Extended abstract TISOLS: Quantifying land subsidence due to shallow-depth subsurface processes in the Groningen gas field area- The Netherlands; a new monitoring site

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Introduction

Land subsidence due to natural and human induced processes occurs on different time scales and depth intervals. The Groningen gas field area in the northeast of the Netherlands (Fig. 1) experiences considerable land subsidence of up to 60 cm since 1960. This is caused by different drivers operating at shallow subsurface depth (excessive land drainage: upper 15 m), intermediate depth (extraction of groundwater from Pleistocene aquifers: tens to hundreds of meters), and kilometer(s) depth (extraction of hydrocarbons since 1959: reservoir-depth). The negative impacts of land subsidence are manifold, affecting amongst others the built environment, infrastructure and water management. Especially since general land use in this area is agricultural, water levels need to be regulated for favourable conditions which in turn impacts subsurface movements. The design of efficient measures mitigating land subsidence requires quantification of the individual processes that contribute to total (sub)surface movement, as well as the development of reliable techniques for monitoring surface elevation changes at high spatial and temporal resolution.

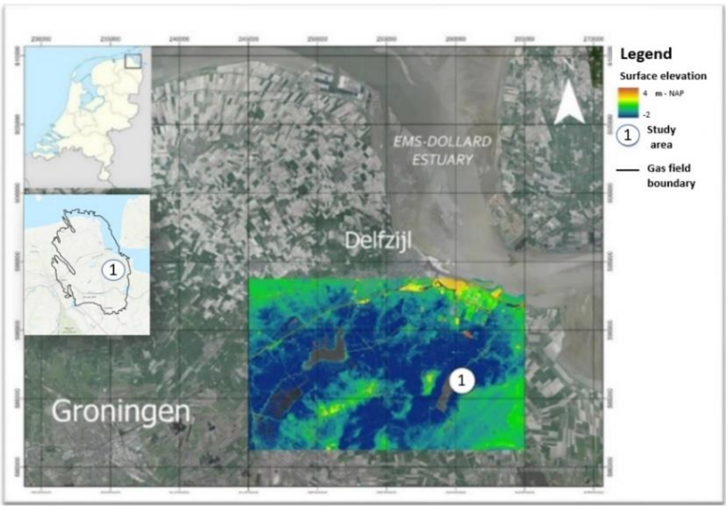

Figure 1 Study area Nieuwolda Groningen, lowly elevated surface within the Groningen gas field area. Coordinates are according to the Dutch national RD-grid (EPSG:28992).

The goal of this research is to quantify the shallow subsurface processes occurring in the Holocene sequence of the Groningen gas field area. The main causes of shallow (sub)surface deformation in the upper 15 meter are initial, primary and secondary compression, oxidation of organic matter and shrinkage and swelling of clay and peat layers (Brouns et al., 2014; van Asselen et al., 2009) (Fig. 2). These processes are driven by changes in internal and exterior stresses mainly caused by loading and changes in phreatic groundwater level. Main boundary conditions determining the vulnerability of the subsurface for these processes and their impact involve subsurface lithology, soil texture, initial porosity, organic matter content and water content (Van Asselen et al., 2009).

In this abstract, two monitoring sites are presented along with preliminary results. The monitoring sites were designed and installed in the area of Nieuwolda (Fig. 1, location 1), in the east of the Groningen gas field area to provide independent, reliable, frequent and precise time series of observed changes in the boundary conditions (such as water content, porosity and organic matter content), and relative vertical distance between several benchmarks, at a location that is expected to show significant temporal variability.

Geological setting and monitoring sites

The (sub)surface of the Groningen gas field area is unique to the Netherlands, in its formation, build-up and post-depositional development. Therefore, two monitoring sites are developed in the town of Nieuwolda. The subsurface lithology for both sites is characterized by alternating, meters thick, Holocene clay (Naaldwijk Fm. – shallow marine/tidal deposits) and peat layers (Nieuwkoop Fm.), positioned on top of the Pleistocene sand layer (Boxtel Fm. – mainly aeolian transported cover sand) that are assumed to be stable with regard to shallow subsurface processes causing (sub)surface movement.

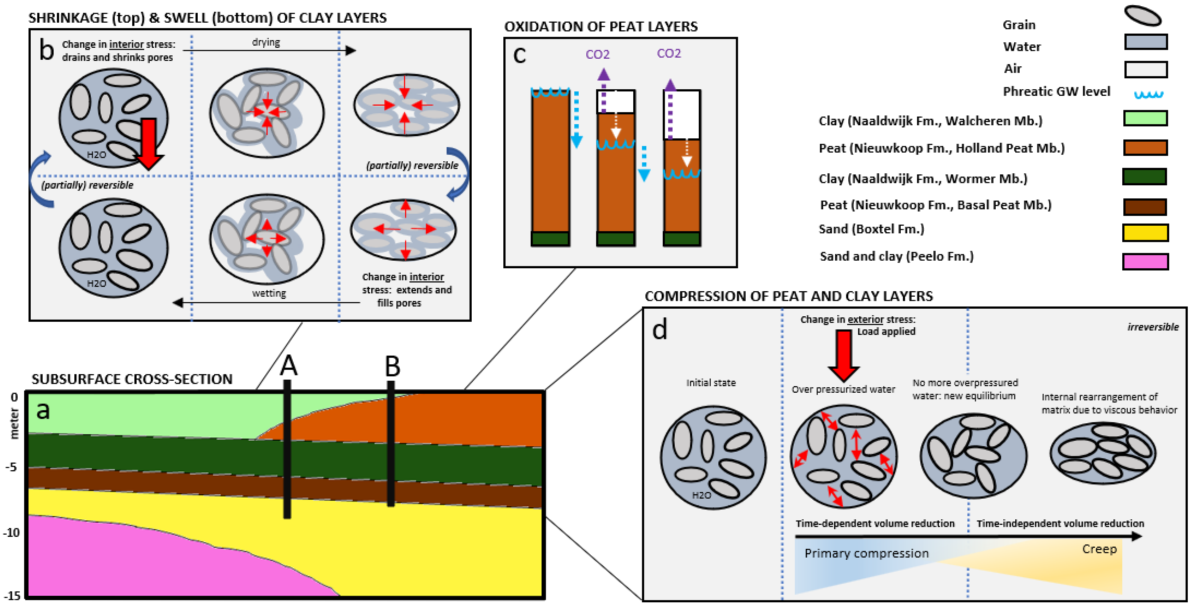

Figure 2 Subsurface processes inducing vertical (sub)surface movement in the upper 15 m of the Holocene sequence. a) Schematic subsurface build-up (approximately 3 km wide), consisting of Holocene and Late Pleistocene deposits, similar to the shallow subsurface of the Groningen gas field area. Location A and B indicate the locations of the surficial clay and peat extensometer. b) Schematic overview of shrinkage and swelling in saturated surficial clay layers induced by changes in interior stresses (red arrows indicate hydraulic stress). c) Schematic overview of lowering of the phreatic groundwater level inducing decomposition of peat layers and subsequent subsidence and CO2 release. d) Schematic overview of compression in peat and clay layers induced by changes in exterior stresses.

The two extensometers were installed penetrating a surficial clay layer (Naaldwijk Fm. – Walcheren Mb.) on top of a peat layer (Nieuwkoop Fm. – Holland Peat Mb.), locally alternated with a clay layer containing numerous plant remains (mainly reed), and a consecutive vertical lithological sequence of a clay layer (Naaldwijk Fm. – Wormer Mb.) on top of a basal peat layer (Nieuwkoop Fm. – Basal Peat), ending in the Pleistocene Boxtel Fm. basement consisting of sand (Fig. 3). The extensometers were designed to document the relative vertical movement of the layers between the anchors in response to changing boundary conditions such as fluctuating groundwater levels. Installation of the extensometers involved several steps and components. At each location, a cone penetration test was performed to determine the initial (t=0) cone resistance for locating the lithological boundaries and the depth of the stable sand layer, followed by the placement of the deepest (reference) anchor into the top of the stable Pleistocene Boxtel Fm. A steel casing was anchored in cement at the bottom of each extensometer borehole along which several (Borros) anchors that were positioned at geohydrological boundaries. The different anchors measure the changes in thickness of the layers between the anchors, with a precision range on millimetre scale (STOWA, 2020).

On extensometer A, several anchors (II, III, IV) were installed within the first two meters beneath the surface. Due to the absence of organic material above the average lowest groundwater level, aerobic oxidation will not occur, and the deformation measured by anchors II and III can only be caused by shrinkage, swell and compression of the clay layer. Additional anchors (IV and V) positioned deeper beneath the surface and the lowest groundwater level will monitor the compression of peat and (organic) clay layers.

Extensometer B, at the site where peat occurs at shallow depth, monitors the combined effect of oxidation of the peat layers above the average lowest groundwater level with anchors II and III, and shrinkage and swelling that occurs in these layers. Since the amount of shrinkage and swelling in peat layers is significantly different compared to shrinkage and swelling of clay layers (Camporese et al., 2006; Oleszczuk et al., 2003) it is important to measure these processes in both a clay (extensometer A) and clay on top of peat (extensometer B) sequence. Furthermore, previous monitoring studies of peatlands throughout the Netherlands showed that peat layers in the saturated zone experience a remarkable amount of deformation (e.g. Van Asselen, 2011; NOBV, 2020). Therefore, anchor IV was placed to monitor the compression of peat in the saturated zone. Anchor V is positioned at the base of the Holocene sequence to monitor the total deformation of the sequence. It is assumed that most deformation between anchor IV and V will occur within the Wormer Mb. of the Naaldwijk Fm., as the basal peat (Nieuwkoop Fm.) has already been mostly compacted.

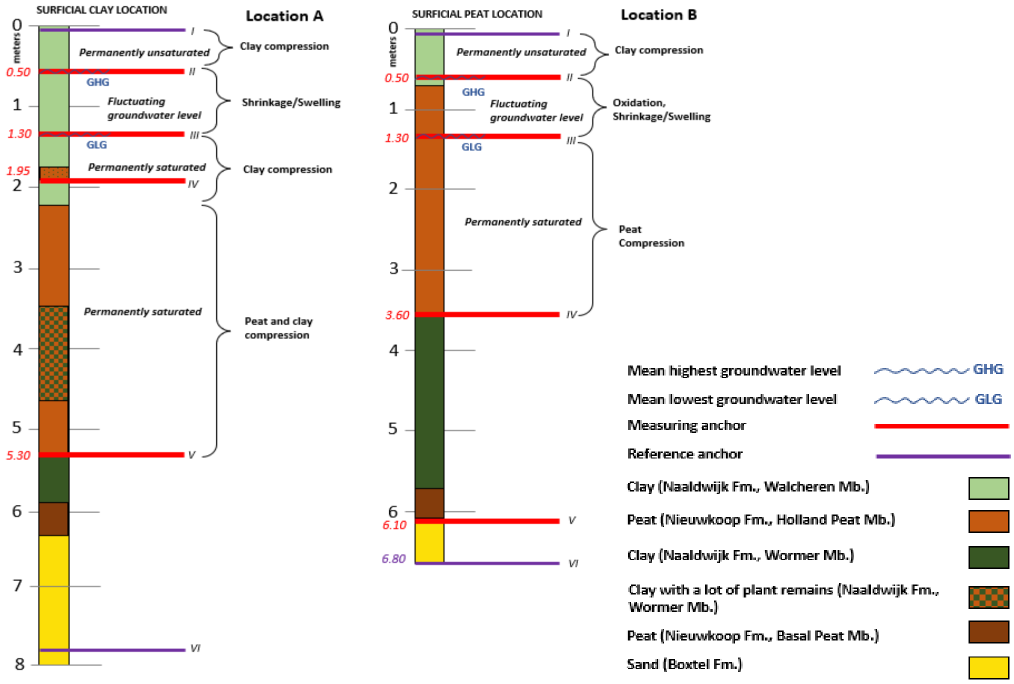

Figure 3 Schematic overview of the lithological build-up and the two extensometer sequences (in meters below the land surface), with their anchor positions and corresponding measuring purposes. The surface level of the surficial clay location is elevated 1.48 m below mean sea level. The surface level of the surficial peat location is elevated 2.40 m below mean sea level.

One of the most prominent boundary conditions that influences the vertical (sub)surface movement processes is phreatic groundwater level fluctuation. To document this, three monitoring wells have been installed for each site, including a 1) phreatic groundwater well at 2 m below the surface near extensometer A with the surficial clay and 1.75 m below the surface near extensometer B where peat occurs at shallow depth (55 cm below surface), 2) a deep groundwater well to monitor hydraulic head, extending into the Pleistocene sand layer founded at a depth of 8 m below surface for location A, and 7 m below surface for location B (first confined aquifer), and 3) a groundwater well in the nearby ditches to monitor the effect of the ditch water level on the measuring sites. Automatic data loggers were installed in all the monitoring wells and extensometers.

First results

The monitoring sites were installed early May 2022. The extensometer measurements and groundwater levels (hydraulic heads shown in the confined aquifer and phreatic groundwater levels in the unconfined aquifer) for both locations over the period of May 5th until July 24th are shown in figure 4. Groundwater levels in general decreased over this period due to a progressively dry weather period with some occasional peaks as a result of precipitation. However, towards the end of the monitoring period, groundwater levels are rising again. Over the same period, the upper four extensometer anchors for location A show an upward trend, describing elevation of the (sub)surface with the exception of the anchor at a depth of 5.30 below surface. For location B a fluctuation in anchor movement is observed with the exception of the anchor nearest to the surface. The surficial anchors are extremely susceptible to events at the surface, such as irrigation, local or temporal loading, and ploughing. Long-term measurements are needed to clarify the elevating trend of the surficial anchors.

The extensometer measurements of the Nieuwolda sites show clear correlations between groundwater fluctuations and anchor movements, although long-term measurements are required to draw more reliable conclusions. However, a short sharp rise in groundwater levels in the order of centimeters, can be correlated to vertical anchor movements in the range of several millimeters as shown for location A for the end of May. Clearly, measurements covering a full year, including the wetter winter period will better reveal the relations between shrinkage, swell, oxidation and compression for both locations, and provide a better understanding of their causing mechanisms and boundary conditions.

Additional quantification devices and modelling

To understand more direct relations between weather conditions, water level management and land use, future additions to the monitoring sites will consist of weather stations, incorporating pluviometers measuring precipitation, radiation monitors, soil moisture measuring devices and thermometers. In addition, transponders will be positioned on both monitoring sites to enable the correlation to InSAR measurements and to work towards improvement of the implementation of shallow (sub)surface processes in the InSAR algorithms.

To quantify shallow subsurface processes over time on a regional scale, we will deploy compression modelling based on the a,b,c isotache method (Den Haan, 1994) and oxidation modelling (based on organic versus mineral content) over the period from 1959 until present to quantify the amount of surface deformation and its net effect due to processes and also specifically water management strategy applied to the Groningen gas field area over time. This enables determining the contribution of these shallow subsurface processes to total land subsidence in this area. For parameter estimation, samples on both sites will be analysed in the lab for organic content and additional lithological properties. The Nieuwolda measurements will serve as validation for these models and quantification at a local scale.

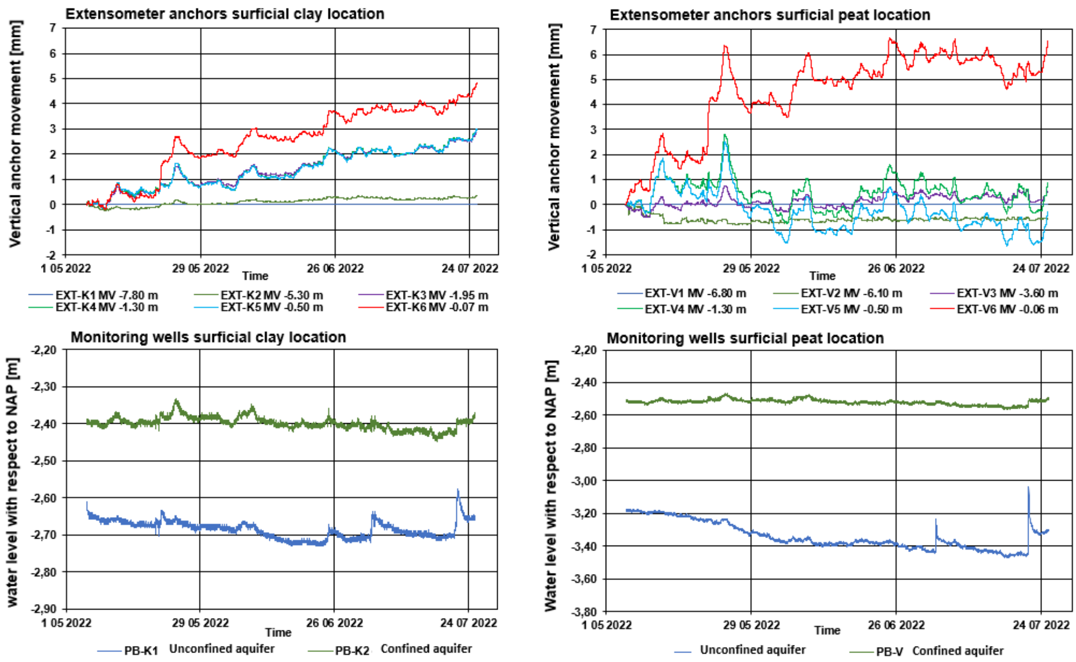

Figure 4 First extensometer results and groundwater level results. Vertical anchor movements in meters are with respect to the original measurement. Anchor positions are with respect to the surface level which is respectively 1.48 m below the mean sea level for location A with surficial clay and 2.40 m below mean sea level for location B with surficial peat.

Conclusion

To quantify the shallow (sub)surface processes occurring in the Groningen gas field area in the northeast of the Netherlands, two measuring sites were developed. The measuring sites govern different lithological build-ups consisting of Holocene clay and peat layers on top of the Pleistocene sand layer, assumed to be stable with regard to shallow subsurface processes resulting in deformation of the (sub)surface. Extensometers were installed at a surficial clay location and at a location with peat occurring at shallow depth, measuring the vertical movement of several anchors at geohydrological boundaries. Additionally, three groundwater monitoring wells were installed on each location consisting of a phreatic groundwater level well, a deeper well reaching into the Pleistocene sand layer for monitoring of the hydraulic heads, and a monitoring well in the nearby ditches to monitor ditch water level.

First order results show correlations between fluctuating groundwater levels and anchor movements. However, yearly measurements are required for reliable conclusions and quantification of the separate processes. Future results in combination with additional measuring devices such as weather station information and InSAR data, will provide more insights into the shallow (sub)surface deformation processes, their response to changing boundary conditions and the effect on the surface of the Groningen gas field area.

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