumulation completely compensated the effect of subsidence. Likewise is stated by the Advisory Board *Hand aan de Kraan Waddenzee* [16]: "the subsidence caused by mining activities so far, has clearly been much smaller than the amount of sedimentation". In the eastern part of the Wadden Sea area the space that becomes available for sediment deposition -either by rising sea level or by subsidence- is immediately filled [12, 17].

Hand-on-the-Tap Principle

The Hand-on-the-Tap Principle is intended as an instrument to prevent damaging the natural values of the Wadden Sea area [A, 16]. Amongst other things, this means that the size of the surface area of the intertidal shoals should not decrease. In the Dutch Wadden Sea area different subbasins can be discerned which receive sediment from different inlets between the Wadden Islands. These are called *tidal basins*. The National Project Decree[3] of 2006 assumes a fixed value for the compensatory accumulation capacity per tidal basin.

In the western Dutch Wadden Sea area the amount of sediment that can be deposited in the tidal basin is limited by the sediment-transporting capacity of the inlets between the islands [12, 14]. Question is how that will evolve by further sea level rise. In the German Wadden Sea area height measurements of the intertidal wad area during 1998-2016 showed an increase in both the height and the size of the surface of the tidal shoals [18]. This development might be the result of sea level rise: because of the increased volume of water moved per tide, that water might transport more sediment, which might lead to sedimentation on the tidal shoals [13].

With regard to the actual compensatory accumulation capacity, both observations and scientific studies show that the Wadden Sea has a larger

compensatory accumulation capacity then currently assumed in the Hand-on-the-Tap Principle [4,12,13,16,17,19]. For the Pinkegat tidal basin, where the gas field north of Ternaard is located, the compensatory accumulation capacity was set at 6 millimeters per year [3]. This potential was based on the development of the Dutch Wadden Sea area over the past 400 years and on a similar development in the west of The Netherlands between about 8000 and 5500 years ago has [4, 14]. However, the current situation is very different compared to the past.

The past as the key to the present?

The sedimentation rate estimated based on historical developments (and therefore the capacity to grow) does not apply to the current situation. The factors that determine the behaviour of the system have been significantly altered by human interventions.

Due to the construction of dikes and the closure of the Zuiderzee and the Lauwerszee, the size of the tidal basins per tidal inlet has decreased enormously. In short: per supply channel, the area in which sediment can be deposited is much smaller. The sediment that is brought in from the North Sea by the flood currents therefore has to be distributed over fewer square meters. At the same time, the height difference between high and low tide has increased [20]. After the Zuiderzee and the Lauwerszee were closed off, the associated tidal channels became shallower or silted up.

An even more important change compared to the past: the amount of sediment available along the North Sea coast is not a limiting factor anymore. As soon as a sediment deficiency is observed, it is supplemented by sand extracted from the North Sea far from the coast [6]. In order to keep our coastline stable and to protect us against flooding, Rijkswaterstaat carries out coastal sand nourishments every year, introducing an artificial sediment supply to the system [17].

In addition, we have to account for the phenomenon that the longer the time period over which an average sedimentation rate is estimated the lower it is [21]. That sounds complicated, but it's not. Tidal channels and shoals are constantly in motion. At each location not only sedimentation takes place, but there are also moments of erosion [B]. The longer the time period, the more erosion phases occur and thus the less sediment is preserved to be counted in calculating the average sedimentation rate. In a recent report [4], Deltares describes a number of aspects from which can be concluded that the maximum sedimentation rates in both past and present are higher than the values that are currently used for the compensatory accumulation capacities of the tidal basins within the Wadden Sea area.

Underestimated compensatory accumulation capacity

The compensatory accumulation capacities as included in the National Project Decree, were based on the geological past. They thus indicate the degree of sea level rise that the Wadden Sea was able to withstand in the past [24]. These numbers reflect the lower limit of the amount of sediment deposited during that time; we know that more sediment has been deposited that was not preserved by the continuous process of erosion and deposition. In this way a lower limit of the compensatory accumulation capacity was determined: for the tidal basin of the Pinkegat 6 millimeters per year. The actual accumulation potential is obviously higher, but how much higher cannot be deduced from geological history.

In 2012 the results of a scientific study [13] were published in which all depth measurements that have been carried out in the Dutch Wadden Sea area since 1925 were mapped and analyzed. Conclusion: the Wadden Sea dynamics are able to import enough sediment to compensate for subsidence and the rate of sea level rise - as it took place in that period - provided that sufficient sediment is available along the North Sea coast. The latter is the case as a result of the coastal nourishments.

A joint study by TNO and the State Supervision of Mines in 2015 [23] indicated that even if the conservative compensatory accumulation capacity of 6 millimeters is used, the chance of submergence of the Pinkegat tidal basin is virtually nil. In 2018, for each tidal basin the actual accumulation potentials were calculated using model calculations [4]. For the Pinkegat, this method results in more than 30 millimeters per year. Such a compensatory accumulation capacity is large enough to cope with subsidence due to gas extraction, even with extreme sea level rise scenarios on top of that.

Both measurements and observations of the system and scientific arguments therefore indicate that the compensatory accumulation capacities included in the National Project Decree are unrealistically low. They are based on estimations derived from geological history, before the construction of dikes and the implementation of coastal nourishments significantly changed the dynamics of the Wadden Sea area. Moreover, the average sedimentation rate over a timescale of hundreds or thousands of years has proved unsuitable for the required predictions over decades. For a well-functioning Hand-on-the-Tap Principle, adjustment of the estimated compensatory accumulation capacities is therefore desirable. This is therefore advised by the advisory board "*Hand on the Tap – Wadden Sea*" [16].

Three variables with their uncertainties

The maximum subsidence that you can expect as a result of gas extraction over a few decades over an area with the size of a number of square kilometers is well known. The resulting volume to be filled with sediment has also been carefully quantified. We do not know exactly what the situation will be with regard to future sea level rise. Different scenarios are being presented. This has had a major impact on the social debate, in which the so-called *worst-case scenario* plays a major role.

According to the latest predictions of the KNMI, sea level will rise by another 1.20 meters this century [24]. Significantly more than the observed relative sea level rise in recent decades: in the period 1993-2017 along the Dutch coast, it averaged 2.4 millimeters per year [22] (if that number remained constant, it would be 24 cm per century). The worst case scenario is now 2 meters of sealevel rise in 100 years [24].

The discussions about the uncertainties regarding future sea level rise receive a lot of attention in the media. However, the compensatory accumulation capacity of a tidal basin has just as much influence on the chance that intertidal shoals will submerge as the rate at which the sea level rises. During the past decades an abundance of sediment has been deposited. This results in a process of emergence instead of submergence - despite the rise in sea level.

The probability of extreme scenarios is small and the probability of multiple extremes occurring at the same time is even smaller. A highly unlikely prediction of the future is portrayed when future intertidal shoals development is based on the most unfavourable sea level rise scenario combined with an underestimation of compensatory accumulation capacities [25]. Dealing with future scenarios in such a way - stacking extremes - results in bad policy [26]. When using the Hand-on-the-Tap Principle, the use of a (too) conservative value for the compensatory accumulation capacity should be avoided.

Adjusting the values for the compensatory accumulation capacities

In current practice, when using the Hand-on-the-Tap Principle, the degree and speed of both subsidence and sea level rise are expressed in an expectation-value. This expectation-value is derived from a probability distribution: on the basis of all available knowledge, it is determined how likely it is that the sea level will rise at a certain speed. Each time the Hand-on-the-Tap Principle is applied, these expectation values can be adjusted in response to the current situation and the most recent predictions regarding the various factors that influence sea level rise or subsidence respectively.

On the other hand, the size of the compensatory accumulation capacity of the various tidal basins is included as a fixed fact in the Hand-on-the-Tap Principle: a minimum size of the compensatory accumulation capacities as derived from geological history. The current situation, observations and recent studies show that the ability of the intertidal shoals to adjust is on average significantly higher. The size of the actual compensatory sediment accumulation varies from place to place and from year to year. Nevertheless, a realistic expectation value can also be established for the compensatory accumulation capacity on the basis of a probability distribution per tidal basin [14, 17].

We advocate that the compensatory accumulation capacities in the Hand-on-the-Tap Principle should no longer be fixed values. Instead, the size of the compensatory accumulation capacities should be based on a probability distribution - just like the values for sea level rise and subsidence. In doing so, the rich archive of long-term measurements and the latest scientific insights can be utilized.

Conclusions

With the current rate of sea level rise and subsidence due to mining activities, the Wadden Sea area will not submerge. According to observations and recent studies, the actual compensatory sediment accumulation potential of the Wadden Sea area is even large enough to compensate for both extreme sea level rise and subsidence due to gas extraction. In recent decades, ample sediment has been deposited. Consequently the heights of the intertidal shoals are increasing – the opposite of submergence.

The Hand-on-the-Tap Principle as such is not discussed in this article. We address the included values for the compensatory accumulation capacities. Linking the most extreme sea level scenario to underestimated compensatory sediment accumulation values leads to a highly unlikely prediction of intertidal shoal evolution, which might result in inadequate policies. It is possible to determine more realistic values in order to formulate appropriate policies.

At this moment the values for the compensatory accumulation capacities included in the Hand-on-the-Tap Principle are too small. The intertidal shoals will only drown in a scenario wherein sea level rises faster than the actual compensatory sediment accumulation can handle. Gas extraction or not: in this most extreme scenario the intertidal shoals will submerge anyway. In that case the moment of drowning is only slightly brought forward just by the gas extraction induced subsidence. Gas extraction is certainly not a decisive factor. For a well-functioning Hand-on-the-Tap Principle adjustment of the compensatory accumulation capacity values is appropriate.

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Foot notes:

[A] NB: emergence of the tidal shoals of the Wadden Sea system is not addressed by the Hand-on-the-Tap Principle.

[B] Before 1600, the Pinkegat was smaller than it is today. Historical sources show that the Pinkegat, probably from 1600, but in any case from 1800 onwards, has a cyclical development. The tidal inlet continuously develops from a single main channel to a multiple main channels and back again. Such cycles last 20 to a maximum of 54 (but probably up to 41) years. In addition, the annual growth of the eastern tip of Ameland sometimes add up to 100 m/year over several decades. With the creation of a new western main channel, this grown point can be turned off again in a few years. p.86 In: Oost, A.P., B.J. Ens, A.G. Brinkman, K.S. Dijkema, W.D. Eysink, J.J. Beukema, H.J. Gussinklo, B.M.J. Verboom & J.J. Verburgh 1998. Integral subsidence study Wadden Sea. Nederlandse Aardolie Maatschappij B.V., Assen. 372 pp

Concepts (as defined in the National Project Decree 2006[3]):

Tidal basin: the catchment area belonging to one tidal inlet, bounded by the dike or salt marsh or supra-tidal sandbank on the mainland side and island side and by the ridges of the adjacent tidal basins. As a result of the tidal changes of the North Sea, the tidal basins flow full to high water during high tide, after which this tidal water runs out again during ebb to low water.

Salt marsh: land formed by siltation that is no longer submerged during normal floods; is characterised by specific communities depending on the altitude.

compensatory accumulation capacity (of a tidal basin): the natural ability of a tidal basin, expressed in mm/year over the entire area, to keep up with the relative sea level rise (rSLR) in the long term while maintaining the geomorphological characteristics and sediment balance.

Relative sea level rise (rSLR): the sum of the rate of sea level rise and the rate of subsidence of the seafloor, which does not take into account erosion and sedimentation.

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